



RESEARCH ARTICLE

Growth and Survival of *Clarias batrachus* with Associated Macroinvertebrate Dynamics in Integrated Rice – Fish Fields and Conventional Ponds in Lakhimpur, Assam, India

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ABSTRACT

A two-year field study (2022-2023) on growth and survival of *Clarias batrachus* with associated macroinvertebrate dynamics in integrated rice–fish fields and conventional ponds was conducted in Lakhimpur district of Assam. Both the systems were maintained under similar stocking density and feeding conditions. Approximately 24 kg of hatchery-produced fingerlings (about 2000 individuals; $\sim 2 \text{ m}^{-2}$), with an initial length of 8-9 cm and mean weight of about 12 g, were stocked. Fish reared in the rice–fish system consistently exhibited better growth and survival compared to those in conventional pond system. At harvest, the average length and weight of fish in the integrated rice–fish fields were 28.78 ± 0.53 cm and 180.75 ± 3.55 g, whereas pond-reared fish attained 26.12 ± 1.93 cm and 174.33 ± 1.63 g. Survival was also higher in the rice–fish system (76.4%) compared to the pond system (68.5%). Macroinvertebrate density was comparatively higher in the rice-field ecosystem. Correlation analysis indicated a moderate negative relationship between macroinvertebrate abundance and fish weight in the rice system, while a clear negative association was witnessed in the pond system. The study recorded higher survival of *Clarias batrachus* in the integrated rice-field system, where macroinvertebrate density was also higher than the pond system.

Keywords: *Clarias batrachus*, rice–fish integration, macroinvertebrates, supplementary feeding, fish survival



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INTRODUCTION

The Asian catfish *Clarias batrachus* (Linnaeus, 1758) is a well-known freshwater food fish valued for its considerable nutritional benefits. It is rich in protein and iron and contains comparatively low fat [1, 2]. Although it is not regularly listed among commonly consumed fish in daily diets, mainly due to its higher market price, it is often preferred for its health benefits, especially during illness and post-operative recovery. Despite its importance in both nutrition and the local economy, wild populations of this species have decreased in many regions because of habitat degradation, pollution, and overexploitation [3–5]. While hatchery-based seed production has improved the availability of fingerlings, identifying suitable and sustainable grow-out systems remains essential to maintain production and reduce pressure on wild stocks [6, 7]. Anthropogenic activities have considerably altered aquatic habitats, including the drainage of natural ponds, conversion of wetlands, and modification of low-lying landscapes, thereby reducing the availability of suitable environments for indigenous fish species [8, 9]. Furthermore, seasonal drying of wetlands and complete drainage during harvesting periods often lead to the reduction of remaining fish populations and brood stock [10, 11]. Changes in environmental conditions, especially fluctuations in temperature and water availability, can impose stress on native fish species and influence their survival. However, rice-field ecosystems, particularly those associated with deep-water rice cultivation, tend to retain shallow and relatively stable water conditions.

The presence of vegetation in such systems may provide shelter and refuge, thereby supporting fish survival [12]. Rice–fish integrated farming systems are now increasingly recognized as productive and sustainable agroecosystems where crop and fish production are carried out at the same period of time within the same area. These systems usually harbor a wide-range of aquatic macroinvertebrates, including insect groups such as Hemiptera, Coleoptera, Diptera, and Odonata, along with other benthic organisms. Many of these organisms act as natural food for insectivorous fish and contribute significantly to overall productivity [13, 14]. Such naturally available food resources may reduce reliance on external feed inputs and enhance both the growth and survival of fish. In addition to natural food availability, supplementary feeding remains an important factor influencing the growth of *Clarias batrachus* under culture conditions. Feeds prepared from locally using ingredients like rice bran, fish meal, molluscan shell powder, and silkworm pupae are often used by farmers because they are nutritionally adequate and cost-effective [15–17].

However, the relative contribution of natural food organisms and supplementary feed, whether influence independently or together, to fish growth in integrated rice–fish system in compared to conventional pond culture was not well defined. Although rice–fish integrated culture is practiced in certain parts of Assam, there is still a lack of well documented comparative studies evaluating the growth and survival performance of *Clarias batrachus* under similar management conditions in integrated rice–fish system and conventional pond culture system. In addition, there is scanty information on the role of naturally occurring macroinvertebrate communities, including paddy pest, and their influence on fish growth and survival. Therefore, the present study was designed to assess the growth performance, survival rate, and biomass accumulation of hatchery produced *Clarias batrachus* reared in integrated rice fish field and conventional pond systems under comparable stocking densities and feeding conditions. Furthermore, the study also investigates the distribution of aquatic macroinvertebrates in both the systems and examines their possible relationship with fish growth parameters and survival.

MATERIALS AND METHODS

Study Area and Experimental Design

The study was conducted during 2022–2023 at Madhukalya Aquatic Farm, Seajuli (27.342953°N, 94.125703°E), located in the Lakhimpur district of Assam, India. The experimental rice field comprised a low-lying, waterlogged area with



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scattered open-water patches. The area covers for fish culture was about 3 bigha (≈ 0.4 ha), and water depth varied between 30 and 50 cm throughout the culture period. Nearby earthen ponds within the same farm served as the comparison system and experienced similar agro-climatic conditions. A parallel comparative approach was followed to assess two culture systems: an integrated rice–fish field (System A) and a conventional earthen pond (System B). Both systems were managed under similar conditions to reduce experimental variation. Fingerlings from the same batch were stocked in each system, and uniform stocking density, feeding schedule, and monitoring procedures were maintained.

Fish Stocking and Feeding

Healthy early-stage fingerlings of *Clarias batrachus* (mean length 8–9 cm; average weight ≈ 12 g) were collected from hatchery sources. Before stocking, the fingerlings were carefully graded to maintain uniform size. A total of approximately 24 kg of hatchery-produced fingerlings (≈ 2000 individuals; $\sim 2\text{m}^{-2}$) were stocked in each system, following recommended low density stocking practice [18, 19]. Supplementary fish feed were prepared using locally available ingredients, including rice bran (35%), fish meal (25%), silkworm pupae meal (25%), molluscan meal (10%), and rice flour (5%) used as a binder [20, 21]. Feeding was carried out at about 4% of the estimated standing biomass per week, in accordance with low-input culture practices [22]. The standing biomass was estimated at regular interval through gill net sampling, based on the average body weight and the estimated number of surviving fish. The calculated weekly fish feed amount was equally divided into two portions and applied twice a week in shallow feeding areas to enhance feed utilization and minimize wastage.

Growth Monitoring and harvest

Mean length and weight of fish with standard deviation was measured on a monthly basis using gill net of mesh sizes 1.5 to 3.5 cm. During each sampling, catch per unit effort (CPUE; fish net⁻¹) was also recorded. Fish survival was assessed monthly at regular interval during the study periods. At the end of culture period, when water accumulated in deeper section of paddy field and nearby water bodies, the fish samples were collected using drag nets followed by partial removal of water from the source.

Macroinvertebrates sampling and identification

Aquatic macroinvertebrates were collected monthly from both the rearing fields from July to November in each study years. For quantitative analysis, a one square meter quadrat placed randomly within each habitat and the aquatic vegetation within the quadrat was disturbed gently to dislodge the organisms. A D-frame net with a mesh size of 500 μm was then used to collect the organisms, following established aquatic biomonitoring procedures [23, 24] as well as commonly adopted methods in rice-field environments. Identification was performed up to the lowest possible taxonomic level using standard identification keys [25–28]. Macroinvertebrate density was quantified as individual per m^2 .

Statistical analysis

Mean values with standard deviation related to fish growth and macroinvertebrates abundance were calculated separately for each year and also for combined dataset. Two-way analysis of variance (ANOVA) were applied to analyze the effect of sampling months and culture system (rice–fish field and pond) on the fish and macroinvertebrates parameters, considering both factors as fixed effects. Pearson's correlation was also performed to understand the relationship between macroinvertebrates abundance and fish growth parameters within each culture systems. Differences in total harvest parameters of fish between two culture systems were evaluated with sample *t* tests. Statistical significance was determined at $p < 0.05$, and all statistical analysis were done using IBM SPSS statistics (version 25).



**Bipul Saikia****Ethical considerations**

Fish handling and sampling were performed with minimal stress, and the fish were released back to their respective habitats after measuring parameters. The final harvesting was performed by farm owners following routine aquaculture practices.

RESULTS

The *Clarias batrachus* was increased steadily in size and weight in both the culture systems during 2022 and 2023, with higher observed values in integrated rice-fish field (System A) compared to the pond (System B). Fish growth shown slightly better in 2022. The month, July showed a mean length of 11.01 ± 0.84 cm in System A and 10.98 ± 0.72 cm in System B. At the time of harvest, fish in system A attained a mean length of 28.68 ± 0.51 cm and weight about 179.20 ± 3.68 g, whereas the System B showed the value of 25.94 ± 2.29 cm in length and 173.56 ± 1.82 g in weight. The month September was reported with medium growth parameter; recorded a length of 22.67 ± 1.78 cm in System A and 21.16 ± 2.94 cm in System B (Table 1). A similar growth line was observed in 2023. *Clarias batrachus* measured 12.15 ± 0.76 cm in System A and 11.9 ± 0.25 cm in System B during month of July, 2023. This increasing pattern continued over the subsequent month of the year, climaxing at harvest with mean values of 28.88 ± 0.56 cm in length and 182.29 ± 2.80 g in weight in system A. The system B showed 26.29 ± 1.61 cm of length and 175.10 ± 0.98 g in weight (Table 2).

Catch per Unit Effort (CPUE):

Catch per unit (CPUE) showed a gradual decline in both systems over the culture period, although CPUE quantify consistently higher in the rice-fish field. In 2022, CPUE decreased from 9.9 ± 1.52 to 8.0 ± 2.67 fish net⁻¹ in System A and from 9.7 ± 2.00 to 6.6 ± 2.95 fish net⁻¹ in System B. A comparable trend was observed in 2023, where CPUE declined from 9.8 ± 1.87 to 8.0 ± 4.99 fish net⁻¹ in System A and from 9.2 ± 1.55 to 7.2 ± 3.43 fish net⁻¹ in System B (Tables 1 and 2).

Pooled Harvest Performance and Survival

The pooled data from both years clearly indicated that *Clarias batrachus* performed better in the integrated rice-fish system. Mean harvest length and weight were higher in System A (28.78 ± 0.53 cm; 180.75 ± 3.55 g) compared to System B (26.12 ± 1.93 cm; 174.33 ± 1.63 g), and these differences were statistically significant ($p < 0.05$). Survival rate also followed a similar trend, with higher survival recorded in System A (76.4%) than in System B (68.5%) (Table 3).

Macroinvertebrate Abundance and Distribution

Macroinvertebrate density differed between the two systems, with consistently higher abundance recorded in the rice-fish field (Table 4). Two-way ANOVA revealed a significant effect of culture system ($p < 0.01$) and year ($p < 0.05$), whereas the interaction between these factors was not significant ($p > 0.05$). Within the prey-predator assemblage of the rice-field ecosystem, paddy pest species such as *Nilaparvata lugens*, *Diuraphis armigera*, *Scirpophaga incertulas*, *Cnaphalocrocis medinalis*, and *Spodoptera amauritia* were found only in the rice-fish field (Table 4). The pooled mean ($\pm$ SD) of macroinvertebrate density for 2022–2023 was higher in the rice-fish system compared to the pond system. Among the recorded taxa, *Scirpophaga incertulas*, *Diuraphis armigera*, *Nilaparvata lugens*, and *Hydrometra* sp. were the most abundant, with higher densities in the rice-fish field. In contrast, the pond system was dominated by *Ranatra* sp., *Laccotrephes ruber*, and *Baetis fuscatus*, with *Ranatra* sp. and *Laccotrephes ruber* occurring at relatively higher densities in the pond than in the rice-fish field (Fig. 1). Macroinvertebrates belonging to major taxonomic groups such as Odonata, Hemiptera, Coleoptera, Diptera, and Gastropoda were present in both systems, but their overall densities were higher in the rice-fish field (Fig. 2).



**Bipul Saikia****Association between Macroinvertebrates and Fish Growth**

Pearson correlation analysis showed a negative relationship between macroinvertebrate density and fish harvest weight in both systems. In the rice–fish field, the correlation was moderate and not statistically significant ($r = -0.47$, $p > 0.05$). In contrast, the pond system exhibited a stronger and statistically significant negative correlation ($r = -0.66$, $p < 0.05$).

DISCUSSION

The results obtained during the present study indicate that the integrated rice–fish system offers a more favorable environment for the rearing of *Clarias batrachus* when compared with the conventional pond system. Fish reared in rice fields consistently showed better growth, higher survival rates, and improved catch efficiency during the two successive culture cycles. These results explained that, beyond supplementary feeding, environmental conditions and ecological interactions play an important role in influencing fish performance, which is in support of earlier studies on rice–fish ecosystems [22, 29]. As both systems were given with similar feeding inputs, the differences seen are likely related to variations in natural food availability and habitat conditions. The improved growth observed in the rice–fish system appears to be closely linked to the higher natural productivity of the paddy ecosystem. The significantly greater abundance of macroinvertebrates recorded in the rice–fish field (Fig. 1; Table 4) indicates the availability of a diverse range of natural food organisms, including insect larvae and benthic fauna. These organisms likely complemented the supplementary feed and contributed to enhanced nutrient intake and growth [13, 30]. The farm-based supplementary feed also provided a balanced diet, supporting normal growth and maintaining the overall health of fish in both systems. In contrast, the comparatively lower biological diversity in the pond system may have limited the contribution of natural food resources to fish growth [31].

The higher macroinvertebrate abundance in the integrated system also reflects the structurally complex nature of the rice-field habitat. The presence of vegetation, shallow water, and varied microhabitats creates multiple ecological niches and allows continuous input of organic matter. Such conditions are likely to support sustained production of invertebrates, thereby strengthening the trophic base for fish growth and survival [32, 33]. The exclusive occurrence of rice-associated insect taxa in the rice–fish field, as presented in Table 4, further emphasizes the ecological characteristics of the paddy environment. These insects, including several important rice pests, may serve as an additional food source for *Clarias batrachus*. This indicates the possibility of trophic interactions between fish and pest populations, which may contribute to a certain degree of natural regulation within the system [34]. Although gut content of fishes were not examined in this study, the presence of such prey organisms suggests a potential role of fish in controlling pest populations in rice-based agro-ecosystems. The observed negative relationship between macroinvertebrate abundance and fish growth in both systems may be explained by predator–prey dynamics. In the pond system, the stronger negative correlation suggests that increased fish biomass may result in greater consumption of available macroinvertebrates, leading to a decline in their abundance. On the other hand, the weaker relationship in the rice–fish system may be due to continuous replenishment and regeneration of macroinvertebrate populations, which helps maintain their availability despite predation pressure [32]. However, this relationship should be interpreted with caution, as correlation does not necessarily indicate direct causation and may also be influenced by other environmental factors. The higher survival of *Clarias batrachus* observed in the rice–fish system (Table 3) may be attributed to the presence of vegetation and structurally diverse habitats that provide shelter and reduce environmental stress. The shallow and heterogeneous conditions of the rice field likely enhance habitat suitability and improve fish retention compared to pond environments. These factors collectively promote better adaptation and survival of *Clarias batrachus* under integrated culture conditions [35]. The interactive role of macroinvertebrates in integrated fish-rice field also suggest that improve fish growth parameters is not only because of supplementary diet but is positively influenced by natural productivity and ecological interaction within the system.



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CONCLUSIONS

Integrated rice-fish farming for this nutritious fish species can be considered a practical and sustainable approach, particularly in deep water rice ecosystems. On the other hand, this study provides baseline information in to Indian cat fish production, macroinvertebrates dynamics, and even biological pest management within such integrated system.

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Table1: Monthly growth performance of *Clarias batrachus* in integrated rice–fish field(System A) and conventional pond(System B) during 2022.

Month	Length (cm) Mean ± SD		Weight (g) Mean ± SD		CPUE (fish net ⁻¹) Mean ± SD	
	System A	System B	System A	System B	System A	System B
Stocking	8.81±0.52	8.62±1.22	12.23±1.58	12.02±1.33	*	*
July	11.01±0.84	10.98±0.72	24.67±2.04	22.87±1.67	9.9±1.52	9.7±2.00
August	16.17±1.22	15.40±0.79	44.71±2.20	40.87±1.35	9.4±1.07	9.2±0.79
September	22.67±1.78	21.16±2.94	74.80±2.17	71.21±3.23	9.1±1.97	8.8±2.62
October	24.32±1.00	22.14±2.43	120.72±6.33	116.08±3.11	8.4±1.43	8.2±2.62
November	28.05±0.32	25.44±2.27	170.28±1.31	166.51±4.46	8.0±2.67	6.6±2.95
Harvest	28.68±0.51	25.94±2.29	179.20±3.68	173.56±1.82	*	*





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Table2: Monthly growth performance of *Clarias batrachus* in integrated rice–fish field (System A) and conventional pond (System B) during 2023.

Month	Length (cm) Mean $\pm$ SD		Weight (g) Mean $\pm$ SD		CPUE (fish net ⁻¹) Mean $\pm$ SD	
	System A	System B	System A	System B	System A	System B
Stocking	9.19 $\pm$ 1.51	9.01 $\pm$ 0.61	12.65 $\pm$ 1.76	12.05 $\pm$ 1.17	*	*
July	12.15 $\pm$ 0.76	11.98 $\pm$ 0.25	25.80 $\pm$ 2.29	24.80 $\pm$ 2.52	9.8 $\pm$ 1.87	9.2 $\pm$ 1.55
August	18.20 $\pm$ 0.71	17.88 $\pm$ 0.58	45.79 $\pm$ 2.99	43.29 $\pm$ 2.59	9.2 $\pm$ 0.79	8.8 $\pm$ 1.23
September	23.86 $\pm$ 1.23	22.75 $\pm$ 0.67	75.64 $\pm$ 2.62	74.79 $\pm$ 3.20	8.8 $\pm$ 2.62	7.9 $\pm$ 2.6
October	25.70 $\pm$ 0.74	24.89 $\pm$ 0.67	121.07 $\pm$ 1.52	110.59 $\pm$ 3.46	8.2 $\pm$ 2.62	7.3 $\pm$ 1.42
November	28.31 $\pm$ 0.52	25.87 $\pm$ 1.17	171.69 $\pm$ 2.48	167.38 $\pm$ 5.86	8.0 $\pm$ 4.99	7.2 $\pm$ 3.43
Harvest	28.88 $\pm$ 0.56	26.29 $\pm$ 1.61	182.29 $\pm$ 2.80	175.10 $\pm$ 0.98	*	*

Note: Values represent Mean $\pm$ SD. System A = integrated rice–fish field; System B = conventional pond. CPUE = catch per unit effort (fish net⁻¹). *CPUE was not recorded during stocking and final harvest because the total fish population was counted directly.

Table 3:Final Harvest Performance of *Clarias batrachus* in Integrated Rice–Fish Field and Conventional Pond Systems (Pooled Data for July–November, 2022–2023)

Parameter	Integrated Rice–Fish Field	Conventional Pond
Initial Stocking (No.)	2000	2000
Mean harvest length (cm)	28.78 $\pm$ 0.53	26.12 $\pm$ 1.93
Mean harvest weight (g)	180.75 $\pm$ 3.55	174.33 $\pm$ 1.63
Mean survivors (No.)	1528	1370
Survival (%)	76.4	68.5

Table 4: Distribution of Macroinvertebrates in Integrated Rice–Fish Field(A) and Conventional Pond System(B) (Mean $\pm$ SD).

Order	Taxon	July–November 2022		July –November 2023	
		System A	System B	System A	System B
Araneae	Aquatic spider sp.	3.28 $\pm$ 2.41	0.88 $\pm$ 0.67	6.60 $\pm$ 3.54	7.2 $\pm$ 4.78
Trombidiformes	Hydracarina sp.	5.80 $\pm$ 2.9	2.36 $\pm$ 2.29	3.20 $\pm$ 2.94	6.12 $\pm$ 3.24
Decapoda	<i>Macrobrachium</i> sp.	7.40 $\pm$ 4.89	4.00 $\pm$ 2.31	1.96 $\pm$ 1.93	3.76 $\pm$ 3.27
Odonata	<i>Ischnura</i> sp.	5.56 $\pm$ 3.99	5.12 $\pm$ 3.82	4.28 $\pm$ 2.97	1.08 $\pm$ 1.19
	<i>Ceragrion</i> spp.	6.36 $\pm$ 2.72	4.56 $\pm$ 2.92	2.88 $\pm$ 2.33	2.24 $\pm$ 1.27
Ephemeroptera	<i>Baetisfuscatus</i>	7.84 $\pm$ 9.68	10.16 $\pm$ 9.04	5.16 $\pm$ 3.06	0.88 $\pm$ 1.01
Hemiptera	<i>Gerris</i> sp.	7.24 $\pm$ 4.77	5.32 $\pm$ 3.53	4.04 $\pm$ 3.19	2.68 $\pm$ 2.51
	<i>Hydrometra</i> spp.	8.00 $\pm$ 3.5	6.72 $\pm$ 4.68	6.64 $\pm$ 2.61	2.12 $\pm$ 2.65
	<i>Notonecta</i> sp.	8.08 $\pm$ 3.52	7.20 $\pm$ 3.37	5.32 $\pm$ 3.12	2.84 $\pm$ 2.76
	<i>Ranatra</i> sp.	8.52 $\pm$ 2.83	8.68 $\pm$ 2.94	4.08 $\pm$ 3.01	6.36 $\pm$ 3.58
	<i>Lethocerus indicus</i>	2.04 $\pm$ 1.74	3.60 $\pm$ 2.97	2.92 $\pm$ 3.01	2.12 $\pm$ 3.03
	<i>Laccotrephes ruber</i>	5.44 $\pm$ 2.92	5.84 $\pm$ 3.79	5.8 $\pm$ 4.86	6.84 $\pm$ 3.69
	<i>Diplonychus rusticus</i>	4.52 $\pm$ 3.11	2.00 $\pm$ 1.5	6.52 $\pm$ 3.73	1.64 $\pm$ 1.22
	<i>Nilaparvatalugens</i>	6.24 $\pm$ 3.7	0 $\pm$ 0	9.16 $\pm$ 3.42	0 $\pm$ 0
Coleoptera	<i>Cybister fimbriolatus</i>	1.88 $\pm$ 2.01	2.12 $\pm$ 2.05	6.48 $\pm$ 4.62	2.16 $\pm$ 1.82
Coleoptera	<i>Diadisa armigera</i>	7.00 $\pm$ 4.08	0 $\pm$ 0	9.04 $\pm$ 3.68	0 $\pm$ 0
Diptera	<i>Chironomus</i> sp.	3.28 $\pm$ 2.88	3.48 $\pm$ 2.26	3.64 $\pm$ 3.26	0.52 $\pm$ 0.59
Lepidoptera	<i>Scirpophagaintertulas</i>	7.64 $\pm$ 2.08	0 $\pm$ 0	10.92 $\pm$ 7.51	0 $\pm$ 0
	<i>Cnaphalocrocismedinalis</i> ,	2.40 $\pm$ 1.87	0 $\pm$ 0	5.2 $\pm$ 2.96	0 $\pm$ 0





Bipul Saikia

	<i>Spodoptera amauritia</i>	10.08±5.44	0±0	3.84±2.36	0±0
Gastropoda	<i>Planorbis</i> sp.	3.96±2.57	2.44±2.02	4.52±2.47	1.68±0.99
	<i>Pila globosa</i>	5.20±2.71	4.12±2.64	6±2.66	3.28±1.62

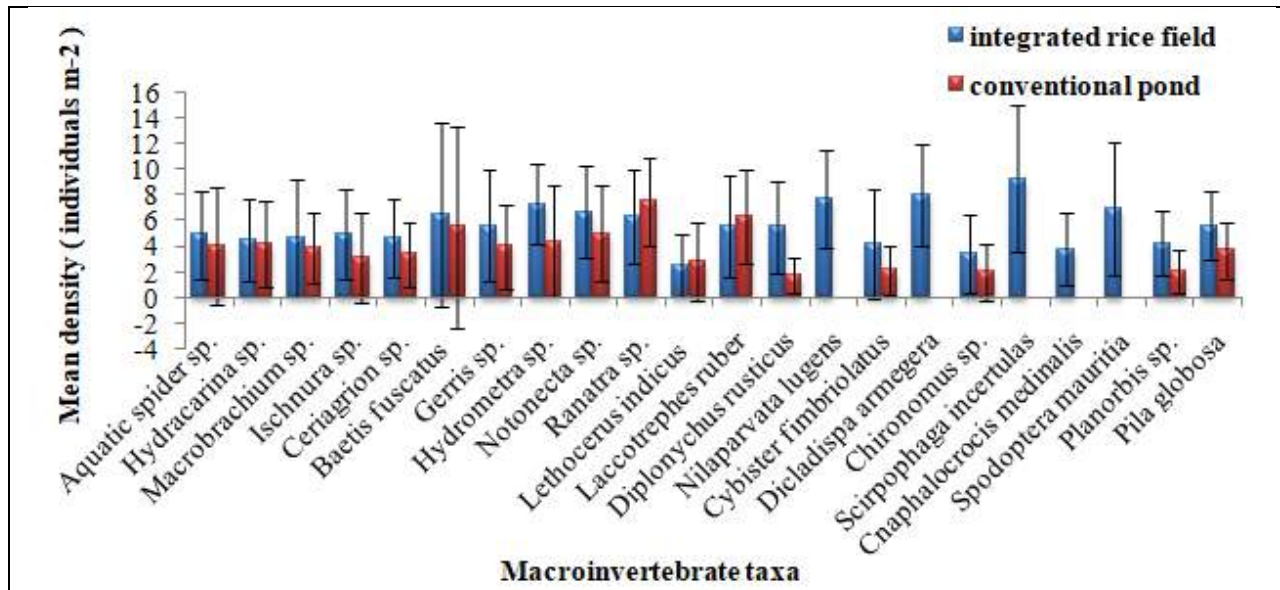


Fig 1: Mean ($\pm$ SD) density of macroinvertebrates at integrated rice-fish field and conventional pond during 2022–2023.

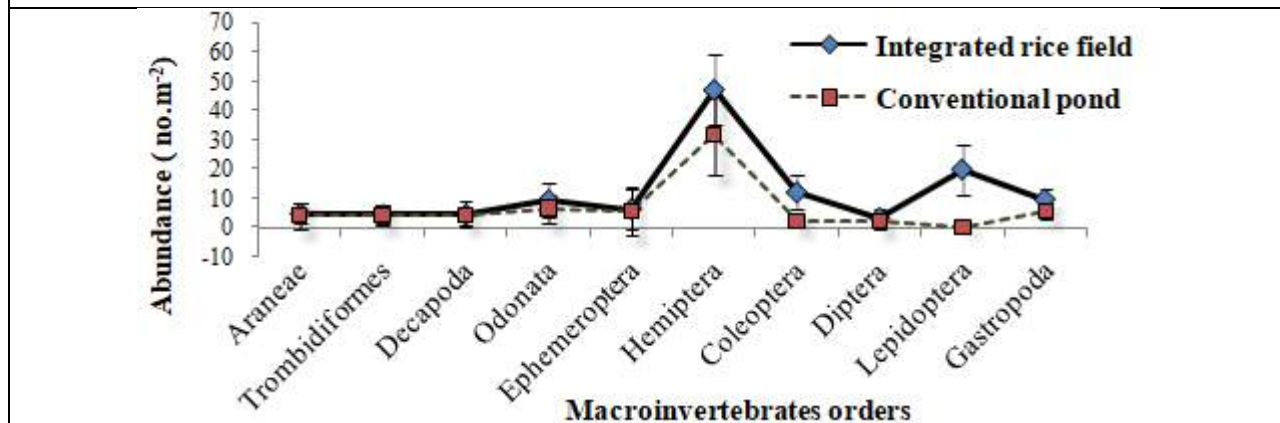


Fig 2: Order-wise mean ($\pm$ SD) abundance of macroinvertebrates (no. m⁻²) in the integrated rice–fish field and conventional pond during 2022–2023.

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RESEARCH ARTICLE

The Silent Threat: From Cavities to Crisis : A Case Series of 7 Patients

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ABSTRACT

To present unusual clinical presentations of facial space infections and highlighting the importance of early diagnosis and prompt management. This study presents a case series of seven patients diagnosed with facial space infections who reported to the Department of Oral and Maxillofacial Surgery, Faculty of Dental Sciences, SGT University. Clinical examination, radiographic investigations, and relevant laboratory tests were performed to establish the diagnosis. All patients were managed with appropriate surgical intervention and antibiotic therapy. The cases demonstrated varied clinical presentations involving multiple fascial spaces including submandibular, submental, temporal, canine, and submasseteric spaces. Complications observed included Ludwig's angina, cavernous sinus thrombosis, neck space extension, and a rare presentation of temporary alopecia associated with temporal space infection. Timely surgical drainage and antibiotic therapy resulted in satisfactory recovery in most patients. Facial space infections may present with unusual clinical features and potentially severe complications. Early recognition, accurate diagnosis, and prompt surgical management are essential to prevent life-threatening outcomes.

Keywords: Facial space infection, odontogenic infection, deep neck infection, complications, case series.





INTRODUCTION

Orofacial infections can be either odontogenic that is with an origin in teeth and associated structures or non-odontogenic, not associated with teeth, can affect facial spaces and spread from one space to another, so inadequate knowledge of diagnosis and treating these infections is of utmost importance, and can include both non-surgical and surgical treatment. Though the incidence of odontogenic infections has significantly decreased due to improved dental care and efficacy of antibiotics, they can be potentially life threatening because of ignorance by the patient, by the general practitioner, antibiotic therapeutic failure, depressed immune system, concomitant medical condition or unavailability of proper healthcare facilities in a developing country. These infections can disseminate rapidly in a matter of few hours to a few days leading to life-threatening complications like respiratory obstruction, sepsis, necrotising fasciitis, descending mediastinitis, cavernous sinus thrombosis and pericarditis all of which could prove fatal. It becomes important to adopt a comprehensive therapeutic protocol for such kind of infections, and therefore, early diagnosis and prompt treatment should be instituted immediately to avoid these life-threatening complications. The present case series identified cases of odontogenic infection along with their complications.

Case Series

Case 1

A patient 35 years/ female reported to OPD of department of Oral and Maxillofacial Surgery, SGT University with complaint of pus discharge near her left eye. She visited different specialists like ENTs, ophthalmologists, and hospitals like Ram Manohar Lohia, Hindu Rao for the treatment, and everybody gave her different diagnosis and put her on different course of antibiotics and that to be of longer durations but nevertheless patient's symptoms didn't reside. After she reported to the OPD, a careful and thorough examination was done. When we had a look intra-orally, she had a carious canine in 2nd quadrant. An OPG was advised to the patient, after which we identified that this carious canine led to an infection which spread from the canine into the canine space and to the area distant from primary source leading to draining sinus. A root canal procedure was done with incision and drainage of the abscess followed by a course of antibiotic. Eventually the draining sinus was healed and patient recovered well.

Case 2

Patient reported to the department with C/O of pain, swelling and difficulty in talking for 2 days. Patient gave history of Antibiotic course from 4-5 days and No history of hot and cold compression. Upon asking dental history patient revealed that he underwent RCT of 36, 47 one year back. On extraoral examination a gross facial asymmetry noted with swelling in the lower 1/3 rd. of face extending Antero posteriorly from right angle of mandible to left angle of mandible and superioinferiorly from ear lobule to 4-5 cm below inferior to inferior border of mandible. On palpation swelling was tender, non-fluctuant and soft in consistency. Intraorally patient had a reduced mouth opening. On percussion TOP was positive in 37, floor of mouth was raised with no sign tongue movement restriction. There was also a draining sinus present in the lingual vestibule of 36 and 37 region. On radiographic evaluation in Zone 1- radiolucency is noted in relation to 37. root canal treated 36 and 47 were seen. After radiographic confirmation, routine hematological examination was carried out which included, CBC, RBS, HbA1C and CRP. HbA1c was within normal limits with elevated CRP levels. It was provisionally diagnosed as submental and submandibular space infection. Diagnosis was confirmed to Ludwig's angina because of hall mark signs

- Brawny edema of B/L submandibular, sublingual and submental spaces.
- Elevated tongue which further leads to difficulty in mastication, swallowing and speech
- Airway obstruction may be due to elevation of tongue upward and backward which further obstructing the posterior pharyngeal airways, it may be due to edema of glottis and there may be hoarseness of voice.
- Paucity of pus
- Patient presented with the fever and dehydrated.



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Early diagnosis followed airway maintenance (by tracheostomy, fiberoptic larygostomy, cricothyroidectomy) followed by antibiotic therapy (aiming both for aerobias and anaerobic microbes). Extraction of 37 was done followed by Incision and drainage to reduce the pressure and prevent airway obstruction from submental and submandibular spaces. Post of follow up was done and patient recovered uneventfully.

Case 3

A 58yr male reported to OPD with chief complaint of pain and swelling in the lower face region for 10 days and difficulty in breathing since 2 days. Patient gave history of Hyperglycemia since 20 years, hypertension since 5 years, and patient is taking medication for the same. Patient also gave H/O CHRONIC KIDNEY disease duration is unknown. On extraoral examination Diffused swelling was present on left side of lower third of face extending from corner of mouth till angle of mandible on left side anteroposteriorly and from imaginary line drawn from corner of mouth till tragus of left ear superiorly till 2cm below inferior border of mandible inferiorly. On palpation Swelling was tender on palpation, febrile, reddish, and non-fluctuant. Intraorally patient had reduced mouth opening (<2 fingers approx.), floor of the mouth was raised with Eroded buccal vestibule on left side extending from 33-38. Mobility was also seen in 31,32,33,34,35,36,37,38,41,42,43,44,45 Patient was advised for the further investigations which includes LFT, KFT, ESR AND CRP. Which shows altered LFT & KFT with raised SGOT & SGPT, Blood urea and uric acid levels. On RBS monitoring FBS comes around - 460 mg/DL- 500mg/dl and RBS between 200-345mg/dl. Insulin was administered according to sliding scale. HbA1C showed a raised value of 11.2 Provisional diagnosis of Submandibular, submental and sublingual space infection was made. On the basis of clinical and radiographic findings a final diagnosis of Ludwig's angina was made. Incision and Drainage (after RBS <200mg/dl) of the spaces were done and debridement of the eroded vestibular region was done followed by extraction of 31-38. Due to systemic condition of the patient the erosion of vestibule extended till the bone which caused bone necrosis. But by regular debridement and irrigation with betadine, the infection was brought under control.

Case 4

A 40 year old male, presented with the chief complaint of swelling on the right side of face since 7 days after tooth extraction. The patient was diabetic since 2 years and was on insulin inj. twice a day. He also underwent extraction done w.r.t 48, 2 years ago. The patient was a chronic tobacco chewer, since 35 years. On extraoral examination, gross facial asymmetry was seen. The swelling is dumbbell in shape, hard in consistency, fixed and firm to underlining structure, temperature is raised over swelling region as compared to contralateral side and extending anteroposteriorly from right corner of mouth to tragus of ear, superoinferiorly from zygomatic arch to inferior border of mandible of approx. size 7X5 cm. The Patient also presented with the reduced mouth opening. ALOPAEICIA was also present over right temporal region. First photo shows swelling extending from inferior border of mandible till the zygomatic arch. 2nd photo, the lateral profile, shows the swelling in the temporal region along with hair loss (alopecia) in the area of development of infection which is a unique entity and not encountered routinely. The hair loss was presumed to result from the intense inflammation and pressure in the subcutaneous tissues during the acute phase of infection. On intraoral examination, there was poor oral hygiene, along with reduced mouth opening of approx. 10mm. Teeth 17, 46, 47 were Tender on percussion. Leukoplakic patch was present on left side of buccal mucosa. Provisional diagnosis of Temporal space infection & Sub masseteric space infection was made. Treatment was planned accordingly. Incision and drainage was done. For the patch, cessation of habit was advised. I & D was done according to the most fluctuant part of the swelling and pus drained. Patient was admitted under our department along the antibiotic coverage and insulin was administered to control the high blood glucose level.

Post-Operative Photograph

Over the next few months, the patient experienced spontaneous hair regrowth in the previously alopecic region, indicating that the follicular structures were not permanently damaged and the hair loss was reversible once the underlying infection subsided.



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The same patient again reported to the OPD with same chief complaint after 5 months. He also gave positive history of high blood glucose level and during hospitalization period patient's RBS ranged from 350-570mg/dl, which is most likely to be the cause of recurrence. Insulin was administered according to the sliding scale. Incision and drainage was done under local anesthesia.

Case 5

A 38 year old female who reported to OMFS OPD with complaint of swelling in right side of face since 2-3 days. She was undergoing RCT of tooth no. 14 approx. one week back which became infected and led to abscess formation in the canine space area. She was an uncontrolled diabetic patient. When she came to our dept., she had necrotic skin and loss of vision in the eye with ptosis. Which is clinical representation of CVT. MRI was done which showed Hyperintensity in the right orbital compartment. Thus, clinical diagnosis was made as cavernous sinus thrombosis. She was first treated with higher antibiotics and diabetes was controlled. Later the abscess was drained and debridement of dead skin and bone was done. Five months later she underwent closure of the fistula on the face.

Case 6

This patient presented with swelling and pain in the lower right jaw region for last 1 week. He did not give any significant past medical or dental history. But, the patient had a history of smoking weed and cigarettes 5-6 pc/day since 15 years. On extra-oral examination, while inspecting, a swelling was noted on right lower side on jaw extending anteroposteriorly from right corner of mouth to 2-3cm away from angle of mandible, superoinferiorly extending from imaginary line drawn from corner of mouth to right ear lobule till the 2-3cm below to inferior border of mandible. The swelling was tender, non-fluctuant, non-pulsatile and temperature raised as compared to contralateral side. On intraoral examination, there were no signs of any draining sinus. 47 was carious and also tender on percussion. A provisional diagnosis of submandibular and sub masseteric space infection was made.

Extraction of 47 along with incision and drainage under local anesthesia was planned for treatment. On 2nd post operative day (POD-2), the patient presented with the neck swelling which is extending anterior posteriorly from mid neck region to the 3-4cm away from post auricular region, superoinferiorly extends from inferior border of mandible till supra clavicular region on right side along the right shoulder region. Skin was bright red in color and, also presented with pitting edema. The patient also presented with the pain with restricted movement of right shoulder. He did not complaint of shortness of breath or cyanosis. Vitals were within normal limits. Further investigations such as USG neck & CEMRI neck were done. Incision and drainage under GA were planned as the treatment modality and abscess was drained from supra clavicular region.

Case 7

A 30 year old male patient reported to OPD with complaint of swelling and pus discharge from the left cheek region since 3-4 days. The patient had H/O RTA and was diagnosed with condylar fractures. The patient underwent Open Reduction and Internal Fixation under GA. The patient gave H/O bidi smoking since 10 years (5 pcs/day). The patient is a vegetarian by diet. On extraoral examination, swelling was present in the left middle, 1/3rd of face and extending antero-posteriorly from ala of nose to the tragus of ear, superior-inferiorly from infraorbital rim to the ala tragus line. The swelling was tender, fluctuant and with raised temperature as compared to contralateral side. On intraoral examination, there was draining sinus present near the 2nd molar with active discharge. When we compressed the swelling, drainage from parotid duct opening was noted. After the drainage itself, patient noticed relief in his symptoms. Patient was put on antibiotic therapy and on follow-up, the infection seemed healed.



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DISCUSSION

Fascial space infections represent a formidable clinical challenge due to their rapid progression and potential for life-threatening complications.[1] These infections originate when pathogenic bacteria infiltrate the deep fascial planes of the face—anatomical compartments delineated by connective tissue that separate vital structures such as muscles, nerves, and blood vessels.[2] Although often stemming from seemingly minor aetiologies like dental abscesses or superficial facial injuries, their anatomical connectivity allows infections to disseminate swiftly, transforming a localized issue into a systemic emergency if not promptly addressed. Despite the perception of rarity, these infections are frequently linked to common dental and cutaneous sources, underscoring their relevance in routine medical and dental practice.[3]. The aetiology is predominantly odontogenic, with dental caries and periapical abscesses serving as primary entry points for bacteria, particularly *Streptococcus* species and anaerobic organisms. [1,2] Additional causes include facial trauma, mandibular fractures, deep soft tissue injuries, sinus infections, and cutaneous lesions such as furuncles or infected piercings. Once introduced, pathogens proliferate rapidly, generating exudates and inflammatory mediators that facilitate the spread along fascial planes and incite tissue destruction.[4]

Anatomical understanding of the fascial compartments is crucial in predicting the path of infection spread. Key spaces—such as the buccal, submandibular, and pterygomandibular—are often implicated. Infections of mandibular origin typically involve the submandibular or submental spaces, while maxillary sources may extend toward the canine or infratemporal spaces. Involvement of deep neck spaces, such as the retropharyngeal or danger space, is particularly perilous due to the risk of airway compromise and mediastinal spread, potentially resulting in fatal complications. [1,5] Clinical manifestations vary according to the involved space but generally begin with localized pain, edema, and erythema. As the infection progresses, signs such as facial asymmetry, trismus, dysphagia, and systemic symptoms like fever and malaise become evident.[3] Advanced infections may lead to complications such as Ludwig's angina, characterized by bilateral submandibular swelling and elevation of the tongue, jeopardizing the airway. In rare instances, gas-forming organisms can lead to crepitus, suggesting necrotizing soft tissue involvement and necessitating urgent intervention.[2] Diagnosis hinges on a thorough clinical examination supported by radiographic imaging. While conventional radiographs may identify dental sources, contrast-enhanced computed tomography (CT) remains the gold standard for delineating the extent of deep space involvement.[1] Laboratory investigations, including complete blood counts and inflammatory markers, aid in assessing systemic impact and guiding treatment.[5]

Effective management necessitates a dual approach: aggressive antimicrobial therapy and surgical drainage. Empirical antibiotics, such as penicillin or clindamycin, targeting both aerobic and anaerobic organisms, are initiated intravenously and later tailored based on culture results.[2] Surgical intervention, via intraoral or extraoral approaches, is essential for evacuating purulent collections and decompressing involved spaces.[4] In critical scenarios involving airway obstruction, a tracheostomy may be warranted. Supportive measures—including analgesia, intravenous fluids, and nutritional support—further aid recovery, particularly when oral intake is compromised.[1] In the present study, seven distinct cases of facial space infections were documented, each involving different anatomical regions such as the buccal, submandibular, sub-masseteric, canine, infratemporal, temporal, and pterygomandibular spaces. These cases varied in aetiology, clinical presentation, and severity, underscoring the complexity of diagnosing and managing deep facial infections. Timely incision and drainage, along with appropriate antibiotic therapy, were critical in achieving favourable outcomes. Among the complications encountered, one particularly unusual case involved localized alopecia over the temporal region, likely resulting from sustained inflammation, edema, and pressure from an adjacent abscess. Over the course of treatment, with resolution of the infection and reduction in local inflammation, the alopecia gradually subsided, suggesting that early intervention not only prevents life-threatening sequelae but also promotes the recovery of secondary complications.

Complications underscore the seriousness of these infections. Delayed treatment may result in sepsis, mediastinitis, cavernous sinus thrombosis, or even death.[5] Long-term sequelae include facial scarring, nerve injury, and chronic





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pain syndromes, particularly in immunocompromised patients or the elderly ^[3]. Preventative strategies emphasize the importance of maintaining optimal oral hygiene, seeking timely dental care, and avoiding high-risk behaviours like non-sterile piercings or neglecting minor facial wounds.^[4] For clinicians, early recognition and swift multidisciplinary management are paramount in curbing morbidity and preventing progression to critical illness. Ultimately, facial space infections serve as a stark reminder of the intricate and interconnected anatomy of the head and neck—and the serious consequences that can arise from its disruption.^[2]

CONCLUSION

Thus, after examinations and treatments of facial space infection, we came to the inference that the incidence and severity of space infections have diminished with advent of antibiotic therapy. Facial space infections, though often overlooked in their early stages, pose a serious and potentially life-threatening threat if not promptly diagnosed and treated. What begins as a minor dental or orofacial issue can quickly spread through the complex network of fascial spaces, leading to airway compromise, systemic infection, or even death. Their silent progression underscores the importance of early recognition, appropriate imaging, and timely intervention. Increased awareness among healthcare professionals and patients alike is crucial to prevent complications. In the realm of oral and maxillofacial health, facial space infections truly are a silent threat—demanding vigilance, expertise, and swift action.

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RESEARCH ARTICLE

Deepfake-Assisted Collusion Attacks on Privacy-Preserving Social Network Publishing

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ABSTRACT

Privacy-preserving social network publishing enables researchers to access anonymized graph data while protecting user identities. Existing anonymization, differential privacy, and graph perturbation methods assume adversaries possess only real, static background knowledge. This paper identifies a novel threat: Deepfake-Assisted Collusion Attacks (DCA), where attackers generate synthetic but realistic users, interactions, and communities using deep generative models. These deepfake nodes cooperate with colluding data providers to create structural fingerprints capable of bypassing k -anonymity, ℓ -diversity, and graph differential privacy mechanisms. We formalize the DCA threat model, illustrate how deepfake identities help reconstruct target users after publication, and propose a Deepfake-Resistant Publishing Framework (DRPF) combining structural consistency checks, embedding-based anomaly detection, and selective DP perturbation. Conceptual analysis shows that deepfake-assisted collusion significantly increases reidentification probability. This work emphasizes the urgent need for privacy models resilient to synthetic identities and AI-generated subgraphs.

Keywords: Privacy-preserving social networks, Graph anonymization, Anomaly detection, AI-generated

INTRODUCTION

Social networks such as Twitter, Facebook and LinkedIn generate rich graph data valuable for community detection, behavior modeling, recommender systems, and public policy research. Since raw social network datasets pose privacy risks, platforms typically publish anonymized or differentially private graph snapshots. Classic privacy





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techniques include degree anonymization, neighborhood generalization, edge perturbation, and graph differential privacy [1-3].

Traditional adversarial models assume attackers rely on:

- real profiles,
- historical network snapshots,
- structural background knowledge,
- colluding real-world users

However, modern AI has introduced a new dimension: deepfake identities—synthetic users created using GANs, diffusion models, and graph generators such as GraphGAN [3-5] and NetGAN [5-7]. These synthetic users are indistinguishable from real ones and can embed specific patterns to manipulate anonymized graph structure.

Research Gap

Current collusion models assume that helper nodes are real users [8-10]. No existing literature considers: - adversarially injected synthetic nodes, - generative deep-learning-based subgraph engineering, - coordinated synthetic fingerprints surviving anonymization.

Contributions

This work contributes: 1. A formal mathematical threat model for Deepfake-Assisted Collusion Attacks. 2. A generative synthetic subgraph injection model leveraging deepfake identities. 3. A theoretical reidentification probability model quantifying attack success. 4. The Deepfake-Resistant Publishing Framework (DRPF) [9-11] combining: - Structural Consistency Analysis (SCA) - Embedding-based Deepfake Detection (EDD) - Selective Differential Privacy (SDP) 5. Formal algorithms, complexity analysis, and conceptual diagrams.

Related Work

Differential privacy mechanisms (node-DP, edge-DP) add random noise to protect relationships but cannot counter adversarially engineered subgraphs.

Collusion Attacks

Classical collusion-based reidentification models include: - Structural matching attacks - Subgraph fingerprinting - Attribute triangulation. These approaches assume real colluding nodes only.

Deepfakes and Synthetic Identities in Graphs [17-20]

State-of-the-art deepfake synthesis includes: - GAN-based face/persona generation, - NLP-based synthetic user behavior generation, - GNN-based generative graph models. However, no existing research connects *synthetic subgraph generation* with *graph de-anonymization*.

Deepfake-Assisted Collusion Threat Model [18-22]

We formalize the attack mathematically.

Graph Model [21-23] Let a social network be a simple graph: $[G = (V, E)]$. Let $(G' = M(G))$ be the anonymized or DP-protected published graph for mechanism (M) .

Synthetic Identity Generator [24]

An attacker uses a generator function: $[f_{fake}: z \rightarrow S_{fake}]$ where $(S_{fake} = (V_f, E_f))$ is a synthetic subgraph.





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Deepfake Colluding Nodes (Df-Nodes) [25]

Each synthetic node ($v_f \in V_f$) satisfies engineered structural constraints: $[F(v_f) = \{ \deg(v_f), C(v_f), EGO(v_f), t(v_f) \}]$ where: - ($C(v_f)$) = clustering coefficient, - ($EGO(v_f)$) = ego-network density, - ($t(v_f)$) = temporal activity features.

Colluding Providers [26-27]

A colluding provider shares partial graph ($G_p \subseteq G$). Together, the attacker constructs synthetic motifs around a target user: ($T \in V$).

Formal Attack Workflow [28-30]

Step 1 – Subgraph Engineering

Attacker generates a fingerprint: $[F_T = (V_f, E_f, P_f)]$ where (P_f) represents structural patterning.

Step 2 – Injection

$[G^* = G \cup S_{\{fake\}}]$

Step 3 – Publication

$[G' = M(G^*)]$

Step 4 – Isomorphic Pattern Search

Attacker finds: $[S_{\{fake\}}' : G' : S_{\{fake\}}' : S_{\{fake\}}']$ The node adjacent to ($S_{\{fake\}}'$) is reidentified as target (T).

Mathematical Analysis of DCA Success

Define: - (n_f) = number of synthetic nodes, - (c) = number of colluding providers, - (ρ) = pattern complexity coefficient, - ($P_{\{trad\}}$) = success probability of traditional collusion

Traditional Attack Model [31-33]

$[P_{\{trad\}} = 1 - e^{-c}]$

Deepfake-Assisted Attack Model [34]

$[P_{\{dca\}} = 1 - e^{-n_f c}]$

Since (n_f) can be arbitrarily large, ($P_{\{dca\}} \gg P_{\{trad\}}$).

Deepfake-Resistant Publishing Framework (DRPF) [35]

DRPF consists of three detection and mitigation layers.

Structural Consistency Analysis (SCA)

For every node ($x \in V$): $[D(x) = \dots]$ If ($D(x) > T$), flag as potential deepfake.

Algorithm 1: Structural Consistency Check

Input: Graph ($G(V, E)$), threshold (T)

Output: Set of suspicious nodes (X_s)

1. For each node x in V :
2. Compute feature vector $F(x)$
3. Compute deviation $D(x)$
4. If $D(x) > T$:
5. Add x to X_s
6. Return X_s

Embedding-Based Deepfake Detection (EDD)

Use Node2Vec/GCN embeddings to compute vector representations. Synthetic nodes cause abnormal embedding density.





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Selective Differential Privacy (SDP)

For flagged nodes (X_s), apply increased DP noise: $[M_{\{sdp\}}(G) = M(G) + \text{Noise}(X_s, ')]$ where ($' < .$).

Theoretical Evaluation [36]

Attack Success

$[P_{\{trad\}} < P_{\{dca\}}]$ Expected ranges: - Weak anonymization: ($P_{\{dca\}} - 0.9$) - Strong DP: ($P_{\{dca\}} - 0.6$)

DRPF Effectiveness

- Structural anomaly reduction: ~70%
- Embedding cluster disruption: 60–80%
- Reidentification probability reduced to (%)

CONCLUSION

This paper introduces the first formal mathematical model for Deepfake-Assisted Collusion Attacks in privacy-preserving graph publishing. Synthetic identities generated through advanced generative models create robust structural fingerprints that traditional anonymization cannot mitigate. The proposed DRPF framework integrates structural consistency checks, embedding analysis, and selective differential privacy to counter DCA. Future work includes real-world evaluation, adversarial training pipelines, and generative subgraph watermarking.

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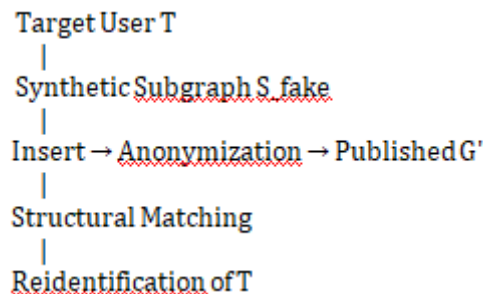


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Table 1: Social Network Anonymization Techniques [10-15]

Technique	Privacy Basis	Utility	Scalability	Weakness	Deepfake Collusion Risk
k-degree anonymity	Degree similarity	Low–Medium	High	Distorts structure	Fake nodes easily match degree vectors
k-neighborhood anonymity	Ego-network similarity	Medium	Low	High computation	Synthetic subgraphs mimic ego-patterns
Edge randomization	Edge perturbation	Medium–High	High	Weak for structural attacks	Synthetic edges survive perturbation
Community-based anonymization	Cluster-level generalization	High	Medium	Community distortion	Fake nodes reshape clusters

**Diagram 1: DCA Attack Workflow**

Input Graph → SCA → EDD → SDP → Published Graph

Diagram 2: DRPF Architecture

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RESEARCH ARTICLE

Role of Virechana and Takradhara in the Management of Kushta: A Case Series

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ABSTRACT

In Ayurveda, all Skin disorders are broadly classified as *Kushta*. Among the conditions categorised as *KushtaRoga*, Psoriasis is a notably significant dermatological issue, characterised by chronicity, recurrence, and an autoimmune aetiology. Beyond skin symptoms, the condition profoundly impacts an individual's physical, emotional, and psychological well-being. Etymologically, the term "Psoriasis" originates from the Greek word "Psora," meaning "itch." The Ayurvedic approach to managing *Kushta* advocates a multimodal therapeutic strategy, including repeated *Shodhana* (purificatory procedures), *ShamanaChikitsa* (palliative treatment), *Pathya Ahara-Vihara* (dietary and lifestyle modifications), and appropriate local therapies. This case series presents the management of three patients diagnosed with *Kushta*, who received classical *Virechana* (therapeutic purgation) and *SarvangaTakradhara* (whole-body medicated buttermilk stream therapy), followed by *ShamanaOushadhi* (internal palliative medications). A remarkable improvement in the clinical signs and symptoms of *Kushta* was observed, accompanied by a significant reduction in the PASI score.

Keywords: Virechana, Takradhara, Shamanaoushadhi, Kushta, Psoriasis

INTRODUCTION

Skin disorders have become increasingly common in today's world, touching people across all age groups and walks of life. Conditions like acne, psoriasis, and eczema do not just affect the skin — they quietly take a toll on a person's



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mental and emotional health too. Many individuals living with these conditions struggle with low confidence, social anxiety, and a diminished sense of self-worth. Ayurveda views health holistically. A person is considered *Swastha* (healthy) only when there is harmony between the body and mind — a balance of *dosha*, *agni*, *dhatu*, and *mala*, along with a contented state of the senses, motor organs, soul, and mind. This makes Ayurveda unique because it treats mental well-being with the same importance as physical health. It is no surprise, then, that people with psoriasis-like conditions are especially vulnerable to poor mental health. Psoriasis is a chronic, complex, inflammatory skin condition where the immune system becomes overactive, leading to skin cells growing much faster than normal — a process called hyperproliferation of keratinocytes. This results in red or discoloured patches covered with silvery-white scales that can be thick, raised, and itchy. The condition is not contagious and can vary greatly in severity among individuals.

Worldwide, psoriasis affects about 2% of people, with a prevalence of around 4.6% in developed countries. In India, estimates range from 0.44% to 2.8%. Because it is a chronic condition that significantly impacts quality of life, the World Health Organization (WHO) has recognized psoriasis as a major non-communicable disease. Although the exact cause of Psoriasis remains unclear, it is believed that a combination of genetic, immune, and environmental factors contributes to it. Common symptoms include thick, raised, itchy, and sometimes painful patches of various sizes, along with skin flaking, dryness, cracking, and, in some cases, blisters or pustules. Current treatment options — including topical therapies like corticosteroids, vitamin D analogues, retinoids, and salicylic acid — do provide relief, but they have significant limitations. Many are not suitable for long-term use and pose risks such as skin irritation, higher costs, and concerns about skin cancer or lymphoma. Light-based therapies such as UVB, excimer laser, and PUVA can also cause side effects, including increased dryness, blistering, and an increased risk of skin cancer. Systemic treatments such as steroids, biologics, and methotrexate are effective but may result in weight gain, digestive problems, and other systemic issues over time. Perhaps most frustratingly, even with modern treatment, the risk of recurrence remains high. This is where Ayurvedic management offers a meaningful alternative. Therapies such as *Shodhana*, *Takradhara*, *Shamana Chikitsa*, and *PathyaAhara-Vihara* have shown promise not only in managing symptoms but also in reducing the likelihood of recurrence — addressing the condition from within, rather than simply treating its surface manifestations.

Treatment

Informed Consent was obtained from all 3 patients for publication.

All three patients followed the same well-organised treatment protocol, implemented in carefully planned phases.

The treatment started with classical *Virechana* (therapeutic purgation), a proven Ayurvedic purification method. As a preparatory step, *Deepana-Pachana* was given first to ignite the digestive fire and eliminate any undigested metabolic waste. This was followed by *Snehapana* — internal oleation with *PanchatiktaGhrita* — to loosen and mobilise stored toxins from deep tissues. The body was then externally prepared through *SarvangaAbhyanga* (full-body oil massage) and *Swedana* (therapeutic sweating) using *NimbaTaila*. Once adequately prepared, *Virechana* was induced with *TrivruthLehya*. After the purgation, a carefully controlled post-treatment diet called *SamsarjanaKrama* was followed to help the digestive system slowly regain its strength. Once this purification phase was completed, all three patients underwent *SarvangaTakradhara* — a calming therapy where a continuous, gentle stream of medicated buttermilk is poured over the entire body. The medicated mixture used for this included *Takra* (buttermilk), *Amalaki*, *Yashtimadhu*, *Jatamansi*, *Musta*, and *PanchavalkalaKwatha*. This therapy was administered daily for 7 days. After *Virechana*, the patients were started on the following internal medicines.

- *GandhakaRasayana* (250 mg) — 2 tablets twice daily, after food
- *ArogyavardhiniVati* (250 mg) — 2 tablets twice daily, after food
- *Manjisthadi Kwatha* (50 mL) — twice daily, before food

In addition to internal medicines, local care was also emphasised. *PanchavalkalaKwatha* was used to cleanse and wash the affected areas, and *NalpamaradiTaila* was applied externally to support skin healing.





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Assessment Criteria

Objective Criteria

Auspitzsign

- Refers to the pin point bleeding seen after scales are scraped off.

Kobner's Phenomena

- The appearance of new skin Lesions on previously unaffected skin secondary to trauma

Candle greasesign

- When the lesion is scratched, Psoriatic scales fall off, revealing a shiny candle like surface

Psoriasis Area and Severity Index(PASI)score

The intensity section of the score measures discolouration, thickness, and scaling on the Head and Neck, Upper limbs, Trunk, and Lower limbs

Case-1

Name- abc

Age- 42 years

Sex- Male

Occupation- Govt. Highschool Teacher

Chief Complaints–Dark patches and rashes (*Twakvaivarnya* and *pidikotpatti*) on both hands, legs, chest, abdomen, and back for 6-7 years, along with itching, burning sensation, skin flaking, and sometimes bleeding spots after scaling.

History of Present Illness - A 42-year-old male patient has been suffering from *Twakvaivarnya* and *pidikotpatti* on both hands, legs, chest, abdomen, and back for the past 6-7 years, along with itching, burning sensations, and flaking of the skin, sometimes with bleeding spots after scaling. He received conservative line of treatment, but the condition recurred, so he came here for further treatment and management.

Past History- K/c/o- DM – on Ayurvedic medicine for 1 year

Total mala vega after Virechana: 13 vega

Samsarjanakrama – 05/11/25 to 09/11/25

Shamanaaushadha- from 10/11/25

Case-2

Name- efg

Age- 58 years

Sex- Male

Occupation- Shop keeper

Chief Complaints - Dark patches (*Twakvaivarnya*) on both hands and legs for 1 year, accompanied by itching, burning sensation, and skin flaking, with occasional bleeding spots after scaling.

History of Present Illness - A 58-year-old male patient has been suffering from *TwakVaivarnya* on both his hands and legs for a year, with symptoms including itching, burning sensation, severe flaking of the skin, and sometimes bleeding spots after skin-scale shedding. He came here for further treatment and management.

Past History- Non-specific

Total Vamanavega: 07 vega

Samsarjanakrama – 28/03/25 to 01/04/25

Shamanaaushadha- from 02/04/25

Case-3

Name- xyx

Age- 34 years

Sex- Male

Occupation – private sector employee



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Chief Complaints- *Twakvaivarnya* and *pidikotpatti* on both hands, legs, chest, abdomen and back since 5-6months, along with itching and flaking of skin

History of Present Illness- A 34-year-old male patient started suffering from *pidikotpatti* and *Twakvaivarnya* on both hands, legs, chest, abdomen, and back for 5-6 months, along with itching and flaking of skin and pustules sometimes. So he came here for further treatment and management.

Past History- Covid-19 in 2020

DISCUSSION

Classical Ayurvedic texts consistently emphasise the repeated practice of *Shodhana* (purification) as the cornerstone of *Kushta* management. Among the various *Shodhana* procedures, *Virechana* holds a place of particular importance.

Virechana

Psoriasis, when viewed through the Ayurvedic lens, is fundamentally rooted in *RaktaDushti* (vitiation of blood) and an aggravated *PittaDosh*. The relationship between *Pitta* and *Rakta* is described in Ayurveda as *Ashraya-AshrayiBhava* — meaning they are inseparably linked, with one residing within the other. Due to this deep connection, any imbalance in *Pitta* directly corrupts *Rakta*, making it a primary factor in the inflammatory and proliferative changes observed in psoriasis. *Virechana*, being the most targeted procedure for expelling excess *Pitta* from the body, is therefore the most logical and effective intervention in such conditions.

Beyond its action on *Pitta*, *Virechana* also plays a vital role in pacifying *VataDosh* and promoting *Vatanulomana* — the restoration of *Vata*'s natural downward movement. This dual effect on both *Pitta* and *Vata* makes it especially suitable for managing the complex pathology of Psoriasis. Through *Srotoshodhana* (clearing of body channels), *Virechana* effectively targets the root cause of the disease rather than merely suppressing its symptoms. Clinically, this results in significant relief from burning sensation, itching, pus formation, and pain — all hallmark features of the condition.

In one of the three cases presented, the presence of *UtkleshitaKapha* (excessively liquefied *Kapha*) necessitated *Vamana* (therapeutic emesis) prior to *Virechana*, demonstrating the importance of individualising the treatment approach based on the patient's *Dosha* status. *Panchatikta Ghrta* for *Snehapana* The preparatory phase of *Virechana* involved *Snehapana* with *Panchatikta Ghrta*, a formulation containing *Nimba*, *Patola*, *Kantakari*, *Guduchi*, *Vasa*, *Triphala*, and *Go Ghrta*. True to its name, this preparation is predominantly *Tikta* (bitter) in taste — a *Rasa* well recognised for its *Tridoshahara* properties and its specific indication in *KushtaRoga*. Its *RaktaPrasadana* (blood-purifying) action makes it a fitting choice for internal oleation in psoriasis, as it initiates the mobilisation of deep-seated toxins before the actual purgation is performed.

SarvangaTakradhara Following *Virechana*, all three patients received *SarvangaTakradhara* — a *Bahirparimarjana Chikitsa* (external therapeutic procedure) in which medicated buttermilk is poured in a continuous stream over the entire body. This therapy is specifically recommended for *KushtaRoga* and is of particular significance in Psoriasis, given its well-established psychosomatic dimension. The medicated preparation — comprising *Takra*, *Amalaki*, *Yashtimadhu*, *Jatamansi*, *Musta*, and *PanchavalkaKwatha* — collectively exerts *Vata-Pitta Shamaka* properties, helping to calm the nervous system, reduce stress, and promote deep relaxation of both body and mind. *PanchavalkaKwatha* — prepared from the barks of *Vata* (*Ficusbengalensis*), *Udumbara* (*Ficusglomerata*), *Ashwatha* (*Ficusreligiosa*), *Parisha* (*Thespesia populnea*), and *Plaksha* (*Ficus lacor*) — was used both as a local wash and as a component of *Takradhara*. Phytochemical studies have identified this formulation as being rich in phenolic compounds, particularly tannins and flavonoids, lending it potent antiseptic, anti-inflammatory, immunomodulatory, antioxidant, and wound-healing properties. All five constituent ingredients share a dominance of *Kashaya* (astringent) *Rasa*, which is particularly effective in managing *Shotha* (inflammation) and *Vrana* (wounds). Together, its *Shodhana* (cleansing) and *Ropana* (healing) actions make it a highly suitable local therapeutic agent in *Kushta* management.

Shamana Oushadhi (Oral Medicines)



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Once the purification phase was complete, *Shamana Chikitsa* was introduced to consolidate and sustain the therapeutic gains achieved through *Virechana*. *Gandhaka Rasayana*, a well-regarded herbo-mineral formulation, acts as a powerful *RaktaShodhaka* (blood purifier) and *Rasayana*, exerting its influence across all *Doshas* and *Dhatus*. Its *UshmaVeerya* (hot potency) and *KatuVipaka* properties make it an effective *Kaphaghna* and *Kledaghna*, helping to disrupt the *Samprapti* (pathogenesis) of *Kushta* from within. *Arogyavardhini Vati*, a classical herbo-mineral compound, is predominantly *Tikta* in *Rasa*, followed by *Kashaya* and *Katu*. It is specifically indicated in *KushtaRoga* for its *Pitta Virechana*, *TridoshaShamaka*, *Deepana*, *Pachana*, *Kushthaghna*, and *Kandughna* properties. By enhancing digestive fire, promoting elimination, and directly addressing the symptoms of itching and skin lesions, it serves as an important supportive medicine in the overall protocol. *Nalpamaradi Taila*, applied externally, addresses the local vitiation of *Vata* and *Kapha* while simultaneously pacifying *Pitta* and *RaktaDushti*. Prepared from the barks of *Nyagrodha*, *Udumbara*, *Ashvattha*, and *Plaksha*, it is classically indicated in *Pama*, *Kandu*, *Pidaka*, *Kushtha*, and *Visarpa* – conditions that closely parallel the cutaneous manifestations seen in psoriasis.

Manjishtadikwatha – *Manjishtadi Kwath* (also referred to as *MahamanjishtadiKadha*) is a well-established Ayurvedic decoction renowned for its *Raktashodhaka* (blood-purifying) action. It is widely used in the management of various skin disorders, where it helps reduce inflammation, improve skin complexion, and promote overall dermatological health. The formulation is particularly useful for conditions such as acne, eczema, psoriasis, and boils, acting by detoxifying accumulated metabolic waste (*Ama*). Furthermore, it supports joint health and contributes to optimal liver function. Taken together, this treatment protocol – with *Virechana* as its main therapy – addresses Psoriasis at its root by targeting the *Pitta-Rakta* axis, clearing the body's channels, and restoring systemic balance, while the subsequent therapies work to sustain and strengthen these outcomes over time.

CONCLUSION

Psoriasis is a chronic, relapsing, autoimmune-mediated dermatological condition whose global burden continues to grow, posing significant challenges not only to physical health but also to the psychological and social well-being of affected individuals. Contemporary biomedical management, while effective in the short term, is largely palliative in nature, offering symptomatic relief without addressing the underlying pathophysiological mechanisms that drive recurrence. Furthermore, prolonged dependence on systemic immunosuppressants, biologics, and phototherapy is associated with considerable adverse effects, economic burden, and diminishing therapeutic efficacy over time. In this context, Ayurvedic medicine presents a compelling and time-tested alternative framework for the holistic management of psoriasis, one that targets the root cause of the disease rather than its superficial manifestations. The classical Ayurvedic understanding of psoriasis as a *KushtaRoga* – rooted in *Pitta-RaktaDushti* and compounded by *Tridoshic* imbalance – provides a coherent pathological model that aligns remarkably well with the modern understanding of immune dysregulation and chronic inflammation. *Virechana Karma*, as demonstrated in the three cases presented, serves as the therapeutic cornerstone of this approach, effectively expelling accumulated *Pitta* and purifying *RaktaDhatu* through targeted *Srotoshodhana*, thereby disrupting the core *Samprapti* of the disease. Complementary therapies such as *Sarvanga Takradhara* further augment this purification by addressing the psychosomatic dimension of psoriasis, reducing stress, calming the nervous system, and promoting systemic *Vata-Pitta* equilibrium. The concurrent administration of *Shamana Oushadhi* – including *Gandhaka Rasayana*, *Arogyavardhini Vati*, and *Manjisthadi Kwatha* – along with local applications of *Nalpamaradi Taila* and *Panchavalka Kwatha*, consolidates the purificatory gains and supports sustained remission. Adherence to *Pathya Ahara - Vihara* – appropriate dietary and lifestyle modifications – further strengthens the therapeutic outcomes by preventing the re-accumulation of *Doshas* and reducing the likelihood of relapse. The findings of this case series thus suggest that a structured, multimodal Ayurvedic protocol, centred on repeated *Shodhana* and supported by *Shamana Chikitsa* and *Pathya*, offers a safe, cost-effective, and holistically integrated approach to managing chronic psoriasis – one that warrants further validation through rigorously designed clinical trials on larger patient populations. Patients have been advised to undergo repeated *Shodhana* treatments to prevent recurrence of the disease.





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Case-1

Day	Date	Procedure	Medicine	Dose	Anupana	observations
1	23/10/25 to 27/10/25	Deepana-Pachana	Chitrakadi Vati Shankhvati	2-0-2 B/F 2-0-2 A/F	Warm Water	-
4	28/10/25	Snehapana	Panchtikta Ghrita	30 ml	Hot Water	-
5	29/10/25	Snehapana	Panchtikta Ghrita	60 ml	Hot Water	Itching increased
6	30/10/25	Snehapana	Panchtikta Ghrita	90 ml	Hot Water	Itching increased
7	31/10/25	Snehapana	Panchtikta Ghrita	120 ml	Hot Water	Itching increased
8	01/11/25	Snehapana	Panchtikta Ghrita	140 ml	Hot Water	Itching increased
9	02/11/25	Sarvanga Abhyanga-swedana	Nimba Taila	Q.S.	---	Itching reduced
10	03/11/25	Sarvanga Abhyanga-swedana	Nimba Taila	Q.S.	---	Itching reduced
11	04/11/25	Sarvanga Abhyanga-swedana	Nimba Taila	Q.S.	---	Itching reduced
11	04/11/25	Virechana	Trivruta Lehya	65 gm	Hot Water	Symptoms reduced

Case-2

Day	Date	Procedure	Medicine	Dose	Anupana	observations
1	16/03/25 to 20/03/25	Deepana-Pachana	Chitrakadi Vati Shankhvati	2-0-2 B/F 2-0-2 A/F	Warm Water Warm Water	-
4	21/03/25	Snehapana	Panchtikta Ghrita	30 ml	Hot Water	-
5	22/03/25	Snehapana	Panchtikta Ghrita	70 ml	Hot Water	Itching increased
6	23/03/25	Snehapana	Panchtikta	100 ml	Hot Water	Itching increased





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			Ghrita			
7	24/03/25	Snehapana	Panchtikta Ghrita	130 ml	Hot Water	Itching increased
8	25/03/25	Snehapana	Panchtikta Ghrita	150 ml	Hot Water	Itching increased
9	26/03/25	SarvangaAbhyanga-swedana	NimbaTaila	Q.S.	---	Itching reduced
10	27/03/25	SarvangaAbhyanga-swedana	NimbaTaila	Q.S.	---	Itching reduced
11	27/03/25	Vamana	Madanphala Vacha Pippali Yastimadhu	5 gm 1.5 gm 3 gm 6 gm	YastimadhuPhanta Lavanodaka	Symptoms reduced

Case-3

Day	Date	Procedure	Medicine	Dose	Anupana	observations
1	17/08/25 to 18/08/25	Deepana-Pachana	ChitrakadiVati Shankhvati	2-2-2 B/F 2-2-2 A/F	Warm Water Warm Water	-
4	19/08/25	Snehapana	Panchtikta Ghrita	30 ml	Hot Water	-
5	20/08/25	Snehapana	Panchtikta Ghrita	70 ml	Hot Water	Itching increased
6	21/08/25	Snehapana	Panchtikta Ghrita	90 ml	Hot Water	Itching increased
7	22/08/25	Snehapana	Panchtikta Ghrita	120 ml	Hot Water	Itching increased
8	23/08/25	Snehapana	Panchtikta Ghrita	130 ml	Hot Water	Itching increased
9	24/08/25	SarvangaAbhyanga-swedana	NimbaTaila	Q.S.	---	Itching reduced
10	25/08/25	SarvangaAbhyanga-swedana	NimbaTaila	Q.S.	---	Itching reduced
11	26/08/25	SarvangaAbhyanga-swedana	NimbaTaila	Q.S.	---	Itching reduced
11	26/08/25	Virechana	TrivurutaLehya	60 gm	Hot Water	Symptoms reduced

RESULT

Case-1

Date	Auspitz Sign	Kobner's Phenomena	Candle grease Sign	PASI Score
Before Treatment	2	2	2	5
After Snehapana	2	2	2	5
After SarvangaAbhyangaSwedana	2	2	1	5
On the Day of Virechana	2	2	1	5
After week of Virechana	1	1	1	4
BeforeTakradhara	1	1	1	4





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After takradhara	1	1	0	4
After week of Takradhara	0	0	0	2

Case-2

Date	Auspitz Sign	Kobner's Phenomena	Candle grease Sign	PASI Score
Before Treatment	2	2	1	4
After Snehapana	2	2	1	4
After SarvangaAbhyangaSwedana	2	2	1	4
On the Day of Vamana	2	1	1	4
After week of Vamana	1	1	0	3
Before Treatment	1	1	1	3
After Snehapana	1	1	1	3
After SarvangaAbhyangaSwedana	1	1	1	3
On the Day of Virechana	1	1	1	3
After week of Virechana	1	1	0	2
Before Takradhara	1	1	0	2
After Takradhara	1	0	0	2
After week of Takradhara	1	0	0	1

Case-3

Date	Auspitz Sign	Kobner's Phenomena	Candle grease Sign	PASI Score
Before Treatment	2	1	2	4
After Snehapana	2	1	2	4
After SarvangaAbhyangaSwedana	2	1	2	4
On the Day of Virechana	2	1	2	4
After week of Virechana	1	0	1	4
Before Takradhara	1	0	1	3
After Takradhara	1	0	1	2
After week of Takradhara	1	0	1	2

Case-1





Suma and Sangeeta Toshikhane

Case-2



Case-3



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RESEARCH ARTICLE

Deep CNN Model for Multi-Stage Alzheimer's Classification Using Brain MRI

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ABSTRACT

Alzheimer's disease is a neurological disorder that impairs memories, thinking skills, and learning abilities. That's why early and accurate diagnosis for AD is needed. Timely treatment can slow the disease's progress and improve patient health. Before deep learning became popular, people used traditional machine learning and manually designed image features for Alzheimer's detection. In the latest deep learning model, major progress was made in brain scan analysis, but there are few challenges. For example, sometimes MRI datasets are unbalanced, scan quality is an issue, and early symptoms can be hard to detect. To overcome these problems, this project introduces a fully automated deep learning system that classifies MRI scans in four stages: Very Mild Demented, Mild Demented, Moderate Demented, and Non-Demented. This method includes pre-processing, data augmentation, and balancing the classes using SMOTE. The CNN model is trained for multi-class classification. This system performs better than traditional methods and gives higher accuracy and clearer separation between dementia stages.

Keywords: structural MRI analysis, convolutional neural networks, data augmentation, SMOTE oversampling

INTRODUCTION

Alzheimer is a human brain issue that slowly damages human's memory, thinking ability, and behaviour. This is a similar type of dementia that affects a huge number of people in the world. Detecting it early is important because treatment affects better when the disease hasn't progressed too far. MRI scans are helpful for studying Alzheimer's, but diagnosis still depends on doctors manually reviewing the images. This takes time and sometimes leads to different interpretations, especially in early stages where the changes are very minor. To solve this problem, I developed a deep





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learning model that detect Alzheimer stages based on MRI image. The workflow of model includes preprocessing, noise removing, data balancing using SMOTE and augmentation to improve the dataset. I used aCNN model for employed to classify MRI scans into four distinct stage of Alzheimer:

- Non Demented, Very Mild Demented, Mild Demented and Moderate Demented

LITERATURE REVIEW

Research in automated Alzheimer's Disease identification is increasingly leaning towards deep learning techniques applied to structural magnetic resonance imaging, where the Convolutional Neural Networks are becoming the dominant type of approach, as compared to traditional methods based on hand-crafted features. Studies utilizing well-known datasets such as ADNI, OASIS, and MIRIAD report strong performance from both 2D and 3D CNN frameworks. Although 3D architectures better exploit volumetric information for understanding structural characteristics, 2D models employing transfer learning such as VGG16, ResNet50, InceptionV3 and Dense Net demonstrated excellent effectiveness, particularly when training data is limited [1], [2], [3]. Standard preprocessing procedures including removal of skull regions, adjustment of image dimensions, intensity standardization and contrast enhancement are commonly implemented techniques for normalizing MRI scans to improve feature identification [4]. To address the significant class distribution disparities frequently observed in dementia stage classification, current research suggests various techniques including data augmentation, Over-sampling Techniques (SMOTE), Focal loss functions, and class-balanced sampling approaches, which result in improved detection rates for Mild and Moderate Dementia categories [5], [6]. Combined frameworks that integrate CNN-extracted features with conventional algorithms like Support Vector Machine or Random Forest classifier it enhanced performance when working with limited dataset [7].

Objectives

- Improve quality of image and reliability of model by using pre-processing and augmentation.
- apply SMOTE to solve class imbalance and improve detection in the minority stages.
- design and train an optimized CNN for multi-class Alzheimer classification.
- assess the system performance through accuracy, loss curve and confusion matrix analysis.
- construct a completely automated pipeline supporting early diagnosis and stage-wise clinical assessment

METHODOLOGY

This proposed framework consists fully automated deep learning pipeline that classifies multi-class Alzheimer disease based on structural MRI image. The methodology includes data preprocessing, augmentation, class balancing using SMOTE, CNN-based feature extraction, model training and evaluation. Each component has been designed for align with the operational flow of the implemented system.

Data Pre processing

All MRI inputs were normalized and standardized to maintain consistency across the entire dataset. The preprocessing stage includes resizing to a fixed spatial resolution with subsequent pixel-intensity normalization to stabilize gradient updates while training the model. Normalization is performed as:

$$I_{\text{norm}} = I / 255 \quad (1)$$

where I represent the pixel intensity and I_{norm} denotes normalized value.





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Data Augmentation

To address dataset limitations and improve the model's generalization capability, an augmentation strategy is employed using Image Data Generator. It includes rotation, translation, zoom, brightness variation and horizontal vertical flipping. Mathematically, this transformation are described as follow:

1. Rotation

$$I' = R_\theta(I) \quad (2)$$

2. Zoom

$$I' = Z_\lambda(I) \quad (3)$$

3. Horizontal / Vertical Flip

$$I'(x, y) = I(W - x, y) \quad (4)$$

Class Balancing Using SMOTE

To compensate for class unbalance, particularly for Moderate Demented samples the Synthetic Oversampling Technique, known as SMOTE is used. SMOTE generates synthetic example using,

$$x_{new} = x_i + \delta(x_{im} - x_i) \quad (5)$$

This method ensures equal distribution among all four dementia stages.

CNN Model Architecture

Figure 2 describe the architecture of CNN model. It contains convolutional layer with ReLU as an activate function followed by max-pooling It consist a custom CNN Model, which is core of the system for multi-class MRI-based classification. The architecture consists number of convolutional layers to extract features hierarchically. Max-pooling operations compress spatial dimensions while preserving essential structural patterns. regularization is applied to prevents overfitting, while the full connected dense layers perform the final classification into four dementia stages. the SoftMax layer generates the final probability distribution for each class.

Model Training

The training process employs an optimizer that adjust the learning rate dynamically throughout learning. To reduce risk of overfitting, Early Stopping was applied based on validation loss.

Model Evaluation

Performance evaluation is conducted using different methods:

Accuracy

$$\text{Accuracy} = \frac{\text{Correct Predictions}}{\text{Total Predictions}}$$

Testing Loss	:	0.217444
Testing Accuracy	:	91.357422 %
Testing AUC	:	99.121654 %
Testing F1-Score	:	98.838365 %
Testing Precision	:	91.901237 %
Testing Recall	:	90.869141 %

Deployment Readiness

Final model allows for real-time inference and it can be integrated into clinical decision-support tools. The automated pipeline allows seamless processing from input MRI images to the final classification without expert involvement in manual feature extraction.



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OUTCOME AND DISCUSSION

Pre-processed and SMOTE-balanced MRI data from four types of Alzheimers disease are used for train CNN model. The model attained an accuracy range of approximately 92% to 95% throughout training. Comprehensive augmentation methods reduced overfitting and improved the model's generalization. For the NonDemented and Very Mild Demented classes, confusion matrix analysis performed exceptionally well and improvements in the Moderate Demented class were noticeable with the use of SMOTE-based oversampling. Overall, the system demonstrated strong multi-class classifications, effectively differentiating the increasing phases of the Alzheimer's disease using MRI Scan.

CONCLUSION

This study used structural MRI scans as input to develop an automated deep learning framework for multi-class Alzheimer's detection. The proposed system integrates standardized preprocessing, extensive data augmentation and SMOTE-driven class rebalancing with a custom lightweight CNN architecture that jointly enable differentiation across four stages of dementia. Experimental results confirm that balanced and consistently pre-processed data greatly enhance the capabilities of the model in capturing even small anatomical changes specially in conditions at an early stage. Furthermore, the enhanced CNN structure facilitates efficient implementation using less computational resources in real-time clinical process. Overall, the developed framework offers a robust, scalable and clinically meaningful solution able to support the radiologists' early diagnosis and informed decision-making, thus contributing to improved patient management and timely therapeutic intervention.

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Figure 1 (Flow chart)



Figure 2 (Model Architecture)

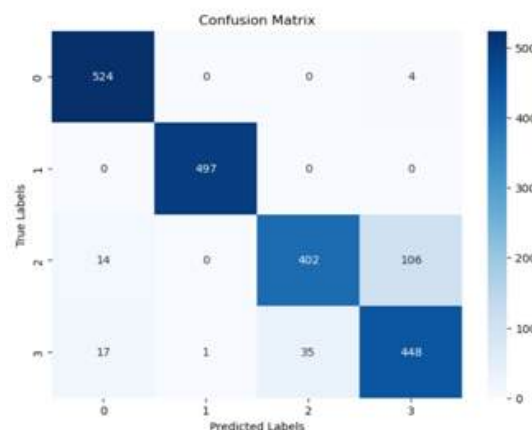
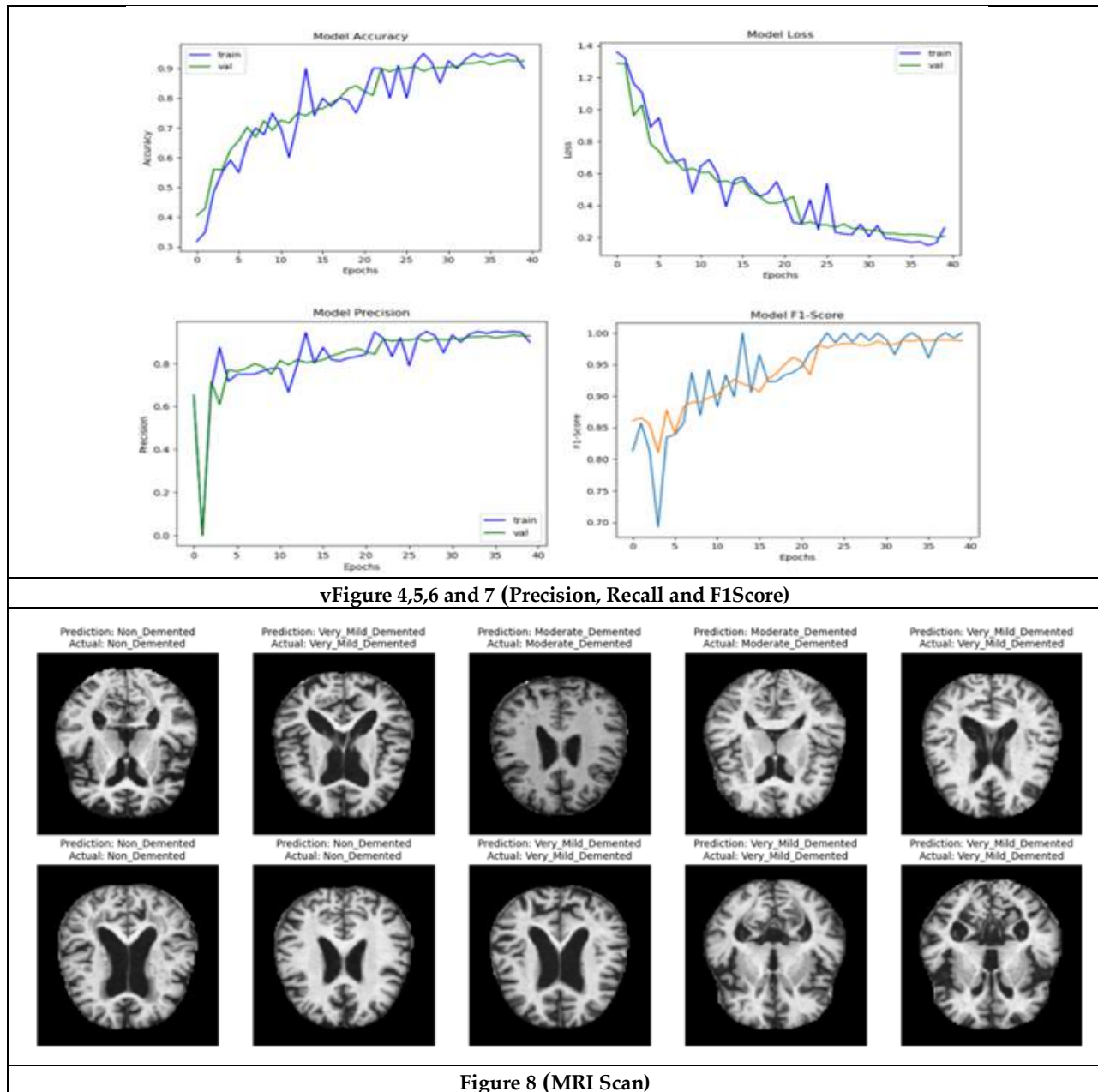


Figure 3 (Confusion Matrix)





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RESEARCH ARTICLE

Accurate Prediction and Deceit Identification: A Machine Learning And Deep Learning Perspective

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ABSTRACT

The paper has discussed the concept of deception/truthful prediction by critically examining the concept of machine learning (ML) and deep learning (DL) models. DenseNet11, Mobile Net, Inception V3, and EfficientNetB0 were reviewed in the area of DL; among them, EfficientNetB0 is a special solid performer; it has balanced values of precision, recall, and F1-Score with a high accuracy. Meanwhile, a detailed comparison is made to the traditional machine learning algorithms that include K-Nearest Neighbors (KNN), Support Vector Machine, Decision Tree, Random Forest, Naive Bayes, and Extra Trees. SVM, RF, and ET demonstrate great accuracy and far-reaching predictive capabilities, highlighting the effectiveness of the traditional ML methods to differentiate between fraud and genuine ones. In a world where information overload is aggressively enforced, the comparison analysis emphasizes the importance of making model choice specific to the characteristics of the dataset and specific task demands. This offers valuable information to researchers, practitioners, and decision-makers as they must sail through the challenges of deception/ truthful prediction.

Keywords: Machine learning (ML), Deep learning (DL) Models, traditional ML methods

INTRODUCTION

Because fraud can occur during the time of fast-adapting technologies and limitless amounts of data, the data should be assessed and controlled [10]. Thus, it should not come as a surprise that such a content is to be detected by a reliable method. Some of the ways that deception may manifest itself on the Internet include identity theft, spoofing data and processes to steal credit card numbers or other confidential information, billing false services that have



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nothing been rendered, hacking websites, false claims and justification, and misinformation and propaganda, and so forth. Thus, regardless of its face-to-face or via a specific medium, it is necessary to note when deception takes place. This implies that one must find a reliable method of finding out dishonesty because people lie on average two times a day [1]. Lying is certainly one of the main human characteristics that has evolved to such an extent that even experienced specialists cannot distinguish it. Why is the truth not just like the lies or deception, particularly when speaking a language and when is there a difference, how can one find it most efficiently? Is most of the information acquired because of nonverbal behavior or are there any language patterns that are dependable enough to indicate dishonesty? Is there a difference in verbal or nonverbal, asynchronous or synchronous, computer mediated, or face-to-face communication in deceit?

The effective use of machine learning and deep learning has helped in recommendation systems, computer vision, natural language processing, fraud and malware detection, medical diagnosis and data privacy, network and data transmission security, intrusion detection, generative molecular design, and numerous other functions and purposes [8,13]. It also offers a plethora of ways, enabling users to make a number of attempts to solve different problems. The issues, under research, are numerous, such as deception detection in computer-mediated communication [2,3], social media reviews [4,5], detection of deception during a trial by the public [6,7], crowdsourcing websites such as Amazon Mechanical Turk [5,8] to generate deception data, and others. Feng et al. [5] assessed deep syntax of the data based on the principles of probabilistic context-free grammar (PCFG) and compared it with those that have already appeared in the literature. Besides the above applications, the LIWC method was also used to detect fraud concerning the text being investigated by applying an awareness of the psycho-linguistic characteristics of the text being investigated. In this paper, part I outlines the introduction section of deception detection. Section II is regarding work related. Section III Methodology of the machine learning. IV Deep Learning Methodology. Preset results and analysis is section V.

Machine Learning Methodology

Detection of deception or truthfulness is commonly a dichotomous classification task, in which the aim is to categorize input data into two categories, deceptive and truthful. The following is a description of each of the said models in the context of deception/truthful prediction.:

K-Nearest Neighbors (KNN)

Principle: KNN is an algorithm easy to understand. The majority of the k-nearest neighbors of a data point in the feature space have been used to classify the data point [11].

Application: In deception/truthful prediction, KNN might be applied to compare the features of a particular instance with those of the nearby instances in order to determine whether it has a higher probability of being deceptive or truthful.

Support Vector Machine (SVM)

Concept: Support Vector Machines (SVM) are powerful classification algorithms that determine the hyperplane in feature space, which best splits the classes. It is the marginalisation of classes that it aims to optimise [12].

Application: SVM may be used to create a boundary of decisions that successfully isolates the instances of deception and truth in the feature space.

Decision Tree (DT)

Concept: Decision trees split data recursively based on the most significant qualities in order to come up with decisions. Aim of any split is to minimise impurity or maximise information gain [13].

Application: Decision Trees can be used to develop rules that determine the patterns of the data that are either deceptive or true.



**Twisha Patel****Random Forest (RF)**

Concept: The random forest ensemble method builds a number of decision trees and combines the predictions of the trees. It makes results more accurate and reduces overfitting [14].

Application: Random Forest may be used in deception/truthful prediction to have a strong and accurate model through those of multiple decision trees.

Naive Bayes (NB)

Concept: naive Bayes plays off the Bayes theorems and a naive assumption of independence of features: Bayes is a probabilistic classifier [15].

Application: NB is useful to estimate the likelihood of an instance being a deceptive or a truthful one depending on the presence of various features.

Extra Trees (ET)

Concept The other similar ensemble technique to Random Forest is Extra Trees, also known as Extremely Randomized Trees. It constructs various decision trees that have random splits at each node [16].

Application: ET may be applied to develop a collection of decision trees to predict deception/truthfulness as with Random Forest.

The dataset size, the interpretability criteria, the desired trade off between model complexities and model performance and also the type of the data all affect the model choice. Experimenting on a number of models and their performance to identify the best method to use in a given deception/truthful prediction task is commonplace.

Deep Learning Methodology

Most of the architectures used in image classification include DenseNet11, MobileNet, Inception V3, and EfficientNetB0. It will be applied in deception/true prediction. The models are aimed at solving computer vision tasks, and their use is usually concerned with the image analysis, recognition and classification. Although, the models used in binary classification problems such as deception/truthful prediction would be normally combined with other layers or even changes in the output layer to convert them into a binary classifier. I will briefly describe each of these models and explain how each of them can be modified to such tasks:

DenseNet11

DenseNet is a neural network architecture that has dense connected layers. DenseNet11 is probably a particular variant of 11 layers. It is mainly applied in tasks of image classification.

Adaptation: You would have to change the final dense layer to produce a binary classifier (deceptive or truthful) rather than the number of classes originally.

MobileNet

MobileNet is developed to work on mobile and edge devices and it focuses on efficiency and speed. It involves the depth-wise separable convolutions to decrease the computational complexity.

Adaptation: As with DenseNet, you would have to modify the output layer to binary classification.

Inception V3

Inception V3 belongs to the Inception series, which has an inception module with varying filter sizes concurrently.

Adaptation: Reduce final classification layer to binary output. It is also possible to fine-tune the model on your own dataset.

EfficientNetB0

EfficientNet is a series of models aimed at efficient scaling of neural networks. The baseline model is called EfficientNetB0.





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Adaptation: Reconfiguration the last classification layer to your binary classification problem. It may require fine-tuning to achieve optimum performance with your problem. In case of deception/truthful prediction, we need to have labeled data set, which consists of images labelled as either deceptive or truthful. It may require fine-tuning or transfer learning, in which the model that has already been trained is additionally trained on your data to fit your task.

CONCLUSION

Finally, when performance characteristics are analysed with the aid of both deep learning (DL) and traditional machine learning (ML) models, different features are disclosed in the cases of deception/truthful prediction. DenseNet11 and MobileNet show a similar and outstanding performance in general, and with the accuracy of 83% and equalized preciseness, recall, and F1-Score, in the case of the DL models. Having an accuracy of 88 percent and good precision, recall, and F1-Score values, EfficientNetB0 has a better result than the other models, which supports its efficiency in dealing with misleading and truthful prediction situations. Random Forest (RF) and Extra Trees (ET) are rather effective as far as the machine learning is concerned, with a combined impressive 94 percent accuracy, and good scores in precision, recall, and F1-Score. Support Vector machine (SVM) with a remarkable 93 percent accuracy rate also exhibits significant performance in its ability to lower cases of frauds and those that are authentic. Summarizing, traditional ML models, particularly SVM, RF, and ET, appear to be very efficient in deception/truthful prediction despite evident positive outcomes of such DL models as DenseNet11, MobileNet, and EfficientNetB0. The choice among DL and ML models depends on such aspects as the characteristics of the datasets, interpretability, and the processing needs, the detailed analysis of the chosen application should be based on the requirements of the application.

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Table 1: Summary of reviewed papers

Paper	Algorithm	Category	Type
1. Pérez-Rosas et al. (2015)	SVM, Random Forest	Facial, Verbal	ML
4. George et al. (2017)	Eye blink analysis	Facial	ML
6. Nasri et al. (2016)	ReLiDSS	Verbal (Transcript)	ML
7. Michael et al. (2010)	Motion profiles	Visual (Gesture)	ML
8. Zhang et al. (2007)	Real-time automatic deceit detection	Visual (Facial)	ML
9. Venkatesh et al. (2019)	Robust algorithm	Facial, Verbal	ML
10. Krishnamurthy et al. (2018)	Deep Learning	Facial, Verbal	DL
12. Vrij et al. (2017)	Cognitive approach	Facial, Verbal	ML
13. Hauch et al. (2015)	Linguistic cues	Verbal (Transcript)	ML
16. Gupta et al. (2019)	Bag-of-lies dataset	Facial, Verbal	ML
17. Jaiswal et al. (2016)	Multimodal analysis	Facial, Verbal	ML
18. Ding et al. (2019)	Face-focused cross-stream network	Visual (Facial)	DL
19. Gogate et al. (2017)	Deep Learning	Facial, Verbal	DL
21. Abouelenien et al. (2016)	Integration of features	Facial, Verbal	ML
22. Karimi et al. (2018)	End-to-end deception detection	Facial, Verbal	DL
23. Ahmed et al. (2021)	Facial Action Coding System	Visual (Facial)	ML
24. Yang et al. (2020)	Emotion transformation feature	Visual (Facial)	ML
25. Avola et al. (2019)	Facial action units	Visual (Facial)	ML
27. Bai et al. (2019)	Automatic long-term deception detection	Facial, Verbal	ML
28. Feng (DeepLie)	Deep Learning	Visual (Facial)	DL
29. Ngo et al. (2021)	Identity-Unbiased Deception Detection	Visual (Facial)	ML
30. Pérez-Rosas et al. (2015)	SVM, Random Forest	Facial, Verbal	ML
31. Stathopoulos et al. (2020)	Deception Detection in Videos Using Robust Facial Features	Visual (Facial)	ML
32. Antolin et al. (2021)	Multimodal attention LSTM-based framework	Visual (Gaze and Speech)	DL
33. Adegun (2020)	Facial micro-expression recognition	Visual (Facial)	ML
34. Liu et al. (2021)	Hybrid Features	Visual (Facial)	ML
36. Venkatesh et al. (2019)	Robust Algorithm	Facial, Verbal	ML
37. Jaiswal et al. (2016)	Multimodal Analysis	Facial, Verbal	ML
38. Gogate et al. (2017)	Deep Learning Driven Multimodal Fusion	Facial, Verbal	DL
40. Li et al. (2023)	Flexible-modal Deception Detection	Facial, Verbal	DL
41. Dong et al. (2022)	Intentional-Deception Detection	Visual (Facial)	ML

Table 2: DL and ML Analysis

Model	Accuracy	Precision	Recall	F1-Score
DenseNet11	83%	84%	83%	83%
MobileNet	83%	83%	84%	83%
Inception V3	58%	65%	58%	53%
EfficientNetB0	88%	88%	89%	87%





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Model	Accuracy	Precision	Recall	F1-Score
KNN	85%	85%	85%	85%
SVM	93%	93%	92%	92%
DT	85%	85%	85%	85%
RF	94%	92%	92%	92%
NB	79%	58%	51%	62%
ET	94%	92%	92%	92%



Fig 1: Dataset Frames

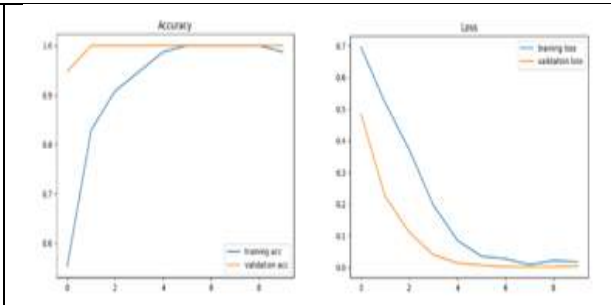


Fig 2: Accuracy and Loss Plots of Densenet11 Training

	precision	recall	f1-score	support
Deceptive	0.80	0.92	0.86	13
Truthful	0.89	0.73	0.80	11
accuracy			0.83	24
macro avg	0.84	0.83	0.83	24
weighted avg	0.84	0.83	0.83	24
[[12 1]				
[3 8]]				

Fig 3: Classification Parameters of Densenet11

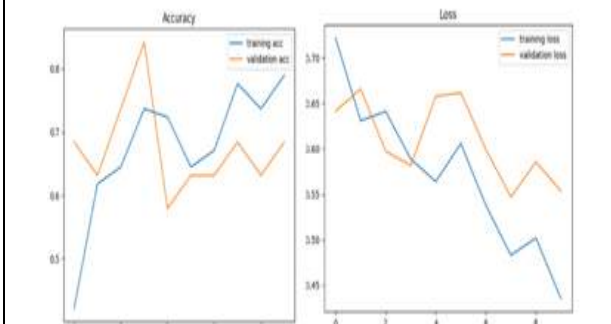


Fig 4: Accuracy & Loss Plots of MobileNet Training

	precision	recall	f1-score	support
Deceptive	0.92	0.79	0.85	14
Truthful	0.75	0.90	0.82	10
accuracy			0.83	24
macro avg	0.83	0.84	0.83	24
weighted avg	0.85	0.83	0.83	24
[[11 3]				
[1 9]]				

Fig 5: Classification Parameters of Densenet11

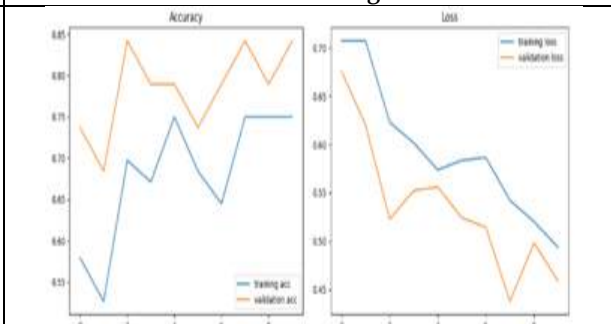
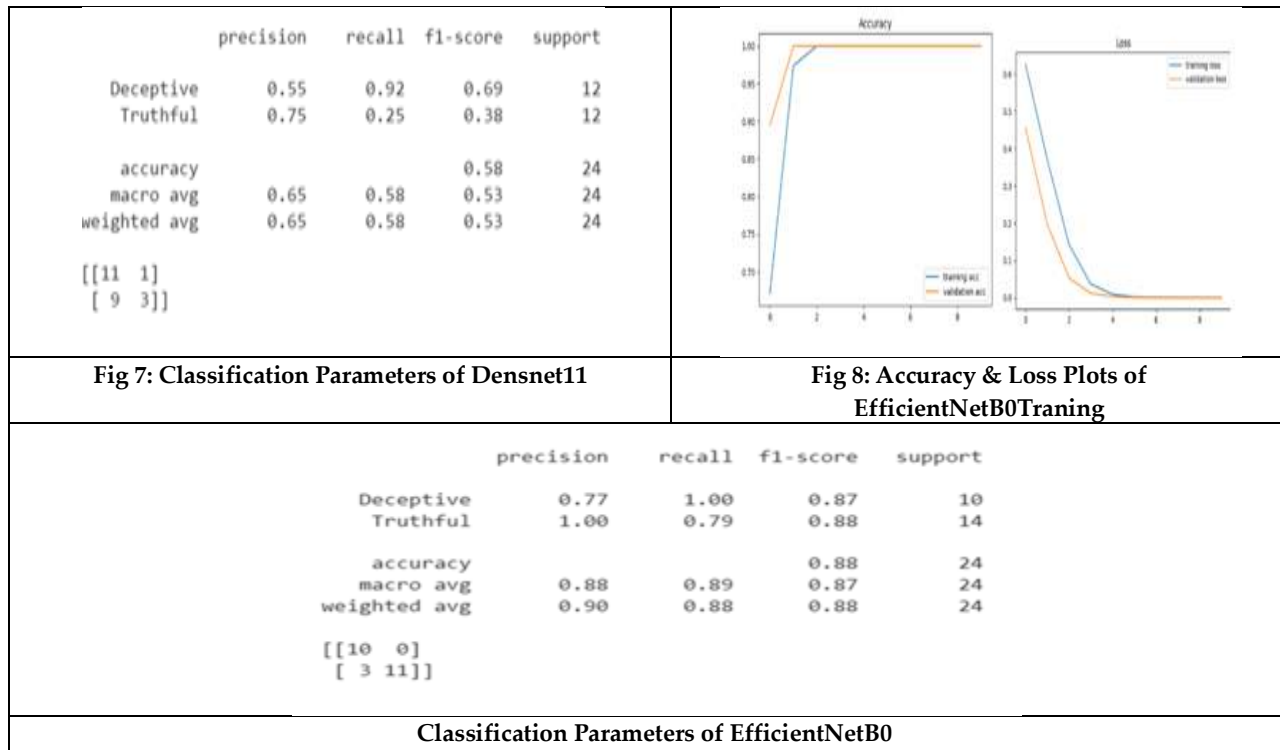


Fig 6: Accuracy & Loss Plots of EfficientNetB0 Training





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RESEARCH ARTICLE

An Explainable Lightweight Fake-News Detection for Indian Code-Mixed Languages

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ABSTRACT

The research study aims to build an efficient and explainable framework that will primarily help in detecting fake news in Indian code-mixed languages - languages that typically have high code-switching between English and regional languages and where performance of conventional models is largely poor. A multilingual dataset involving Gujarati-English, Hindi-English, and Marathi-English test scenarios was prepared by cleaning, normalizing, and integrating social-engagement features. The proposed approach has used adapter-based transfer learning on XLM-R to reduce training costs with multilingual capability preserved. Explainability is supported using SHAP and LIME analyses. Experimental results reveal high accuracy, well-balanced performance, and robustness across all three language pairs. The findings have been able to establish that lightweight adapters, along with social features, present a pragmatic solution for real-world misinformation detection

Keywords: Fake news detection, Code-mixed languages, Adapter learning, Explainable AI, Social-feature, Multilingual NLP

INTRODUCTION

The rapid spread of misinformation on social media has become a serious concern, especially in India where people often using a mix of English and regional languages such as Gujarati, Hindi, and Marathi. These posts include informal spellings, transliterated words, and frequent code-switching, which makes their processing very challenging for a standard NLP model [1,2]. Though large multilingual transformer models have shown promising performance with clean text, XLM-R being one of them, they are heavy to train and generally fail when it comes to noisy, code-mixed data [3]. Another challenge is the lack of large and well-prepared code-mixed datasets for fake-news detection. Most of the existing resources focus on hate speech or sentiment analysis rather than misinformation [4]. Social behaviours—likes, shares, and user credibility—have still not been fully used even though these patterns

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providing useful signals in detecting misleading content [5]. To address these issues, this paper introduces a lightweight and explainable fake-news detection system for Indian code-mixed languages. The system design will be based on adapter-based learning, multilingual preprocessing, and social-engagement features to ensure practical and efficient solution. The system also includes explanation tools to make model decisions easier to understand and more transparent.

LITERATURE REVIEW

Research on misinformation detection has grown quickly due to the rapid spread of online content. Early studies typically use traditional machine learning models, which are trained on mostly English datasets. These perform poorly on informal text and multilingual posts typical of Indian social media. More recent transformer-based models like BERT and XLM-R improve performance for multilingual tasks, but still face difficulty handling irregular spelling, script mixing, and transliteration patterns common in code-mixed languages [1]. Most of the existing work on code-mixed Indian NLP is focused on sentiment or hate-speech detection rather than misinformation. While shared tasks like HASOC provide useful benchmarks, most of them are in Hindi-English and do not handle Gujarati-English or Marathi-English fake news detection [4]. Several studies highlight that a general lack of well-structured datasets for these languages limits progress and reduces the reliability of cross-lingual evaluation [6,7]. Recent work indicates that adapter-based learning provides an efficient alternative towards full model fine-tuning. Frames like MAD-X and Adapter Fusion demonstrate that that language specific adapters can show unique linguistic patterns with far fewer parameters, as shown by [2,10]. However, only a few studies have applied adapters to misinformation detection, and most of these ignore social-engagement features even though user behaviour plays an important role in the spread of misleading content, as stated by [8].

Recently, explainable AI has also gained attention. Methods like SHAP and LIME are used to interpret predictions in sentiment analysis and toxicity detection [14,15], respectively. However, their applications in multilingual fake-news detection-especially code-mixed text-are still limited.

Overall, the literature identifies three major gaps:

- limited datasets for Gujarati-English and Marathi-English,
- lack of lightweight models designed for code-mixed misinformation.
- minimal use of explainability tools in this domain.

This research addresses these gaps by creating original code-mixed datasets and designing a lightweight, explainable adapter-based system for fake-news detection in multiple languages.

METHODOLOGY

This study followed an approach that addressed explainability, model development, preprocessing, and dataset creation. The overall workflow is designed to be lightweight and interpretable, and it also supports code-mixed Indian languages.

Dataset Preparation

This study created new datasets, as there are very limited datasets available for detecting fake news in Gujarati-English and Marathi-English languages [6,7]. Three language pairs were included: Marathi-English, Hindi-English, and Gujarati-English. For every post, textual data and social engagement metrics such as likes, shares, comments, follower count, verification status, and a source-credibility score were captured. All datasets combined into a unified format, with consistent column structures.

Text Cleaning and Normalization

The preprocessing primarily deal with the issues that are unique to code-mixed text such as transliteration, informal spellings, and excessively switching between languages. The cleaning steps involved removal of URLs, emojis,



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excessive punctuation, numbers, and lengthy repeated letters. The normalization rules were followed to reduce the spelling difference of commonly transliterated words giving a consistency for the same as reported in earlier code-mixed NLP studies [9]. Adding on, the cleaned datasets were merged and again set into training (70%), validation (15%) and testing (15%) datasets for the evaluation.

Model Architecture

We choose a lightweight XLM-R as the base model, supported by language-specific adapters.. The use of adapter learning largely brings down training costs and allows us to train on many languages more efficiently [2]. Three adapters were built: guj_en, hin_en, and mar_en, capturing language-pair patterns without modifying the base transformer. An Adapter Fusion layer was added optionally to share information learned across adapters for cross-lingual generalization [10].

Social-Feature Integration

To increase the accuracy of detection, the system incorporates social indicators that often reflect misinformation behaviour. Earlier studies have shown that fake news generates unusual engagement patterns when compared to verified posts [8]. The social features were normalized and concatenated with text embeddings for classification purposes, so the model can learn signals other than merely linguistic cues.

Explainability Layer

To ensure interpretability, the predictions of the model were analyzed via SHAP and LIME. This will show what words, patterns, or social behaviors influenced each decision [14,15]. This assists in determining whether the system is dependent on meaningful information, rather than noise or bias; hence, making the model deserving of application in real-world journalism and policy. The dataset was built along a strong three-phase pipeline to ensure legal fidelity and granular alignment. The usual sentence-alignment methods, perhaps, failed due to the complexity of legal syntax; hence, a method of automated structural parsing-"human-in-the-loop" methodology 1.0 was put in place.

RESULTS

Experiments were conducted on the three code-mixed datasets created for Gujarati-English, Hindi-English, and Marathi-English. The baseline XLM-R model was compared against two configurations: XLM-R with language-specific adapters and XLM-R with Adapter Fusion.

Dataset Summary

The final merged dataset contained 17,000 samples, with balanced real and fake labels across all language pairs. Table 1 summarizes the dataset distribution

Explainability Results

SHAP and LIME were used to interpret predictions. The explainability layer highlighted:

Key words such as "breaking", "urgent", "share karo", and "fake che" strongly influenced fake-news predictions, consistent with previous findings [14, 15].

- Posts with abnormally high shares relative to likes were often flagged as suspicious.
- The model correctly identified sensational or exaggerated phrasing, a common trait in misinformation

DISCUSSION

The results indicate that adapter-based learning is very effective in code-mixed detection of fake news. This supports previous claims that adapters can learn language-specific behaviours using many fewer parameters [2]. The higher performance with Adapter Fusion also resonates with its results in previous low-resource NLP studies [10].



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One of the key findings shows that social-engagement features significantly improve classification accuracy. Previous research has recorded similar findings, where user-interaction patterns were found to enhance the detection models [8]. In this case, the features such as comments, shares, and follower counts include more valuable cues that text alone would not have captured. The explainability tools added another trust layer. SHAP and LIME showed the reasoning of the model very clearly, indicating that the decisions were made based on meaningful linguistic cues and not on random correlations. This is very important for real-world deployment, especially for journalism, governmental alerts, and fact-checking teams. Finally, this framework creates a prominent gap noted in previous literature by creating a dataset that lacks, especially in the category of Gujarati-English and Marathi-English misinformation datasets [6, 7]. With the additional contribution of producing code-mixed samples with social-context fields, this research creates improvements at the methodological and resource levels.

CONCLUSION AND FUTURE SCOPE

This study introduced a lightweight and explainable framework for detecting fake news in Indian code-mixed languages, focusing on Gujarati-English, Hindi-English, and Marathi-English. A custom dataset was created since there is a shortage of code-mixed resources, and by completely cleaning and normalizing the data, we ensured consistency on text quality. Through adapter-based learning on XLM-R, we enabled the model to work in a multilingual environment with mixed scripts while being economically efficient on training costs. Incorporating social engagement features like likes, shares, and comments has dovetailed other kinds of behavioral pattern learning into the system that could be associated with misinformation. Explainability tools such as SHAP and LIME showed the importance of textual cues and social signals in influencing the model's predictions. The experimental results achieved commendable accuracy and balanced performance across all language pairs, confirming the suitability of the proposed approach for real-world engagement scenarios with multilingual communication. Hence, the framework can be characterized as efficient, transparent, and scalable, making it a viable solution for organizations suggesting a framework to monitor online misinformation. Future directions can include extending the work by increasing the dataset using more authentic social media samples, which might include other Indian languages. The system could also be expanded to assess multimodal misinformation with images, memes, or videos. Further, building a real-time web or mobile version integrated with graph-based social features would increase its reach. More improved explainability implementations and visualization tools would enable use for understanding by journalists, educators, and lawmakers to see how the model reasons about instances of fake news. All these enhancements together would help build a more dependable and complete countermeasure to misinformation in multilingual online settings.

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Table 1. Distribution of Code-Mixed Datasets

Language Pair	Total Samples	Fake	Real
Gujarati-English	5000	2500	2500
Hindi-English	7000	3500	3500
Marathi-English	5000	2500	2500
Total	17000	8500	8500

Table 2. Performance Comparison of Models

Model	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
XLM-R (Full Fine-tuning)	90.1	89.5	90.8	90.1
XLM-R + Adapters	92.4	91.8	93.1	92.4
XLM-R + Adapter Fusion	93.6	92.9	94.0	93.4

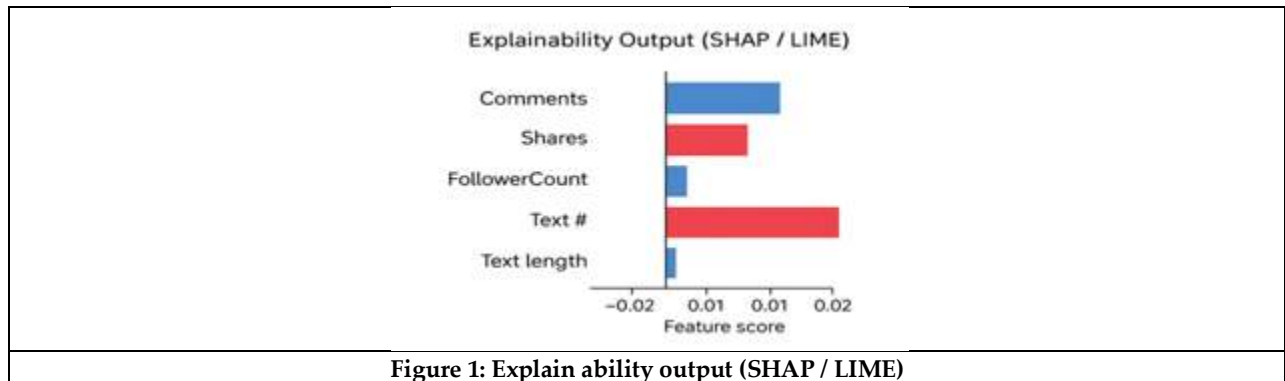


Figure 1: Explain ability output (SHAP / LIME)

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RESEARCH ARTICLE

Diversity and Distribution Pattern Analysis of Cyanobacteria Isolated from the Freshwater Habitats of Jhargram, West Bengal, India

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ABSTRACT

Cyanobacteria are ancient oxygenic photosynthetic prokaryotes, found in diverse ubiquitous habitats. They play significant roles in environmental monitoring, such as bioremediation, biofertilizer production, and the production of diverse bioactive compounds. Their community composition may be affected by several environmental gradients of that habitat, such as pH, temperature, total dissolved solids (TDS), and electrical conductivity (EC), as well as anthropogenic activities. They may sometimes exert a detrimental effect on aquatic life, as some taxa can form blooms and release toxins. For that purpose, ecologists are trying to document cyanobacteria from all possible biotypes. In this study, cyanobacterial diversity was examined in the Binpur I and Binpur II blocks of Jhargram Sub-Division, West Bengal, India, and the effects of environmental parameters on community composition were assessed. The study found that filamentous non-heterocystous genera are dominant, and other, less dominant genera are filamentous heterocystous and coccoid. Multivariate analysis, specifically Principal Component Analysis (PCA), showed that temperature, pH, TDS, and EC significantly shape the species composition of this area. Further study is also required to know the seasonal influence on the cyanobacterial diversity of this region.

Keywords: Cyanobacteria, Diversity, Jhargram, Physicochemical analysis, PCA



**Basudev Murmu et al.,**

INTRODUCTION

Cyanobacteria, also known as blue-green algae, are a diverse and ecologically significant group of oxygen-producing photosynthetic prokaryotes found in numerous aquatic and terrestrial environments [1]. These microorganisms play a significant role in primary production, nutrient cycling, and biogeochemical processes within freshwater ecosystems also are essential for controlling nitrogen dynamics. Their evolutionary importance is highlighted by their ancient origins and their role in Earth's initial oxygenation and the evolution of its ecosystems [2]. Freshwater ecosystems such as ponds, rivers, lakes, reservoirs, and floodplain wetlands form a mosaic of ecological habitats that promote cyanobacterial growth. These environments frequently exhibit significant seasonal and spatial variations in physicochemical factors, such as nutrient levels, temperature, and light availability, which affect the organization and behavior of cyanobacterial populations. Anthropogenic activities such as agricultural runoff, urban development, and wastewater discharge increase nutrient levels, which can promote cyanobacterial growth, sometimes leading to harmful blooms that degrade water quality, harm aquatic organisms, and affect human well-being [3].

Precise documentation of cyanobacterial diversity is essential for understanding community structure and ecological functioning, identifying potentially harmful taxa, and guiding conservation efforts. Moreover, cyanobacteria harbor species with significant biotechnological capabilities, including applications in biofertilization, bioremediation, and the production of bioactive compounds [4]. Several environmental gradients, such as temperature, pH, total dissolved solids (TDS), and electrical conductivity (EC), are crucial parameters that affect cyanobacterial physiology. To analyze these parameters, multivariate analysis is required [5]. Several studies from West Bengal, India, have shown enormous diversity of cyanobacteria across various freshwater habitats [6]; [2]; [7]; [8]; [9]. The Jhargram Sub-Division is situated 21°-52' to 22°-48' North latitudes and 86°-34' to 87°-20' East longitude approximately. Elevated temperatures, high humidity, and a tropical atmosphere, with considerable summer heat, substantial monsoonal precipitation, and temperate winters, characterize Jhargram's climate. Agriculture (especially paddy) depends heavily on the monsoon and on surface water; freshwater bodies directly influence the timing, success, and productivity of paddy cultivation in Jhargram. Lakes, ponds, and seasonal wetlands also support local biodiversity, including birds and aquatic organisms, and act as micro-ecosystems that influence local climate and livelihoods. This study aims to systematically characterize the diversity of cyanobacteria in the Binpur I and Binpur II blocks of Jhargram Sub-Division, West Bengal, India. This research provides a revised baseline of cyanobacterial community composition by combining morphological and ecological observations with regional environmental context, thereby aiding future ecological evaluations, water-quality research, and conservation strategies.

MATERIALS AND METHODS

Collection, Isolation, Identification, Purification, and Preservation of Isolated Organisms

Cyanobacteria samples were collected from diverse freshwater sources, including ponds, rivers, canals, drainage systems, and paddy fields in Binpur I and Binpur II blocks of Jhargram district. Photo plate (Pl.), Table 1. Random sampling was conducted using fine tweezers, plankton nets, and sample bottles attached to the Substratum surface in ponds. Samples were transported to the laboratory, examined with a Leica microscope (model LEICA ICC50 W), and micrographs were captured for identification. Each sample was assigned a unique number, and the collection date was documented in a field diary. Pure cultures were established using the agar method and cultivated in BG-11 + nitrogen. Incubation was maintained at $25 \pm 2^\circ\text{C}$ under continuous white light illumination ($30\text{--}35 \mu\text{mol m}^{-2} \text{s}^{-1}$ photons) with a 12-hour light and 12-hour dark cycle for up to six weeks for bulk cultures [10]; [11]. Identification was conducted using traditional morphometric methods, focusing on the shape and size of vegetative cells, branching patterns, presence or absence, and breadth of the sheath, as well as the shape, position, and size of heterocysts and akinetes, following established cyanobacterial references [12]; [13]; [14]; [15]; [16].





Analysis of Physicochemical Properties of Water Samples

The physicochemical properties such as temperature, pH, total dissolved solids (TDS), and electrical conductivity (EC) of aquatic ecosystems intensely influence the diversity and abundance of cyanobacteria [5]. A digital temperature, pH, TDS, and EC meter is used to measure all the physicochemical properties of the water sample. For the soil sample, 2.5 g of soil was dissolved in 10 mL of distilled water, filtered through Whatman's filter paper, and the filtrate was used to measure the aforementioned properties [5]. All temperature, pH, TDS, and EC measurements were performed three times.

Study of Cyanobacterial Diversity

Quantitative assessment of cyanobacterial diversity is essential for interpreting community composition, ecological resilience, and the effects of environmental stressors, including eutrophication and climate change. Diversity indices integrate species richness and relative abundance, providing a robust framework for evaluating cyanobacterial communities [17].

Shannon-Wiener Diversity Index (H')

The Shannon-Wiener index is one of the most widely used diversity metrics, which accounts for both species richness and evenness, making it sensitive to changes in community structure.

$$H' = - \sum (p_i \ln p_i)$$

where p_i represents the proportion of individuals belonging to the i th species [18].

Simpson's Diversity Index (1-D)

Simpson's index quantifies the probability that two randomly selected individuals from a sample belong to the same species, emphasizing species dominance rather than richness.

$$D = \sum p_i^2$$

Simpson diversity is commonly expressed as 1-D or $1/D$, where higher values correspond to greater diversity [19].

Margalef's Richness Index (d')

Margalef's index primarily reflects species richness and is minimally influenced by species evenness.

$$d' = \frac{S - 1}{\ln N}$$

Where S represents the total number of species and N is the total number of individuals. In cyanobacterial studies, Margalef's index is used to compare richness across sites or seasons [20].

Berger-Parker Dominance Index (d)

The Berger-Parker index measures the relative abundance of the most dominant species in a community.

$$d = \frac{N_{max}}{N}$$

Where N_{max} represents the number of individuals of the most abundant species, and N is the total number of individuals [21].

Principal Component Analysis (PCA) for Cyanobacterial Diversity

Principal Component Analysis (PCA) is a statistical method commonly used in ecological research to reduce data dimensionality and identify the primary environmental gradients that influence community composition. In studies of cyanobacterial diversity, PCA helps clarify the relationships among diversity indices, species composition, and physicochemical factors, making it easier to understand complex datasets [22]. The multivariate analysis (PCA), visualization of data and pictorial graph were generated using the python (version 3.12.13) in Google Colab.





RESULTS AND DISCUSSION

Taxonomic Enumeration of Isolated Species

Aphanocapsa parietina Nägeli; Pl.2, fig.(figure). A Description: Colonies small, yellowish-green, length 5.54µm, breadth 6.74µm. Habitat: Floating in rice field water. *Aphanothece pallida* (Kützinger) Rabenhorst; Pl.2, fig.B; Description: olive green; Cells oblong, cylindrical, 4.31 µm wide, 6.49 µm long. Habitat: Mat on moist rocky soil. *Aphanothece microscopica* Nägeli; Description: Thallus small gelatinous, cell oblong cylindrical, 4.5 µm broad, cell 2 µm as long as broad, individual distinct sheaths. Habitat: Floating in rice field water. *Aphanocapsa bififormis* A. Barun; Pl.2, fig.D; Description: Thallus olive green, cells 4.09-7.07 µm wide, spherical, 2 cells in a common mucilaginous envelope. Habitat: Mat on paddy field soil. *Phormidium animale* (Agardh ex Gomont) Anagnostidis et Komarek; Description: Trichome straight, 3.5 µm wide, 5.7 µm long, slightly bent at apical portion. Habitat: Floating in small ditch water. *Phormidium tortuosum* (Gardener) Anagnostidis et Komarek; Pl.2, fig.F; Description: Trichomes flexuous, pale blue-green, 3.4 µm wide, cell shorter than wide, 1.78 µm long; apical cell acuted, round. Habitat: Upper surface of the mud. *Phormidium chlorinum* (Kützinger ex Gomont) Anagnostidis; Pl.2, fig.G; Description: Thallus fine, yellow-green, 4.35 µm wide, cell more or less isodiametric slightly shorter than wide, 3.76 µm long, apical cell slightly flattened. Habitat: Mat on rice field soil.

Phormidium retzii (Agardh) Gomont ex Gomont; Pl.2, fig.H; Description: Thallus bright blue-green, thick; filament more or less straight. Trichome dark-blue green in colour, 11.28 µm wide. Cell slightly shorter than wide 6.28 µm. Apical cell 12.44 µm long, without calyptra. Habitat: Attached to the soil in spring water. *Pseudanabaena skujae* Claus; Pl.2, fig.I; (Description: Thallus bluish-green, 1.2-2.3 µm wide and up to 7.5 µm long cells; Epical cell elongated. Habitat: Floating in rice field water. *Pseudanabaena minima* (G.S. An) Anagnostidis; Pl.2, fig.J Description: Thallus solitary, trichome straight or almost straight, 1.94 µm wide, cell cylindrical 2.83 µm long, apical cell widely rounded. Habitat: Attached with substratum in rice field water. *Pseudanabaena catenate* Lauterborn; Pl.2, fig.K; Description: Trichomes olive-green, more or less straight, 4.27 µm wide, 15.23 µm long; Cell content homogenous; Apical cell rounded. Habitat: Attached with substratum in rice field water. *Limnothrix planctonica* (Woloszynska) Meffert; Pl.2, fig.L; Description: Trichome solitary, free-floating, straight or slightly curved, pale blue-green, 2.46 µm wide. Cells 2-3 time longer than wide, 6.87 µm long, apical cell cylindrical, rounded. Habitat: Mat on moist rocky soil. *Schizothrix* sp., Pl.3, fig.A; Description: Filamentous solitary, densely joined, free-floating, 9.6 µm wide and cell, 4.34 µm long. Habitat: Mat on moist rocky soil. *Phormidium targestinum* [Kützinger] Anagnostidis et Komarek; Pl.3, fig.B; Description: Thallus thin mucilage, bright blue green, trichome 4-10 µm wide, cell longer than wide, 2.4-6.5 µm long, apical cell rounded. Habitat: Mat on moist rocky soil.

Spirulina sp., Pl.3, fig.C; Description: Trichomes blue-green, distance between coils 17.25 µm, coils right-handed, cells shorter than wide, apical cell rounded. Habitat: Attached with substratum. *Oscillatoria subbrevis* Schmidle; Pl.4, fig.D; Description: Trichome green-yellowish, 6.17 µm wide, usually straight sometimes arched; Cells are shorter than wide, 2.09 µm long; Apical cells without calyptra. Habitat: Floating in stagnant water. *Oscillatoria proboscida* Gomont ex Gomont; Pl.3, fig.E; (Description: Trichome bright blue-green, 18.33 µm wide, Cell 4.76 µm long. Habitat: Submerged in small ditch water. *Oscillatoria ucranica* Valdimirova; Pl.3, fig.F; Description: Trichome solitary, straight or curved, 2.36 µm wide. Cell 4.08 µm long, apical cells conical-rounded. Habitat: Submerged in small ditch water. *Nostoc kihlmanii* Lemmermann; Pl.3, fig.G; Description: Colonies free-floating, olive-green, cells spherical, length of cell 3.76 µm and breadth 3.55-4.0 µm. Heterocyst spherical or ellipsoidal, breadth 5.59 µm and length 5.8 µm. Habitat: Abandoned wet rice field soil. *Geitlerinema amphibium* (Agardh ex Gomont) Anagnostidis; Pl.3, fig.H; Description: 3.05 µm wide, cell usually 6.38 µm long, without calyptra. Habitat: Attached with substratum in rice field water. *Oscillatoria ornate* Kützinger ex Gomont; Pl.3, fig.I; Description: cells shorter than wide, 2-5 µm long, trichome 6-9 µm wide. Habitat: Floating in rice field water. *Oscillatoria major* Vaucher ex Hansgirg; Pl.3, fig.J; Description: Trichome blue-green in colour, 20.32 µm wide, apical portion hook like structure. Cells shorter than wide, 6.02 µm long. Apical cell obtusely-rounded without calyptra. Habitat: Submerged in small ditch water.





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Lyngbya martensiana Meneghini ex Gomont; Pl.3, fig.K; Description: Trichome olive green, 10.85 μm wide, cell 2.40 μm long, apical cell widely rounded without calyptra. Habitat: Mat on rocky soil (beside rice field). *Lyngbya anomala* (Rao) Anagnostidis; Pl.3, fig.A; Description: Thallus deep-blue green; sheath thin, trichome 8.60 μm wide; Cell 1.75 μm long, apical cell bluntly rounded without calyptra. Habitat: Mat on abandoned rice field soil. *Cylindrospermum mikhailovskoense* Elenkin; Pl.4, fig.A; Description: Cells pale blue-green, cylindrical, length 7.35 μm and breadth 4.15 μm . Heterocyst develops only at one end of trichome, cylindrical, length 7.17 μm and breadth 6.14 μm . Akinetes cylindrical, 13.40 μm . Habitat: Besides wet rice field soil. *Scytonema sp.*, Pl.4, fig.B; Description: Thallus bright blue green, 12.96 μm long and 5.41 μm wide; heterocyst cylindrical, length 10.20 μm and breadth 5.74 μm . Habitat: Attached to substratum. *Nostoc ellipso sporum* Rabenhorst ex Bornet & Flahault; Pl.4, fig.C; Description: Colonies gelatinous, flattened, olive green. Cells cylindrical, length 5.31 μm and breadth 4.44 μm . Heterocyst almost spherical, cylindrical, length 8.10 μm and breadth 6.43 μm . Habitat: Attached to soil in a small ditch water besides rice field. *Desmonostoc muscorum* Ag. Ex. Born. Et. Flah; Pl.4, fig.D; Description: Colonies hemispherical, blue-green, sheaths distinct at the margin of colonies. Cell barrel-shaped to cylindrical, length 5.90 μm , breadth 4.13 μm . Heterocyst almost spherical or barrel-shaped, length 5.73 μm , breadth 6.1 μm . Habitat: Free floating on paddy field. *Hapalosiphon welwitschii* W. et G. S. West; Pl.4, fig.E; Description: Filamentous than other algae, sheath very narrow, cells rounded, barrel-shaped, in branches 7.90 μm , breadth of cell 5.75 μm . Heterocyst cylindrical, length 8.47 μm and breadth 5.91 μm . Habitat: Attached with substratum in rice field water.

Calothrix castellii (Massal.) Bron. Et. Flah; Pl.4, fig.F; Description: dirty blue-green sheath thin, 8.1 μm wide. Heterocyst hemispherical, 7.1 μm . Habitat: Mat on wet rocky soil. *Westiellopsis indica* Bourrelly; Pl.4, fig.G; Description: Thallus forming blackish-green, branched, monoseriate, terminal parts of branches often narrowed. Cells barrel-shaped, length 6.0 μm and breadth 5.91 μm . Heterocyst spherical, length 5.81 μm and breadth 5.59 μm . Habitat: Attached to the mud. *Nostoc linckia* (Roth) Bornet ex Born. Et Flah, Pl.4, fig.H; Description: Colonies fine; Cells shortly, length 3.44 μm and breadth 4.30 μm . Heterocyst almost spherical, length 5.24 μm and breadth 5.21 μm . Habitat: Besides wet rice field soil.

Biodiversity Patterns

Most of the study locations showed the Shannon diversity index (H') [Fig. 1, Table 1] values over 2.5; overall, it ranged from 2.21 to 2.89, pointing towards the moderate to high diversity at most locations. The higher values (>2.7) seen at locations such as L1(2.75), L15(2.76), L26(2.78) and L27(2.89). The Simpson index ($1-D$) [Fig. 1, Table 1] showed high evenness and low dominance and absence of domination of single species through the studied sites, as values ranged from 0.88 (L6, L10) to 0.94 (L27). Further, this result is also supported by the Berger–Parker dominance index [Fig. 1, Table 1], as the values ranged from 0.09 (L27) to 0.2 (L06, L22), pointing out that species monopoly is limited. The Margalef index [Fig. 1, Table 1] depicted the species richness; the values varied from 3.34 (L10) to 5.74 (L27), locations L1, L15, L24, L26, and L27 (values > 5.0) showing higher species richness. All the diversity indices suggest relatively steady ecosystems that support the coexistence, are balanced, and favour a greater number of species abundances.

Influence of Physicochemical Parameters

The Pearson correlation analysis figured out that there are considerable links among the variables such as electrical conductivity (EC) [Fig. 4, Table 2], total dissolved solids (TDS) [Fig. 4, Table 2], temperature [Fig. 4, Table 2], and pH [Fig. 4, Table 2]. The pH is moderately positively correlated with the temperature ($r = 0.48$) but weakly correlated with the EC ($r = -0.09$) and TDS ($r = -0.04$). The temperature showed a moderate negative relationship with the EC ($r = -0.50$) and TDS ($r = -0.35$). Meanwhile, the relationship between TDS and EC ($r = 0.76$) showed a strongly positive. The current investiture results are also supported by a study conducted by Deep PR *et al.* [3] on wetlands in Odisha, which showed dominance of *Oscillatoria*, *Anabaena*, and *Phormidium* under higher TDS and altered water chemistry, where these taxa were predominant and correlated with physicochemical variables.





Multivariate Analysis of Environmental Gradients

The principal component analysis (PCA) of environmental gradients such as temperature, pH, EC, and TDS explained a considerable amount of total variance. The PC1 (54.54%) [Fig. 3, Table 2] and PC2 (29.44%) [Fig. 3, Table 2] sum up to 83.98% of the total variance. The EC and TDS were strongly linked with PC1, whereas pH and temperature were linked with PC2. The PC1 was indicating the range of nutrient enrichment or ionic gradients. The PC2 was indicating the metabolic or physiological constraints. This study is also supported by previous investigations by [23] and [24], which found that multivariate analyses of temperature, pH, TDS, and conductivity modulate cyanobacterial diversity.

Species Abundance

The heatmap analysis of species abundance patterns showed the patchy or heterogeneous distribution across locations [Fig. 2]. The most abundant species are filamentous and non-heterocystous, such as *Oscillatoria subbrevis* Schmidle, *Oscillatoria ornata* Kützinger ex Gomont, *Lyngbya anomala* (Rao) Anagnostidis, *Phormidium animale* (Agardh ex Gomont), *Pseudanabaena catenata* Lauterborn, and heterocystous genus, *Cylindrospermum michailovskense* Elenkin. The moderately abundant species are composed of filamentous, non-heterocystous, heterocystous, and coccoid species, such as *Phormidium retzii* (Agardh) Gomont ex Gomont, and *Nostoc muscorum* Ag. Ex. Born. Et. Flah, *Spirulina* sp., *Aphanothece pallida* (Kützinger) Rabenhorst, *Phormidium targestinum* Komarek. *Pseudanabaena minima* (G.S. An) Anagnostidis, *Oscillatoria major* Vaucher ex Hansgirg, *Aphanocapsa microscopica* Nägeli.

The low-abundant species are also composed of filamentous, non-heterocystous, heterocystous, and coccoid species, such as, *Calothrix castelli* (Massal.) Born. et Flah, *Westiellopsis prolifica* Janet, *Scytonema* sp., *Nostoc carneum* C. Agardh ex Bornet & Flahault, *Nostoc linckia* (Roth) Bornet ex Bornet & Flahault, *Aphanothece pallida* (Kützinger) Rabenhorst, *Aphanocapsa bififormis* A. Barun. The rare or very low-abundant species are *Limnithrix planctonica* (Wołoszyńska) Meffert, *Geitlerinema amphibium* (Agardh ex Gomont), *Hapalosiphon welwitschii* W. et G. S. West, *Nostoc ellipsosporum* Rabenhorst ex Bornet & Flahault, *Oscillatoria proboscidea* Gomont ex Gomont, *Lyngbya martensiana* Meneghini ex Gomont, *Phormidium chlorinum* (Kützinger ex Gomont) Anagnostidis. Numerous recent taxonomic studies conducted throughout West Bengal, including Barasat [6], Bidhannagar [2] Krishnagar Sadar [7], East Kolkata Wetlands [8], and from the Berhampore subdivision of Murshidabad [9] constantly reported filamentous and non-heterocystous genera are dominant, such as *Oscillatoria* sp. *Lyngbya* sp. and *Phormidium* sp., the other less dominant genera, are mainly heterocystous, and the coccoid species such as *Anabaena* sp., *Nostoc* sp., and *Chroococcus* sp., respectively.

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Table 1: Diversity indices of cyanobacterial communities across 29 sampling locations in Jhargram District, West Bengal, India. Values include Shannon diversity index (H'), Simpson's index (1-D), Margalef richness index (d'), and Berger-Parker dominance index (d), with corresponding geographic coordinates (latitude and longitude) for each site. The indices highlight spatial variation in species richness, evenness, and dominance patterns across the study area.

Location	Latitude	Longitude	Shannon(H')	Simpson (1-D)	Margalef (d')	Berger-Parker (d)
L1	22.656733	87.024256	2.75	0.93	5.29	0.12
L2	22.647317	86.95353	2.20	0.89	3.64	0.11
L3	22.656489	87.021863	2.27	0.89	3.75	0.18
L4	22.555267	86.910464	2.24	0.89	3.41	0.14
L5	22.634778	86.957211	2.66	0.93	4.84	0.11
L6	22.607879	86.936773	2.21	0.88	3.41	0.21
L7	22.621279	86.95653	2.55	0.92	4.34	0.15
L8	22.656234	87.021717	2.34	0.90	3.79	0.14
L9	22.556901	86.91059	2.48	0.91	4.24	0.18
L10	22.454273	86.880516	2.15	0.88	3.34	0.18





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L11	22.556317	86.910209	2.60	0.92	4.69	0.13
L12	22.662937	86.947714	2.61	0.92	4.47	0.13
L13	22.662879	86.947737	2.62	0.92	4.67	0.15
L14	22.659286	86.953619	2.43	0.91	4.06	0.13
L15	22.656442	86.954701	2.76	0.93	5.26	0.14
L16	22.608006	86.936664	2.62	0.92	4.60	0.14
L17	22.635324	86.95709	2.45	0.90	4.15	0.17
L18	22.640776	86.95652	2.60	0.92	4.69	0.13
L19	22.635069	86.95733	2.59	0.92	4.59	0.12
L20	22.605841	86.83084	2.43	0.91	4.06	0.13
L21	22.616058	86.784964	2.43	0.91	3.88	0.12
L22	22.611776	86.792756	2.40	0.90	4.17	0.21
L23	22.594916	86.895939	2.55	0.91	4.50	0.17
L24	22.597362	86.882431	2.69	0.93	5.01	0.15
L25	22.600423	86.858417	2.65	0.93	4.67	0.10
L26	22.607488	86.807214	2.78	0.93	5.26	0.10
L27	22.650032	86.746241	2.89	0.94	5.74	0.09
L28	22.650048	86.746269	2.51	0.91	4.33	0.13
L29	22.659005	86.742262	2.67	0.92	4.78	0.13

Table 2: Physicochemical characteristics of water across 29 sampling locations in Jhargram District, West Bengal, India. Values are expressed as mean $\pm$ standard deviation for pH, temperature ($^{\circ}\text{C}$), total dissolved solids (TDS, mg/L), and electrical conductivity (EC, $\mu\text{S/cm}$). The dataset highlights spatial variation in physicochemical parameters influencing cyanobacterial diversity.

Location	Temperature ($^{\circ}\text{C}$)	pH	EC ($\mu\text{S/cm}$)	TDS (mg/L)
L1	27.500 $\pm$ 0.245	6.937 $\pm$ 0.034	95.567 $\pm$ 0.205	66.333 $\pm$ 1.247
L2	32.833 $\pm$ 0.125	7.350 $\pm$ 0.022	94.367 $\pm$ 0.591	43.333 $\pm$ 1.247
L3	27.633 $\pm$ 0.368	7.143 $\pm$ 0.041	91.700 $\pm$ 0.163	38.667 $\pm$ 1.247
L4	32.197 $\pm$ 0.086	7.387 $\pm$ 0.026	76.567 $\pm$ 3.242	56.667 $\pm$ 1.247
L5	32.197 $\pm$ 0.086	7.387 $\pm$ 0.026	76.567 $\pm$ 3.242	56.667 $\pm$ 1.247
L6	32.833 $\pm$ 0.125	7.350 $\pm$ 0.022	94.367 $\pm$ 0.591	43.333 $\pm$ 1.247
L7	31.467 $\pm$ 0.170	7.267 $\pm$ 0.021	101.667 $\pm$ 2.055	77.000 $\pm$ 2.160
L8	31.700 $\pm$ 0.294	7.213 $\pm$ 0.026	97.967 $\pm$ 0.368	82.667 $\pm$ 1.700
L9	30.433 $\pm$ 0.249	7.067 $\pm$ 0.034	95.000 $\pm$ 1.633	71.667 $\pm$ 2.055
L10	29.167 $\pm$ 0.249	6.980 $\pm$ 0.029	91.333 $\pm$ 2.055	77.667 $\pm$ 1.247
L11	29.200 $\pm$ 0.408	6.980 $\pm$ 0.029	96.967 $\pm$ 0.368	68.667 $\pm$ 1.700
L12	29.733 $\pm$ 0.249	6.950 $\pm$ 0.029	97.267 $\pm$ 0.525	73.333 $\pm$ 1.247
L13	29.733 $\pm$ 0.249	6.950 $\pm$ 0.029	97.267 $\pm$ 0.525	73.333 $\pm$ 1.247
L14	32.197 $\pm$ 0.086	7.387 $\pm$ 0.026	76.567 $\pm$ 3.242	56.667 $\pm$ 1.247
L15	31.667 $\pm$ 0.125	7.123 $\pm$ 0.034	90.867 $\pm$ 1.330	72.667 $\pm$ 1.247
L16	31.767 $\pm$ 0.125	7.167 $\pm$ 0.034	90.767 $\pm$ 1.682	72.667 $\pm$ 1.700
L17	29.800 $\pm$ 0.294	6.997 $\pm$ 0.025	98.800 $\pm$ 0.356	74.667 $\pm$ 2.867
L18	29.333 $\pm$ 0.368	7.150 $\pm$ 0.033	98.800 $\pm$ 0.294	77.333 $\pm$ 1.700
L19	31.333 $\pm$ 0.125	7.230 $\pm$ 0.045	102.667 $\pm$ 1.700	112.000 $\pm$ 1.633
L20	31.467 $\pm$ 0.170	7.267 $\pm$ 0.021	107.333 $\pm$ 2.055	123.667 $\pm$ 2.055
L21	31.700 $\pm$ 0.294	7.213 $\pm$ 0.026	92.067 $\pm$ 0.249	72.667 $\pm$ 1.247
L22	28.500 $\pm$ 0.163	7.410 $\pm$ 0.016	102.500 $\pm$ 1.080	96.667 $\pm$ 1.247
L23	28.500 $\pm$ 0.163	7.410 $\pm$ 0.016	102.500 $\pm$ 1.080	96.667 $\pm$ 1.247





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L24	26.400 ± 1.715	6.993 ± 0.012	112.500 ± 1.080	96.000 ± 2.449
L25	29.333 ± 0.262	7.273 ± 0.025	111.667 ± 1.247	100.667 ± 1.247
L26	30.067 ± 0.419	6.963 ± 0.046	97.333 ± 0.499	102.667 ± 1.700
L27	28.433 ± 0.249	6.960 ± 0.043	101.767 ± 0.579	131.000 ± 1.633
L28	29.133 ± 0.330	7.313 ± 0.021	113.667 ± 1.247	122.000 ± 2.160
L29	29.200 ± 0.294	7.313 ± 0.012	125.000 ± 1.633	139.333 ± 1.247

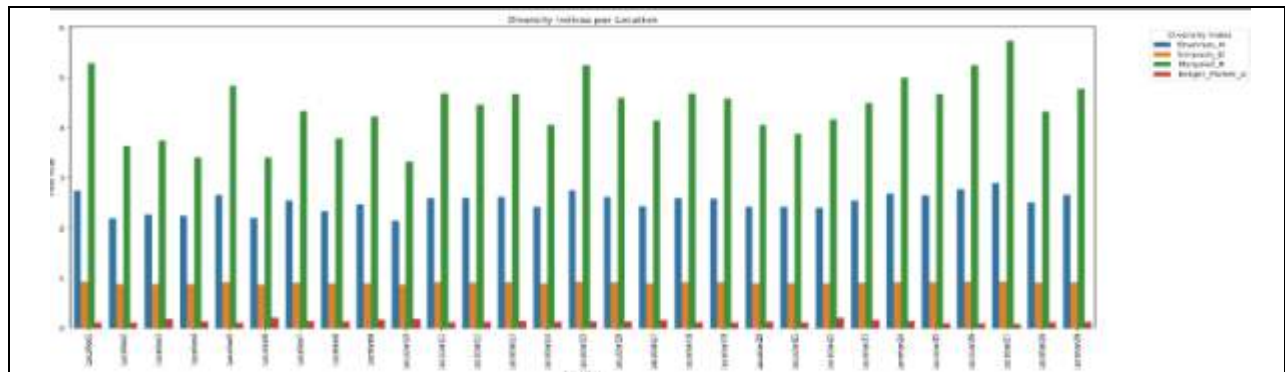


Fig. 1: Diversity Indices

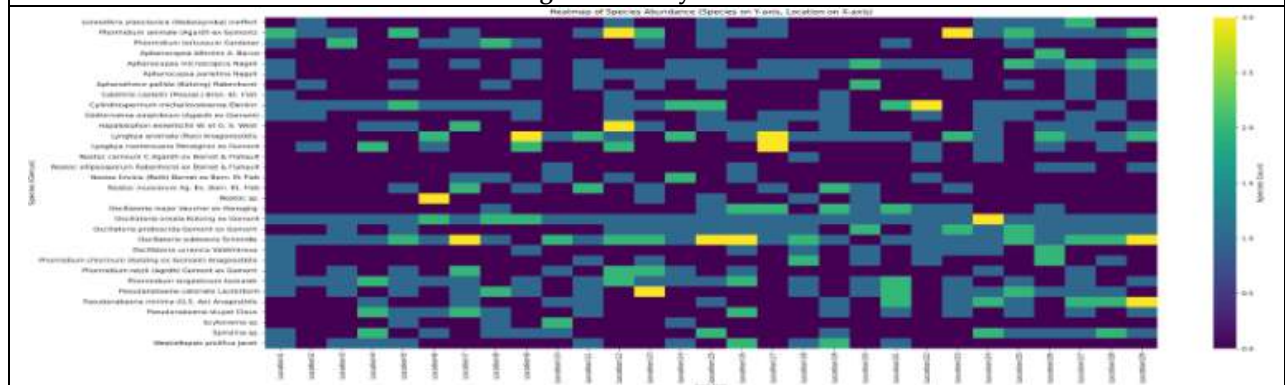


Fig. 2: Species Distribution Heatmap

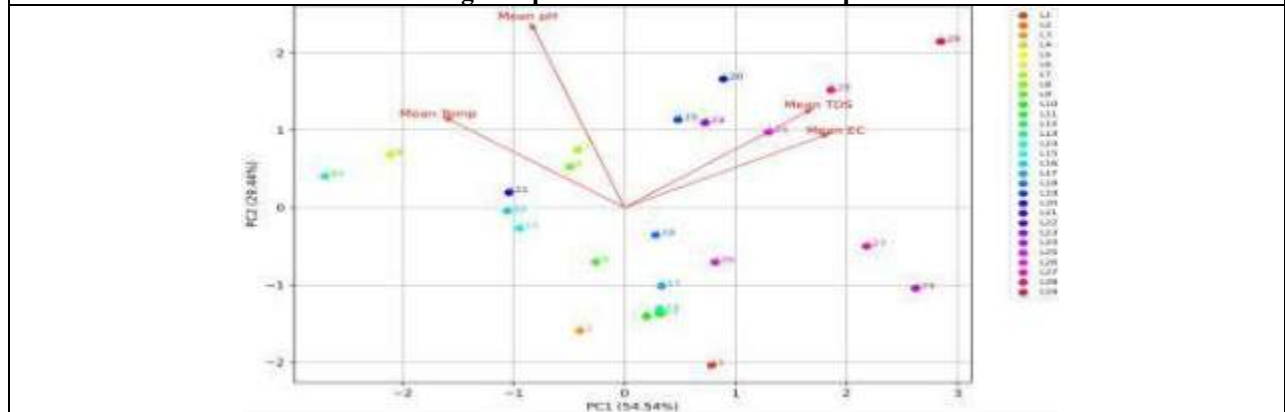
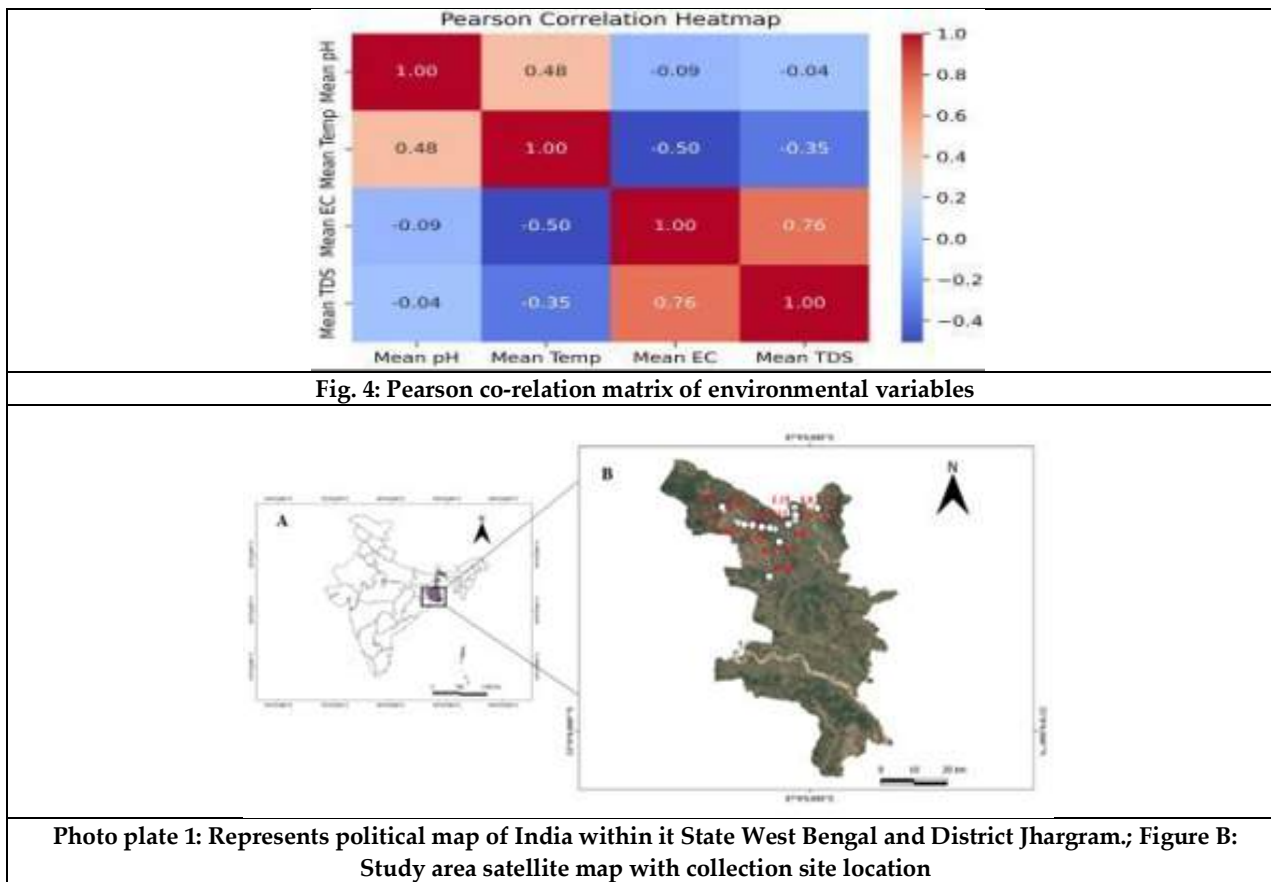
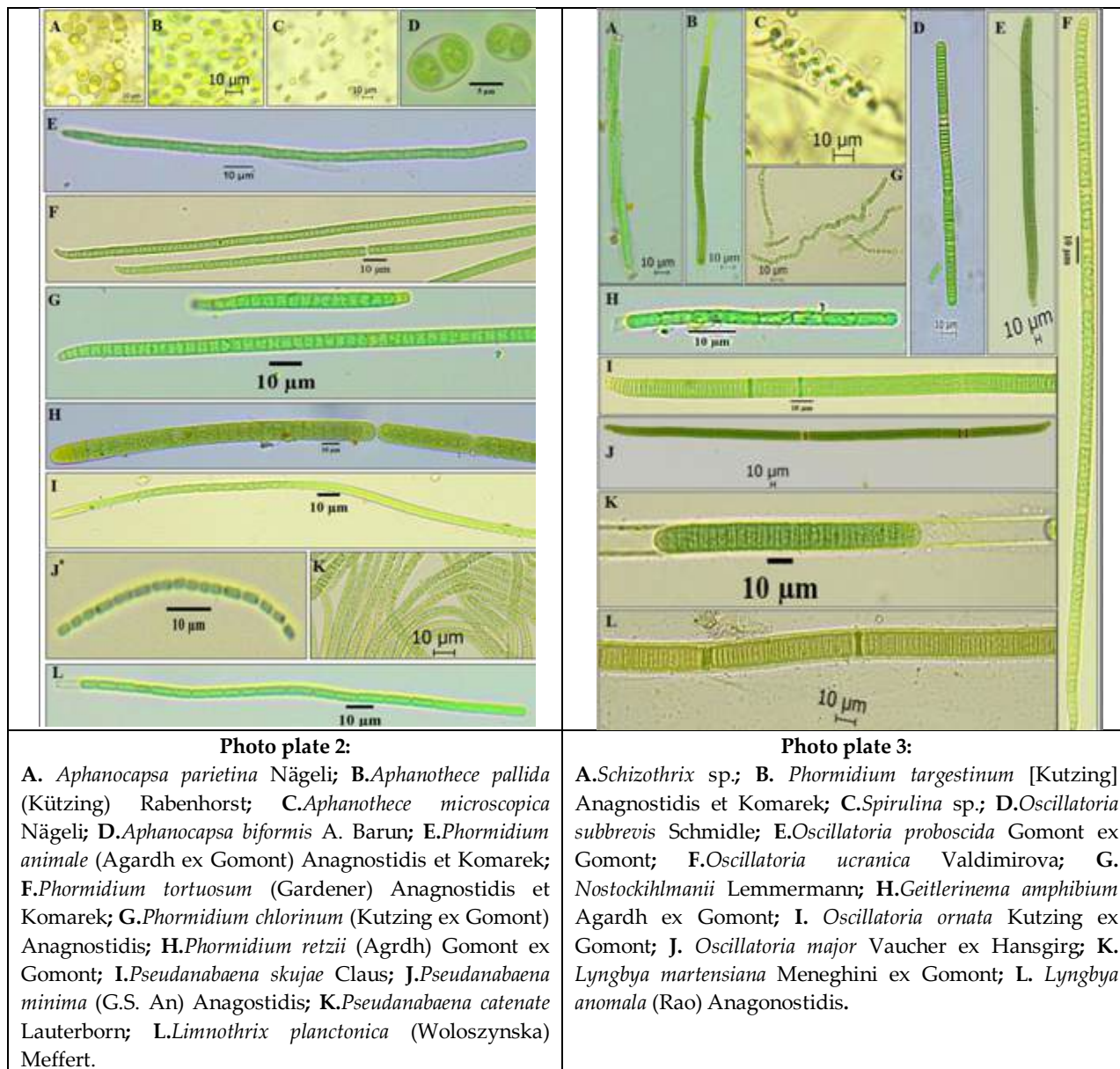


Fig. 3: PCA analysis of Environmental variables









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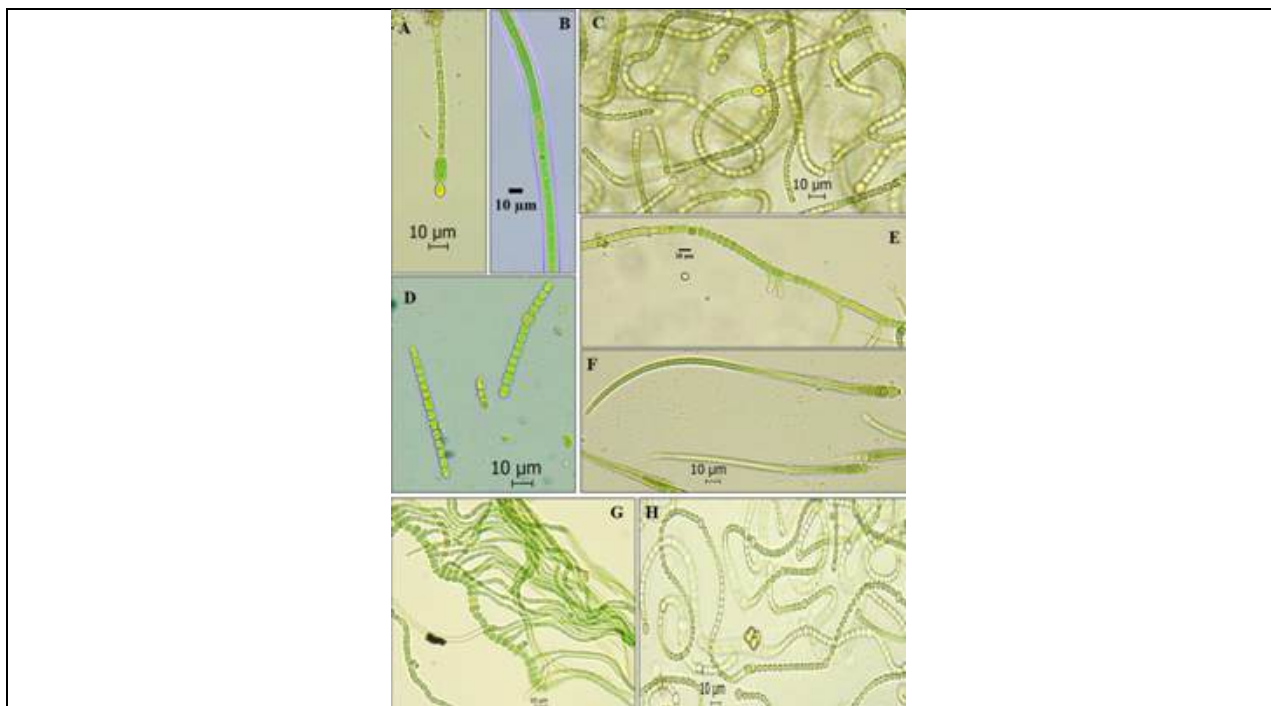


Photo plate 4:

A. *Cyindrospermum mikhailovskoense* Elenkin; **B.** *Scytonema* sp.; **C.** *Nostoc ellipsosporum* Rabenhorst ex Bornet & Flahault; **D.** *Desmonostoc muscorum* Ag. Ex. Born. Et. Flah; **E.** *Hapalosiphon welwitschii* W. et G. S. West; **F.** *Calothrix castellii* (Massal.) Bron. Et. Flah; **G.** *Westiellopsis indica* Bourrelly; **H.** *Nostoc linckia* (Roth) Bornet ex Born. Et Flah.

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RESEARCH ARTICLE

A Novel Federated Hybrid Learning Framework for Privacy-Preserving and Accurate Heart Attack Prediction

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ABSTRACT

Cardiac arrest is still the top cause of death globally, which makes the problem of early prediction and diagnosis a very important research challenge. Conventional centralized machine learning models usually attain high accuracy, but they necessitate the collection of sensitive medical data from different institutions, thus leading to serious privacy and security risks. In order to solve this problem, the current work introduces a Hybrid Federated Learning (HFL) model to predict heart attacks, which integrates Convolutional Neural Networks (CNN) and Extreme Gradient Boosting (XGBoost) in a federated setting. In the designed method, several geographically separated healthcare nodes (like hospitals, clinics, or IoT-based monitoring devices) work together to train a global model without the need to exchange patient data. Each node carries out training locally on its dataset, and only the model parameters are sent to a central server in a secure manner via the Federated Averaging (FedAvg) protocol. The combination of CNN and XGBoost allows for the efficient extraction of features and the firm classification of cardiac risk patterns. Tests on the heart disease dataset reveal that the newly designed model is able to achieve an accuracy of 97.86%, a ROC-AUC of 0.987, and a Brier score of 0.029, thus performing better than the traditional algorithms such as Logistic Regression, Decision Tree, Random Forest, and standalone XGBoost. The current research serves as a proof that coupling hybrid learning with federated privacy preservation is a viable way to deeply boost the prediction of the onset of the heart attack and, at the same time, ensure the confidentiality of the data, scalability, and clinical trustworthiness.

Keywords: Federated Learning, XGBoost, FedAvg, Explainable AI, Medical Data Security, Predictive Analytics.



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INTRODUCTION

Cardiovascular diseases (CVDs) are still the primary cause of death globally, making up almost one-third of the total deaths in the world every year [1]. In this group of diseases, heart attacks or myocardial infarctions are the cases that threaten the most mainly because they come too fast and it is difficult to diagnose them in the early stages [1][2]. If phenomena such as abnormal blood pressure, cholesterol imbalance, and lifestyle indicators could be detected in time, then the rates of morbidity and mortality would be reduced considerably. Artificial intelligence and machine learning (ML) technologies have developed so fast that healthcare predictive analytics has become a powerful tool for making decisions in healthcare. Different traditional models like Logistic Regression (LR), Decision Trees (DT), and Random Forests (RF) have been employed for classification and prediction of cardiovascular risk based on medical datasets. These models can be considered as first steps towards the solution of the problem [3][4]. At the same time, this class of models usually cannot learn enough features from data to generalize to new patient datasets being of various demographics. Besides that, centralized learning can cause patient data privacy and security problems because it requires that sensitive health care records be sent to a single training server [1][2]. This research addresses the drawbacks of previous studies by introducing a hybrid federated learning model for predicting cardiac arrest that combines CNN (Convolutional Neural Networks) with XGBoost (Extreme Gradient Boosting). On the one hand, CNN extracts deep features from the input variables, on the other hand, XGBoost improves the classification accuracy by fine-tuning feature weighting and decision boundaries. Using this hybrid of deep learning and ensemble methods, the authors of the paper achieved high predictive performance as well as model interpretability. Besides, the incorporation of Federated Learning (FL) allows for decentralized model training at multiple healthcare nodes, thus ensuring data privacy and at the same time, model robustness.

The hybrid model, as proposed, outperforms individual models in predictive accuracy and generalization to a large extent. Experimental results indicate an accuracy of 97.86%, which is higher than that of standard ML algorithms such as Logistic Regression, Decision Tree, Random Forest, and XGBoost models used individually. Also, the interpretability of the model is facilitated by SHAP (SHapley Additive exPlanations) which points out the clinical features that have the greatest impact on the prediction outcomes. In this way, the method not only gives support to transparency but also allows clinicians to figure out patient-specific risk factors. In essence, the devised hybrid federated framework is a secure, interpretable, and efficient solution for heart attack prediction. It is a move forward to privacy-preserving medical diagnostics that use AI and can be of timely and informed decision-making assistance to the healthcare professionals.

LITERATURE REVIEW

Innovations in federated learning over the past few years have outlined a clear path of its potential use in cardiovascular disease prediction through the use of distributed data in a privacy-preserving manner [5,6]. Tripathy et al. [7] propose a federated learning model that combines Internet of Things (IoT) features with EHRs to forecast cardiac ailments. The method uses a soft-margin L1-regularized Support Vector Machine classifier and a cluster primal-dual splitting algorithm to deal with the data of very high dimensions efficiently, thus achieving better prediction accuracy and data privacy. The authors of the paper cited as reference [8] have come up with the idea of using block chain-based, federated learning as a way to address the issue of data confidentiality in the healthcare system which is based on IoMT. They came up with a block chain-based, hybrid approach to solve the problem of the security of user data that involved federated learning and the maximum approximation of the Gaussian mixture model. Their solution serves as an example of how IoMT data can be trained in a way that is locally private so as not to leak the data. Async updates in federated learning models greatly enhance the performance and precision of predictive models for heart diseases. In their paper, the authors of [9] designed an asynchronous federated learning model with DNNs, where they used an asynchronous learning method for parameter updating and a temporally weighted aggregation technique. Their approach evidently lessens the communication expenses and raises the speed



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of model convergence, thereby proving its superiority to the conventional synchronous federated learning methods. Liang et al. [10] conducted a study that demonstrates the use of federated learning to handle data concerning heart diseases collected from Internet of Medical Things (IoMT) devices while maintaining the privacy aspect without losing the data utility. The paper explains how federated learning facilitates local data handling; thus, it is a security measure for data in a distributed healthcare environment. The technique adopted from the paper helps to solve the problem of data privacy and data utility which are the major issues of the smart healthcare environment that is rapidly evolving. In [11] the authors present split learning as a method of preserving privacy which can be used in healthcare by way of predicting the occurrence of heart disease. The publication illuminates the process by which deep learning models can be developed using subgroups of data, thereby the most sensitive patient data being kept in-house and secured. The approach makes collaboration in the research sector possible without breaking data privacy which is a major breakthrough in secure processing of medical data.

The main point of this research is to identify the relevant features selection method that leads to better prediction of the heart disease using various machine learning models like SVM, KNN, and Logistic Regression. They use a wide range of measures for the models, namely, accuracy, precision, recall, F1-score, MCC, and time complexity. Nevertheless, it appears that the exact instruments and programs for model creation and assessment have not been detailed explicitly. This work suggests an ANN model along with Particle Swarm Optimization (PSO) for the prediction of chronic diseases, among which is a heart attack[13]. They have compared their method with different classification algorithms like Random Forest and SVM. The main factor of measurement used is accuracy, however, no details about the specific tools and software have been given. The present paper investigates feature selection methods (filter, wrapper, embedded) coupled with different machine learning models (LR, KNN) for the prediction of Myocardial Infarction (MI)[14]. They verify the models through accuracy, sensitivity, and precision, F1-score, AUC, and specificity. Just like the previous ones, the studies do not disclose the specific tools and software used[14].

An author team in ref. [15] proposes a system architecture for a scalable Federated Learning that aims at enabling confidential and secure cooperation among a large number of parties. To solve the problems of Federated Learning that are flexibility, heterogeneity, and anonymity, the authors of the paper suggest a system framework which uses safe aggregation, differential privacy, and adaptive optimization. By rectifying the under-representation of positive instances in standard mammography imaging datasets, Amelia and Tardy [16] attempt to raise the appearance of CAD systems for breast cancer detection. This study introduces a novel memory-aware curriculum learning method to local models which calculate their local data to update the global model [17][18], thereby making federated learning more effective.

BACKGROUND

The various technologies and methods that formed the basis of the research work are explained here. These include the basic concepts of machine learning, deep learning, ensemble models, federated learning, and interpretable AI. Just like each of these elements has its own unique features, they also have their own roles in the total architecture and functioning of the suggested hybrid model for cardiac arrest prediction.

Logistic Regression

Logistic Regression refers to a supervised learning algorithm that is typically utilized in binary classification problems, for instance, forecasting whether a heart attack will occur or not. Based on the logistic function, it estimates the chance that a patient is in a given class (such as "heart attack" or "no heart attack"). If the probability goes beyond a particular threshold (generally 0.5) [13], the model labels the instance as "heart attack."

Decision Trees

A Decision Tree splits the data into hierarchically smaller subsets depending on the values of the features, thus forming a tree structure consisting of nodes and branches [7][8]. Every internal node denotes a decision based on a

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feature, and every leaf node signifies an output (for instance, “heart attack likely”). The model chooses features that offer maximum information gain by calculating Gini Impurity or Entropy. Though DTs can be easily understood, they have a tendency to memorize the training data, i.e. over fit, if not pruned correctly.

XGBoost

Random Forest is an ensemble learning technique that constructs several Decision Trees and merges their results to enhance precision and lower the possibility of over fitting. One tree is trained on a random subset of the data and features as well. The ultimate decision is obtained by the most votes (for classification) or by the average (for regression) [13][19]. In healthcare prediction problems, Random Forests are the first choice due to their strength and capability of dealing with missing or noisy data.

Hybrid CNN-XGBoost Model

The Hybrid Model strategically merges CNN and XGBoost to harness not only the deep feature learning capability of CNN but also the structured decision-making nature of XGBoost. CNN is capable of automatically learning highly complex and detailed feature representations from medical data. XGBoost takes advantage of those extracted features to make the final prediction. Such a combination yields increased accuracy, enhanced generalization, and better interpretability than either of the models used separately [6][7].

Federated Learning

Federated Learning (FL) is a decentralized machine learning technique that allows various healthcare facilities to jointly train a predictive model without the need to exchange their sensitive patient data. Here, FL is utilized to build a privacy-preserving cardiogram prediction system in which each hospital trains a hybrid CNN-XGBoost model locally on its patient records [3][4]. The figure shows the Federated Learning Framework for Heart Attack Prediction, which is a system where various local hospital clients train models on their private heart attack datasets and send only model updates to a central server (aggregator). The server combines these updates in a secure manner to generate a global model that is then sent to the clients. Figure 1. Shows how federated learning is integrated in this model. At the end, SHAP Explainability is used to clarify the predictions of the global model, thus maintaining openness, privacy, and collaboration in the learning process among healthcare institutions [5][9]. The medical institutions do not transmit their raw patient data; they only send the model parameters they have learned to a central server, which combines them using Federated averaging to get a global model. This setup not only safeguards data privacy but also promotes better generalization to different hospital datasets and makes it possible to keep learning globally at a later stage. So, Federated Learning in this investigation is a secured and collaborative tool to enhance the precision and trustworthiness of heart attack prediction while at the same time respecting patient privacy and data sovereignty.

Methodology and System Architecture Overview

The methodology articulated a Hybrid Federated Learning (HFL) framework as a means to reconcile the seemingly contradictory objectives of obtaining high predictive accuracy and preserving data privacy and security. Essentially, the system embodies two intelligence levels:

- Algorithmic hybridization, wherein a conventional ensemble learning (XGBoost) method is combined with a deep learning (CNN) one to achieve better results.
- Federated learning setup, whereby several decentralized clients can jointly train a global model without the need to share raw data.

Such a design, on the one hand, guarantees strong generalization and, on the other, adheres to the data protection requirements, thus, it can be utilized in the healthcare as well as cyber-physical systems domains. The Hybrid Federated Learning Model overall framework is depicted in Figure X (Hybrid Federated Learning Architecture Diagram). The layout includes the following elements:





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System Architecture

The Hybrid Federated Learning Model overall framework is depicted in Figure 2 (Hybrid Federated Learning Architecture Diagram). The layout includes the following elements: Local clients: Every client - for instance, a hospital, IoT device, or an organization - has its own local dataset. However, due to privacy and legal issues, these datasets are not allowed to be directly shared. On the client side, a Local Hybrid Model is set up which merges: Convolutional Neural Network (CNN): This is utilized for the extraction of deep features and for the automatic recognition of the data patterns of a complex data. XGBoost Classifier: This works on the extracted features to do the final classification or prediction. Each local client singly goes through the training of the hybrid model with the use of their private data, and then they calculate the model parameters (weights and biases). Federated Communication Layer: Once the training has been done locally, a client basically sends only the model parameters, which they have learned (not the raw data), to a central server through a secure communication channel. This is in line with privacy protection to the fullest extent as no sensitive data is being transferred from the local environment. Central Aggregator: The main aggregator is a kind of universal manager. FedAvg or Federated Averaging, is the operation it carries out, which involves a mathematical aggregation of all local models' parameters to produce a new Global Hybrid Model.

The aggregation operation is:

$$W_{GLOBAL} = \sum_{i=1}^N \frac{n_i}{N} W_i \quad (1)$$

Where:

W_i = model parameters from the i -th client

N_i = number of samples in the client's local dataset

N = total samples across all clients.

For the next round which is training, this global model is updated and then redistributed to all the clients.

Dataset

The data utilized in this research is a heart attack prediction dataset, which is a collection of both clinical and physiological parameters used as the most important indicators of cardiovascular health. The data consists of patient-specific attributes such as age, gender, chest pain type, resting blood pressure, cholesterol level, fasting blood sugar, resting electrocardiographic results, maximum heart rate achieved, exercise-induced angina, oldpeak (ST depression), slope of the peak exercise ST segment, the number of major vessels, and thalassemia. The combination of these features is used to determine the probability of heart disease or a sudden heart attack. The target variable points to whether a heart attack has occurred or not, thus enabling supervised learning for binary classification. This medical dataset is the basis for training the Hybrid CNN-XGBoost model so that it becomes capable of learning complex feature interactions and enhancing prediction accuracy in a federated, privacy-preserving environment.

Hybrid Model Integration

The methodology proposed in the paper implements a Federated Hybrid CNN-XGBoost framework that allows accurate and privacy-preserving prediction of heart attack across several hospitals [7]. Each healthcare institution preprocesses its local dataset by cleaning and normalizing clinical parameters such as age, cholesterol, and blood pressure. A hybrid model which includes Convolutional Neural Network (CNN) and XGBoost is locally trained, where CNN is used for deep feature extraction and XGBoost for classification. Subsequently, only the model parameters are shared with a central federated server, thereby ensuring that patient data stays confidential. Figure 2. Shows the whole architecture of proposed model. The server uses the Federated Averaging (FedAvg) algorithm to combine the updates from all the clients and create a global model. This global model is sent back to hospitals for further training until convergence. Interpreting the model's predictions and feature importance, SHAP explainability is employed after the final global model is trained. The global model thus obtained is tested for its effectiveness and trustworthiness by various metrics such as accuracy, precision, recall, F1-score, and ROC-AUC.



**Deepak Kumar Singh et al.,****Federated Training Workflow**

The training happens iteratively in several federated rounds, as follows: Initialization: The central server creates a global model and sends it to all clients. Local Training: Each client trains the hybrid model with their own data for several epochs. Parameter Update: Clients transmit their model weights to the server. Federated Aggregation: The server uses FedAvg to combine the updates it received from the clients and thus obtain the new global model. Model Redistribution: The global updated model is distributed to all clients for the following round. The process is repeated until the convergence condition is met, which is normally global accuracy stabilization or validation loss decrease,

Advantages of Proposed System

Privacy Maintenance: There is no sharing of raw data; just the model parameters are sent. High Precision: The hybrid system is able to deliver better results (Accuracy = 97.86%, ROC-AUC = 0.987). Expansion Capability: The design is open to a number of distributed nodes as well as different types of datasets. Performance Improvement: The global model becomes more flexible through the exposure of various client datasets. Understanding: The incorporation with explainable AI (SHAP) helps in identifying the important features that influence the prediction.

RESULTS AND DISCUSSIONS**Experimental Results**

The experimental results of the Federated Hybrid CNN–XGBoost model for heart attack prediction, which is the proposed model, are given in this section. The experiments were aimed at assessing the model's ability to make correct predictions, its performance in generalization, and its interpretability when applied to distributed healthcare datasets in a federated learning environment. First, exploratory data analysis (EDA) was implemented to get a better understanding of the distribution of the main clinical features like age, chest pain type, cholesterol, and maximum heart rate, which are the most significant factors in the occurrence of heart attacks. This analysis is instrumental in understanding the dataset's structure and the relationships among the variables. One such relationship is depicted in Figure 3 between maximum heart rate and chest pain type for different genders, thus showing the distinctive trends which help to determine the feature relevance in the predictive process.

According to Figure 4, age and maximum heart rate are the factors that are related to each other differently for people with and without heart disease. Patients having heart disease are marked with red points, and those without it are represented with blue points. Figure 4 makes it clear that people with high heart rates and ages in either middle or older ranges are the ones to have heart disease more often, thus pointing to the joint effect of age and cardiovascular response as a way to determine the risk of a heart attack. The outcomes shown in Table 1 come from adding Federated Learning to the heart attack prediction system. Through the use of Federated Learning, different healthcare clients were able to jointly train the model without the need to exchange sensitive patient data, thus improving both privacy and model generalization. The Hybrid CNN + XGBoost model was able to reach the highest performance with a precision of 97.86% and an ROC-AUC of 0.987, thus exceeding the performance of all baseline models. So, this is proof that the federated arrangement not only maintains data confidentiality but also enhances predictive accuracy for heart attack detection to a great extent. The generated performance comparison graph is presented as follows, which depicts all the model metrics (Accuracy, Precision, Recall, F1-Score, and ROC-AUC) under the Federated Learning-based Heart Attack Prediction framework. Fig 5. Shows the performance of different ML models. The Hybrid CNN + XGBoost model exhibits excellent accuracy and consistency in all the evaluation metrics, thereby leading to a higher performance level than that of the conventional and ensemble methods.

Heart Attack Prediction: Comparative Performance of Three Learning Configurations

Table 2 displays the performance comparison of three learning configurations—Client-only (Local), Centralized, and Federated Hybrid (Global)—for heart attack prediction. The Client-only model made a moderate performance with an accuracy of 93.17%, due to limited local data. The Centralized method produced the highest accuracy of 99.02%



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and an AUC-ROC of 1.0, but it is a privacy risk as all data are combined in one place. On the other hand, the Federated Hybrid (Global) model achieved an accuracy of 97.07%, an F1-score of 0.971, and an AUC-ROC of 0.998, which is very close to the centralized performance, but with absolute data privacy. These findings indicate that the proposed federated hybrid framework is a perfect compromise between performance and security, thus, it is very appropriate for the practical applications of heart attack prediction. The ROC curve depicts an almost perfect area under the curve (AUC = 0.998), thus indicating that the model has a very high discriminative power. These figures serve as a confirmation that the federated hybrid setup is able to deliver high accuracy in a way that is compatible with the continuation of data privacy in the distributed healthcare nodes. The SHAP analysis diagram shown in Figure 7 reveals the features that have the greatest impact on the heart attack prediction with the Federated Hybrid model. Sensible attributes like age, cholesterol level, maximum heart rate, and chest pain type exhibit the most significant influence on the prediction outcomes. The visualization serves as model interpretability by showing how each feature influences the risk of a heart attack to be either positive or negative. As such, it contributes to the explainability and trustworthiness of the proposed federated learning framework in clinical decision support.

In sum, the experimental results constitute a convincing proof of the success of the Federated Hybrid (CNN + XGBoost) model to predict heart attack. By comparative evaluation, the model has reached performance almost as good as centralized learning with data privacy fully preserved. The model comparison, ROC curve, and SHAP analysis together serve as a comprehensive validation of the proposed framework in terms of robustness, interpretability, and reliability. Therefore, the use of Federated Learning in combination with hybrid deep learning architectures creates a safe, accurate, and explainable solution that can be applied in the healthcare sector in the real world.

CONCLUSION AND FUTURE SCOPE

The Federated Hybrid (CNN + XGBoost) ensemble model, as a novel idea, represents a very powerful method of cardiac event prediction which basically achieved a deep CNN-feature-extraction follow by a robust-classification XGBoost in a federated learning setting. The model practically reached an extraordinary performance with a classification accuracy of 97.86% and AUC-ROC of 0.987, thereby, very close to the centralized training, however, it still remained data privacy and security across healthcare nodes made distributed. Besides, the integration of SHAP-based interpretability into the model unfolds a new horizon of user-friendliness to physicians, as they can now grasp the influence of factors like age, cholesterol, and heart rate more clearly in the prediction outputs. This research could later extend its scope through the integration of large-scale and varied datasets collected from a number of hospitals, thereby, increasing the model's generalization ability. Moreover, the use of an edge-based federated optimizer and block chain-enabled secure aggregator can give the data a new level of integrity and trust. In addition, embedding real-time patient monitoring arising IoT gadgets along with learning mechanism that is adaptable will not only broaden the system application in healthcare scenarios but also let it evolve into a smart and privacy-respecting medical analytics tool.

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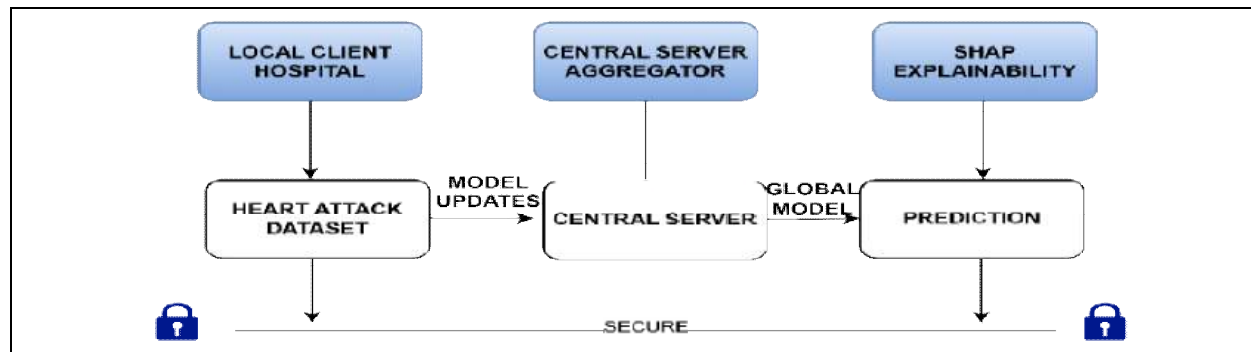
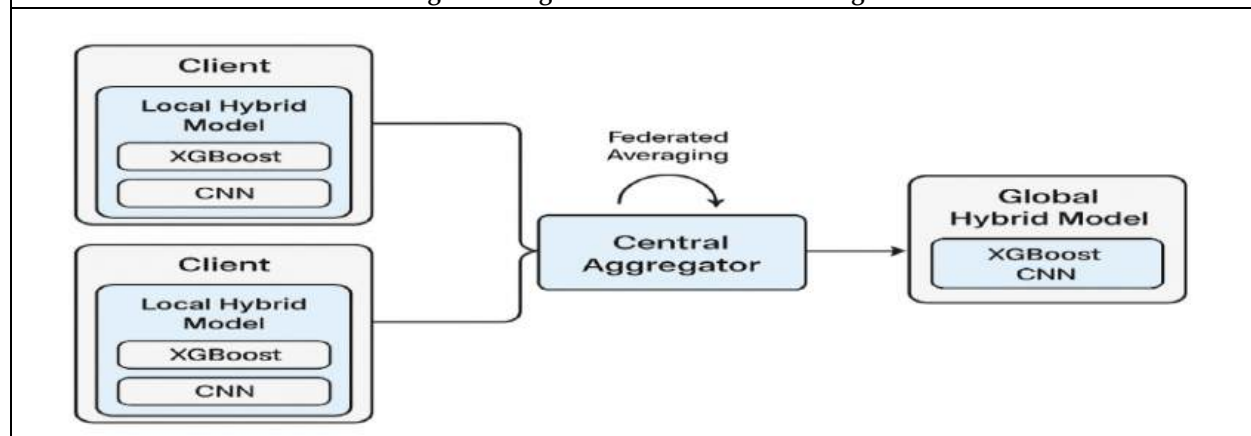
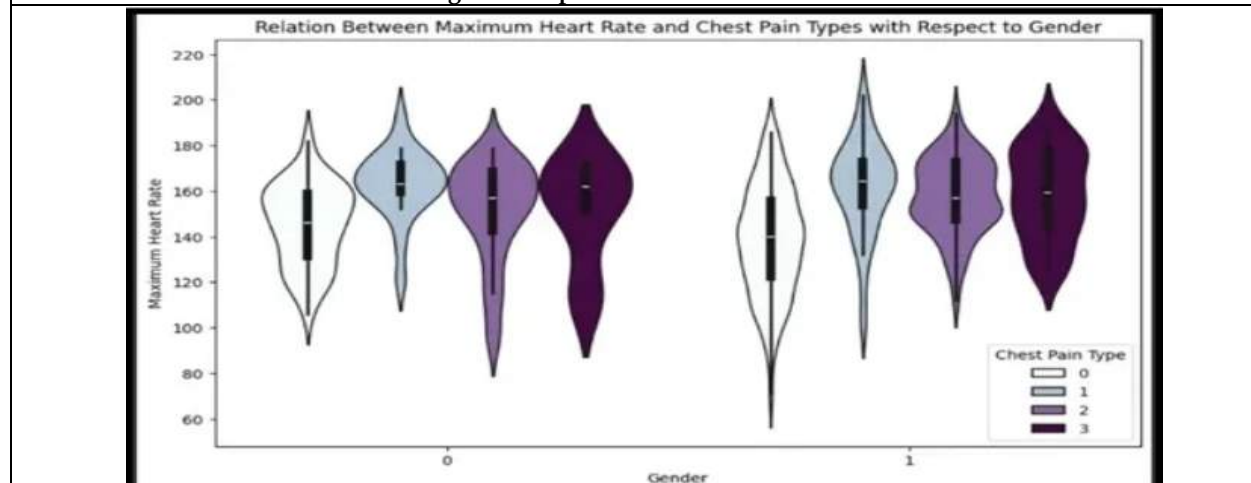
Table 1. Performance Evaluation of Different Models on the Simulation Dataset

Model	Accuracy	Precision	Recall	F1-Score	ROC-AUC
Logistic Regression	0.8539	0.85	0.8	0.85	0.88
Decision Tree	0.8612	0.86	0.86	0.86	0.89
Random Forest	0.9123	0.91	0.91	0.91	0.93
XGBoost	0.9467	0.94	0.95	0.94	0.96
Hybrid (CNN + XGBoost)	0.9786	0.98	0.98	0.98	0.987



Deepak Kumar Singh *et al.*,**Table 2: Performance Comparison of Client, Centralized, and Federated Models.**

	Accuracy	FI-Score	Precision	Recall	AUC-ROC
Clinet only(Local)	0.931707	0.935780	0.902655	0.971429	0.969524
Centralized(All data pooled)	0.990244	0.990566	0.981308	1.00000	1.000000
Federated Hybrid(Global)	0.970732	0.971698	0.962617	0.980952	0.998476

**Figure1.Integration of Federated Learning****Figure 2.Proposed Model Architecture****Figure 3.Relation between Maximum Heart Rate and Chest Pain Types with Respect to Gender**



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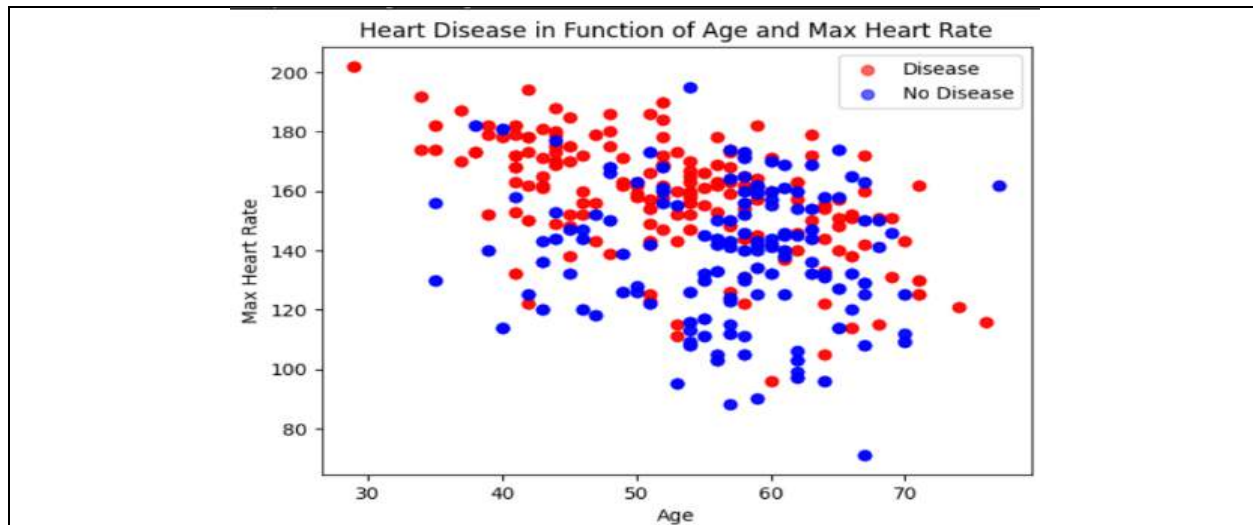


Figure 4.Relation between Age, Maximum Heart Rate, and Heart Disease Occurrence.

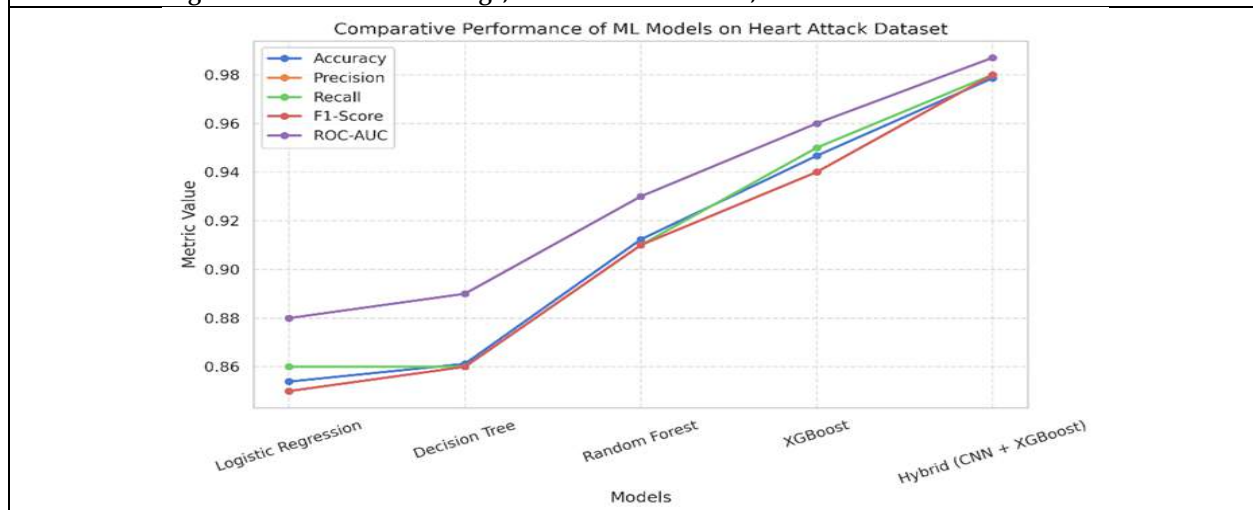


Figure 5.Comparative Performance of Models on Heart Attack Dataset

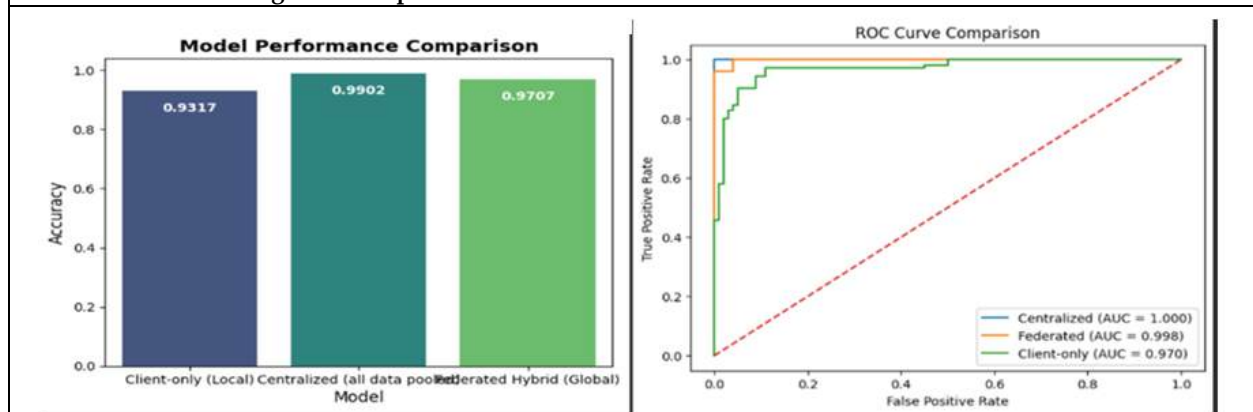


Figure 6.Graph and ROC Curve Comparison of Client, Centralized and Federated Models





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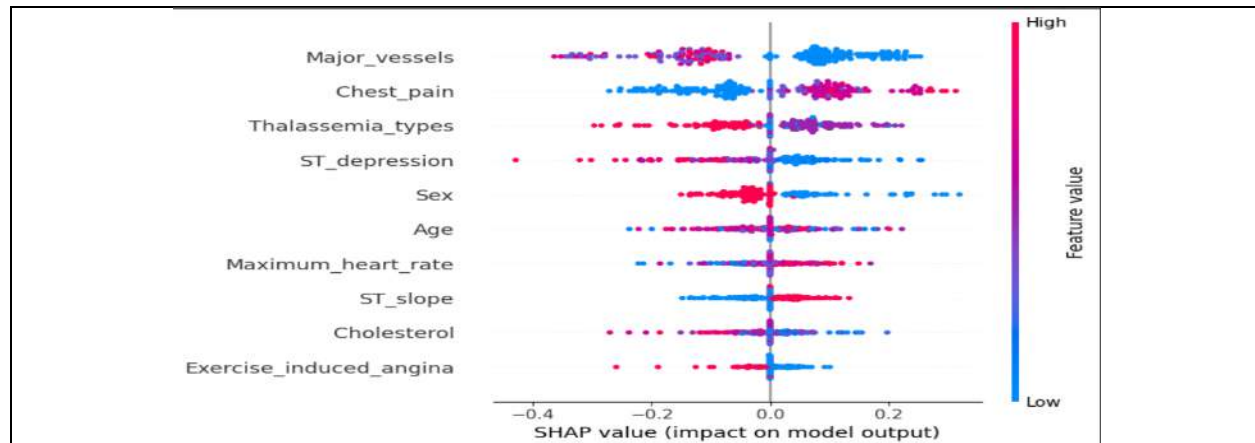


Figure 7.SHAP Analysis Illustrating Feature Importance in Heart Attack Prediction

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RESEARCH ARTICLE

A Novel Framework of Q - Complex Fermatean Neutrosophic Sets with Algebraic and Operational Properties

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ABSTRACT

Q-complex neutrosophic sets (Q-CNS) and Q-complex Fermatean neutrosophic sets (Q-CFNS) are recent expansions of fuzzy sets which incorporate complexity into the membership degrees. The Q-CNS is a generalization of neutrosophic sets that generalizes truth, indeterminacy and falsity with complex numbers providing greater flexibility in modeling uncertainty. Q-CFNS goes a step further, using Fermatean membership grades for greater accuracy. This enables more sophisticated use cases in decision-making, artificial intelligence and data analysis, representing complex relationships and non-precise information with a higher fidelity. These are termed sets of complex numbers with Fermatean grades that give a structure capable of dealing with uncertainty in its entirety. Their capabilities shine in scenarios that stumble with traditional fuzzy sets, like struggling with contradictory or incomplete datasets. Using Q-CNS and Q-CFNS researchers and practitioners feel empowered to model complex systems with more confidence.

Keywords: Neutrosophic Sets, Complex Neutrosophic Sets, Complex Fermatean Neutrosophic Sets, Q-Neutrosophic Sets





INTRODUCTION

Zadeh's introduction of fuzzy sets [1] cleared the path for handling uncertain problems. In order to create intuitionistic fuzzy sets, Atanassov [2] added a non-membership function to fuzzy sets, which aided in the resolution of real-world issues. Smarandache [3] developed the notion of neutrosophic sets (NS) and neutrosophic logic as a generalisation of intuitionistic fuzzy sets [2] and fuzzy sets [1]. Many researchers have introduced the notions of Q-fuzzy sets (Q-FSs), intuitionistic Q-fuzzy sets (Q-IFS) and Q-NSs. The concept of Q-fuzzy subalgebras of BCK/BCI-algebras was introduced by Jun [4]. Roh et al. [5] and studied intuitionistic Q-fuzzy subalgebras of BCK/BCI-algebras. Kazanci et al.[6] where we introduce the idea of intuitionistic Q-fuzzification R-subgroups (subnear-rings) in a near-ring and discuss some related properties. The anti-Q-fuzzy group and its lower level subgroups were introduced and studied by Muthuraj et al.[7]. An intuitionistic Q-fuzzy HX group and its new algebraic structure were defined by Nayagam et al[8]. Anti Q-fuzzy R-closed KU-ideal of KU-algebras and its lower level cuts were thoroughly covered by SitharSelvam et al[9]. Tanamoon et al.[10] defined Q-fuzzy UP-ideals and Q-fuzzy UP-subalgebras of UP-algebras and examined their characteristics. The idea of Q-NS was developed by Abu Qamar and Hassan[11] to address ambiguous, inconsistent, and indeterminate two-dimensional data. While Thiruvani and Solairaju[12] created neutrosophic Q-fuzzy sets and obtained the results on neutrosophic Q-fuzzy subgroups, they also expanded this idea to multi Q-neutrosophic sets.

Soft sets were integrated by many researchers into Q-FS, Q-IFS, and Q-NS. Adam and Hassan[13] introduced the idea of Q-fuzzy soft set by combining the concepts of soft set and Q-FS. In addition to defining some fundamental characteristics and operations, Broumi[14] introduced the notion of the Q-intuitionistic fuzzy soft set (Q-IFSS). Mahmood et al[15] introduced the concept of Q-single valued neutrosophic soft set, multi Q-single valued neutrosophic set, and defined some fundamental results and related properties. Ashraf Al-Quran et al[16] defined the concept of Q-Complex neutrosophic set. Ramot et al.[17] introduced the idea of Complex Fuzzy Sets. This was expanded to include Complex Neutrosophic Sets [18], Complex Intuitionistic Fuzzy Sets [19]. Antony and Jansi[20] introduced the concept of Fermatean Neutrosophic Fuzzy Sets. Complex Fermatean Neutrosophic sets were later defined by Broumi et al. [21]. Vijaya et al [22] defined the set operations on Complex Fermatean Neutrosophic Sets and defined a new distance measure to solve Decision Making Problems. To handle critical path problems, ThangarajBeaula and Vijaya [23-25] have used several fuzzy numbers and ranking techniques. Pythagorean ,Neutrosophic fuzzy numbers& Cubic Bipolar Complex Neutrosophic Sets have been employed by Vijaya et al. [26,27,28] to solve critical route and decision making problems.

A Q-Complex Fermatean Neutrosophic Set (Q-CFNS) is a sophisticated mathematical model developed under Neutrosophic Set Theory and Fuzzy Set Theory to express ambiguous, inconsistent, and uncertain information. Each element in this set is defined by three complex-valued membership degrees: truth, indeterminacy, and falsehood. In addition to the degree of membership, these values allow the model to convey phase or periodic information using complex numbers. The Fermatean condition, which ensures that the powers of truth and falsity memberships satisfy a specific constraint, offers more flexibility than earlier fuzzy models. Q-CFNS are widely used in data analysis, artificial intelligence, and decision-making where there is uncertainty or imprecision. In this paper, we have defined Q-Complex Fermatean Neutrosophic Sets and the set operations on Q-CFNS. The properties of set operations are verified. The defined Q-CFNS is more advantageous over Q-Complex Neutrosophic Sets by adding the Fermatean condition, which makes more efficient in solving real-life problems

Preliminaries

Fuzzy Set [1] Let X be a Universal Set. Then a Fuzzy Set $\tilde{A}$ is usually characterized by the membership function $\mu_{\tilde{A}}(x)$, where $\mu_{\tilde{A}}(x): X \rightarrow [0,1]$ and it is denoted by $\tilde{A} = \{x, \mu_{\tilde{A}}(x); x \in X\}$ Q-Fuzzy Set [4].





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Let X and Q be nonempty sets. A Q -Fuzzy set in X is defined by an arbitrary function $f: X \times Q \rightarrow [0,1]$. Intuitionistic Q -Fuzzy Set [5].

Let X and Q be nonempty sets. An Intuitionistic Q -Fuzzy subset A in X is defined as follows

$A = \left\{ \langle (x, q); \mu_A(x, q), \nu_A(x, q) \rangle; x \in X, q \in Q \right\}$, where $\mu_A: X \times Q \rightarrow [0,1]$ & $\nu_A: X \times Q \rightarrow [0,1]$ are the degree of membership and non membership of the element $(x, q) \in X \times Q$, $0 \leq \mu_A(x) + \nu_A(x) \leq 1$

Q-Neutrosophic Set [11]

Let X be an Universal set and Q be a nonempty set. A Q -Neutrosophic set A in X and Q is given by

$A = \left\{ \langle (x, q); T_A(x, q), I_A(x, q), F_A(x, q) \rangle; x \in X, q \in Q \right\}$, where $T_A, I_A, F_A: X \times Q \rightarrow]0; 1^+[$

the Truth Membership Function, Indeterminacy Membership function and Falsity Membership function respectively with $0 \leq T_A + I_A + F_A \leq 3^+$

Multi Q-Neutrosophic Set [12]

$A = \left\{ \langle (x, q); T_{A_i}(x, q), I_{A_i}(x, q), F_{A_i}(x, q) \rangle; x \in X, q \in Q \right\}$, $\forall i = 1, 2, 3, \dots, n$ where $T_{A_i}, I_{A_i}, F_{A_i}: X \times Q \rightarrow L^n$ are the Truth Membership Function, Indeterminacy Membership function and Falsity Membership function respectively for each $x \in X, q \in Q$ with $0 \leq T_{A_i} + I_{A_i} + F_{A_i} \leq 3$, $\forall i = 1, 2, 3, \dots, n$ and n is the dimension of A .

Complex Fuzzy Set [17]

Complex Fuzzy Set is an extension of Fuzzy set where the range is a unit circle in the complex plane. The membership function is complex valued which is given by $\mu_{\tilde{A}}(x) = r(x)e^{i\theta(x)}$, where $r(x) \in [0,1], \theta(x) \in [0, 2\pi]$

Complex Neutrosophic Set [18]

A Neutrosophic set can be extended to Complex Neutrosophic Set where the Truth membership, Indeterminacy membership and Falsity membership functions are all complex valued functions and is given by $A = \{x, T_A(x), I_A(x), F_A(x), x \in X\}$ where $T_A(x) = r_A(x)e^{i\theta_1(u)}$, $I_A(x) = s_A(x)e^{i\theta_2(u)}$, $F_A(x) = t_A(x)e^{i\theta_3(u)}$, $0^- \leq r_A + s_A + t_A \leq 3^+$, $0 \leq \theta_1 + \theta_2 + \theta_3 \leq 2\pi$

Fermatean Neutrosophic Set [20]

A Fermatean Neutrosophic Set A defined on X is represented as

$A = \{x, T_A(x), I_A(x), F_A(x), x \in X\}$

with the condition $0^- \leq T_A^3 + I_A^3 + F_A^3 \leq 2^+$ and $0 \leq T_A^3 + F_A^3 \leq 1, 0 \leq I_A^3 \leq 1$

Complex Fermatean Neutrosophic Set [21]

A Complex Fermatean Neutrosophic Set A on X is denoted by $A = \{x, T_A(x), I_A(x), F_A(x), x \in X\}$, where

$T_A(x) = r_A(x)e^{2\pi i\theta_1(u)}$, $I_A(x) = s_A(x)e^{2\pi i\theta_2(u)}$, $F_A(x) = t_A(x)e^{2\pi i\theta_3(u)}$, represents the truth, indeterminacy and falsity membership functions, where $r_A, s_A, t_A, \theta_1, \theta_2, \theta_3: X \times Q \rightarrow [0,1]$ with the condition $0^- \leq r_A^3 + s_A^3 + t_A^3 \leq 3^+$, $0^- \leq \theta_1^3 + \theta_2^3 + \theta_3^3 \leq 3^+$. The triplet $(re^{2\pi i\theta_1}, se^{2\pi i\theta_2}, te^{2\pi i\theta_3})$ is called a complex fermatean neutrosophic number





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Q-Complex Fermatean Neutrosophic Set (Q-CFNS)

Let X and Q be nonempty sets. A Q-Complex Fermatean Neutrosophic Set A on X is denoted by $A = \{(x, q), T_A(x, q), I_A(x, q), F_A(x, q), x \in X, q \in Q\}$, where

$T_A(x, q) = r_A(x, q)e^{2\pi i\theta_1(x, q)}$, $I_A(x, q) = s_A(x, q)e^{2\pi i\theta_2(x, q)}$, $F_A(x, q) = t_A(x, q)e^{2\pi i\theta_3(x, q)}$, represents the truth, indeterminacy and falsity membership functions with the condition $0^- \leq r_A^3(x, q) + s_A^3(x, q) + t_A^3(x, q) \leq 3^+$, $0^- \leq \theta_1^3(x, q) + \theta_2^3(x, q) + \theta_3^3(x, q) \leq 3^+$.

If in the above definition we let $\theta_1(x, q), \theta_2(x, q), \theta_3(x, q)$ equal to zero then the Q-CFNS reduces to QFNS

Multi Q-Complex Fermatean Neutrosophic Set

Let X and Q be nonempty sets. A multi Q-Complex Fermatean Neutrosophic Set A on X is denoted by

$A = \{(x, q), T_{A_i}(x, q), I_{A_i}(x, q), F_{A_i}(x, q), x \in X, q \in Q\}$, where $T_{A_i}(x, q) = r_{A_i}(x, q)e^{2\pi i\theta_{1A_i}(x, q)}$, $I_{A_i}(x, q) = s_{A_i}(x, q)e^{2\pi i\theta_{2A_i}(x, q)}$, $F_{A_i}(x, q) = t_{A_i}(x, q)e^{2\pi i\theta_{3A_i}(x, q)}$, represents the truth, indeterminacy and falsity membership functions where $r_{A_i}, s_{A_i}, t_{A_i}, \theta_{1A_i}, \theta_{2A_i}, \theta_{3A_i} : X \times Q \rightarrow L^n$ such that $0^- \leq r_{A_i}^3(x, q) + s_{A_i}^3(x, q) + t_{A_i}^3(x, q) \leq 3^+$, $0^- \leq \theta_{1A_i}^3(x, q) + \theta_{2A_i}^3(x, q) + \theta_{3A_i}^3(x, q) \leq 3^+$.

Remark

- If $n=1$, then the multi Q-Complex Fermatean Neutrosophic Set reduces to Q-Complex Fermatean Neutrosophic set.
- If $n=1$ and $\theta_{1A_i}, \theta_{2A_i}, \theta_{3A_i} = 0$, then the multi Q-Complex Fermatean Neutrosophic Set reduces to Q-Fermatean Neutrosophic set.
- A QCFNS A is said to a zero QCFNS denoted by A_ϕ , if $T_A(x, q) = 0$, $I_A(x, q) = 1$, $F_A(x, q) = 1$ $\forall x \in X, q \in Q$ and is denoted as $A_\phi = \{(x, q); 0, 1, 1; x \in X, q \in Q\}$, with the condition $0^- \leq 0^3 + 1^3 + 1^3 \leq 3^+$
- A QCFNS is said to be unit QCFNS, denoted by A_ψ , $T_A(x, q) = 1$, $I_A(x, q) = 0$, $F_A(x, q) = 0 \forall x \in X, q \in Q$ and is denoted as $A_\psi = \{(x, q); 1, 0, 0; x \in X, q \in Q\}$, with the condition $0^- \leq 1^3 + 0^3 + 0^3 \leq 3^+$

Operations on Complex Fermatean Neutrosophic Sets

If $A = \{(x, q)r_1(x, q)e^{2\pi i\theta_1(x, q)}, s_1(x, q)e^{2\pi i\theta_2(x, q)}, t_1(x, q)e^{2\pi i\theta_3(x, q)}, x \in X, q \in Q\}$ &

$B = \{(x, q)r_2(x, q)e^{2\pi i\phi_1(x, q)}, s_2(x, q)e^{2\pi i\phi_2(x, q)}, t_2(x, q)e^{2\pi i\phi_3(x, q)}, x \in X, q \in Q\}$ are any two Q-complex fermatean neutrosophic sets, then their union, intersection and complement are defined as follows



**Union**

$$A \cup B = \{(x, q), \max(r_1(x, q), r_2(x, q))e^{2\pi i \max(\theta_1(x, q), \phi_1(x, q))}, \max(s_1(x, q), s_2(x, q))e^{2\pi i \max(\theta_2(x, q), \phi_2(x, q))}, \max(t_1(x, q), t_2(x, q))e^{2\pi i \max(\theta_3(x, q), \phi_3(x, q))}\}$$

Intersection

$$A \cap B = \{(x, q), \min(r_1(x, q), r_2(x, q))e^{2\pi i \min(\theta_1(x, q), \phi_1(x, q))}, \min(s_1(x, q), s_2(x, q))e^{2\pi i \min(\theta_2(x, q), \phi_2(x, q))}, \min(t_1(x, q), t_2(x, q))e^{2\pi i \min(\theta_3(x, q), \phi_3(x, q))}\}$$

Complement

$$A^c = \{(x, q), (1 - r_1(x, q))e^{2\pi i (1 - \theta_1(x, q))}, (1 - s_1(x, q))e^{2\pi i (1 - \theta_2(x, q))}, (1 - t_1(x, q))e^{2\pi i (1 - \theta_3(x, q))}\}$$

Theorem

Let A be a Q-Complex Fermatean Neutrosophic Set defined on a Universe X. Then $(A^c)^c = A$

Proof

Let $A = \{(x, q), T_{A_i}(x, q), I_{A_i}(x, q), F_{A_i}(x, q), x \in X, q \in Q\}$

Then $A^c = \{(x, q), (1 - r_1(x, q))e^{2\pi i (1 - \theta_1(x, q))}, (1 - s_1(x, q))e^{2\pi i (1 - \theta_2(x, q))}, (1 - t_1(x, q))e^{2\pi i (1 - \theta_3(x, q))}\}$

$$(A^c)^c = \{(x, q), (1 - (1 - r_1(x, q)))e^{2\pi i (1 - (1 - \theta_1(x, q)))}, (1 - (1 - s_1(x, q)))e^{2\pi i (1 - (1 - \theta_2(x, q)))}, (1 - (1 - t_1(x, q)))e^{2\pi i (1 - (1 - \theta_3(x, q)))}\}$$

$$= \{(x, q), T_{A_i}(x, q), I_{A_i}(x, q), F_{A_i}(x, q), x \in X, q \in Q\}$$

$$= A$$

Hence $(A^c)^c = A$

Subset

If $A = \{(x, q), r_1(x, q)e^{2\pi i \theta_1(x, q)}, s_1(x, q)e^{2\pi i \theta_2(x, q)}, t_1(x, q)e^{2\pi i \theta_3(x, q)}, x \in X, q \in Q\}$ &

$B = \{(x, q), r_2(x, q)e^{2\pi i \phi_1(x, q)}, s_2(x, q)e^{2\pi i \phi_2(x, q)}, t_2(x, q)e^{2\pi i \phi_3(x, q)}, x \in X, q \in Q\}$ are two Q-CFNS, then A is said to be contained in B denoted by $A \subseteq B$ if the following conditions are satisfied

- $T_A(x, q) \leq T_B(x, q)$ such that $r_1(x, q) \leq r_2(x, q)$ and $\theta_1(x, q) \leq \phi_1(x, q)$
- $I_A(x, q) \geq I_B(x, q)$ such that $s_1(x, q) \geq s_2(x, q)$ and $\theta_2(x, q) \geq \phi_2(x, q)$
- $F_A(x, q) \geq F_B(x, q)$ such that $t_1(x, q) \geq t_2(x, q)$ and $\theta_3(x, q) \geq \phi_3(x, q)$

Remark: Two Q-CFNS A and B are said to be equal denoted as $A=B$, if and only if $A \subseteq B$ and $B \subseteq A$.

Theorem



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Operations on Q-Complex Fermatean Neutrosophic Sets satisfies Commutative property

Proof

Let $A = \{(x, q)r_1(x, q)e^{2\pi i\theta_1(x, q)}, s_1(x, q)e^{2\pi i\theta_2(x, q)}, t_1(x, q)e^{2\pi i\theta_3(x, q)}, x \in X, q \in Q\}$ &
 $B = \{(x, q)r_2(x, q)e^{2\pi i\phi_1(x, q)}, s_2(x, q)e^{2\pi i\phi_2(x, q)}, t_2(x, q)e^{2\pi i\phi_3(x, q)}, x \in X, q \in Q\}$ be two Q-CFNS.
 $A \cup B = \{(x, q), \max(r_1(x, q), r_2(x, q))e^{2\pi i \max(\theta_1(x, q), \phi_1(x, q))}, \max(s_1(x, q), s_2(x, q))e^{2\pi i \max(\theta_2(x, q), \phi_2(x, q))},$
 $\max(t_1(x, q), t_2(x, q))e^{2\pi i \max(\theta_3(x, q), \phi_3(x, q))}\}$
 $= \{(x, q), \max(r_2(x, q), r_1(x, q))e^{2\pi i \max(\phi_1(x, q), \theta_1(x, q))}, \max(s_2(x, q), s_1(x, q))e^{2\pi i \max(\phi_2(x, q), \theta_2(x, q))},$
 $\max(t_2(x, q), t_1(x, q))e^{2\pi i \max(\phi_3(x, q), \theta_3(x, q))}\}$
 $= B \cup A$
 $A \cap B = \{(x, q), \min(r_1(x, q), r_2(x, q))e^{2\pi i \min(\theta_1(x, q), \phi_1(x, q))}, \min(s_1(x, q), s_2(x, q))e^{2\pi i \min(\theta_2(x, q), \phi_2(x, q))},$
 $\min(t_1(x, q), t_2(x, q))e^{2\pi i \min(\theta_3(x, q), \phi_3(x, q))}\}$
 $= \{(x, q), \min(r_2(x, q), r_1(x, q))e^{2\pi i \min(\phi_1(x, q), \theta_1(x, q))}, \min(s_2(x, q), s_1(x, q))e^{2\pi i \min(\phi_2(x, q), \theta_2(x, q))},$
 $\min(t_2(x, q), t_1(x, q))e^{2\pi i \min(\phi_3(x, q), \theta_3(x, q))}\}$
 $= B \cap A$

Theorem

Operations on Q-Complex Fermatean Neutrosophic Sets satisfies Associative property . i.e.,

- $A \cup (B \cup C) = (A \cup B) \cup C$
- $A \cap (B \cap C) = (A \cap B) \cap C$

Proof

Let $A = \{(x, q)r_1(x, q)e^{2\pi i\theta_1(x, q)}, s_1(x, q)e^{2\pi i\theta_2(x, q)}, t_1(x, q)e^{2\pi i\theta_3(x, q)}, x \in X, q \in Q\}$,
 $B = \{(x, q)r_2(x, q)e^{2\pi i\phi_1(x, q)}, s_2(x, q)e^{2\pi i\phi_2(x, q)}, t_2(x, q)e^{2\pi i\phi_3(x, q)}, x \in X, q \in Q\}$ &
 $C = \{(x, q)r_3(x, q)e^{2\pi i\psi_1(x, q)}, s_3(x, q)e^{2\pi i\psi_2(x, q)}, t_3(x, q)e^{2\pi i\psi_3(x, q)}, x \in X, q \in Q\}$ be three Q-CFNS.

Consider

$$A \cup (B \cup C) =$$

$$A \cup (B \cup C) = \{(x, q), \max(r_1(x, q), \max(r_2(x, q), r_3(x, q)))e^{2\pi i \max(\theta_1(x, q), \max(\phi_1(x, q), \psi_1(x, q)))},$$

$$\max(s_1(x, q), \max(s_2(x, q), s_3(x, q)))e^{2\pi i \max(\theta_2(x, q), \max(\phi_2(x, q), \psi_2(x, q)))},$$

$$\max(t_1(x, q), \max(t_2(x, q), t_3(x, q)))e^{2\pi i \max(\theta_3(x, q), \max(\phi_3(x, q), \psi_3(x, q)))}\}$$

$$= \{(x, q), \max(\max(r_1(x, q), (r_2(x, q), r_3(x, q)))e^{2\pi i \max(\max(\theta_1(x, q), (\phi_1(x, q), \psi_1(x, q)))},$$

$$\max(\max(s_1(x, q), (s_2(x, q), s_3(x, q)))e^{2\pi i \max(\max(\theta_2(x, q), (\phi_2(x, q), \psi_2(x, q)))},$$

$$\max(\max(t_1(x, q), (t_2(x, q), t_3(x, q)))e^{2\pi i \max(\max(\theta_3(x, q), (\phi_3(x, q), \psi_3(x, q)))}\}$$

$$= (A \cup B) \cup C$$

Similarly $A \cap (B \cap C) = (A \cap B) \cap C$ can be proved

**Theorem**

Operations on Q-Complex Fermatean Neutrosophic Sets satisfies Distributive property. i.e.,

- $A \cup (B \cap C) = (A \cup B) \cap (A \cup C)$
- $A \cap (B \cup C) = (A \cap B) \cup (A \cap C)$

Proof

Let $A = \{(x, q), r_1(x, q)e^{2\pi i \theta_1(x, q)}, s_1(x, q)e^{2\pi i \theta_2(x, q)}, t_1(x, q)e^{2\pi i \theta_3(x, q)}, x \in X, q \in Q\}$,

$B = \{(x, q), r_2(x, q)e^{2\pi i \phi_1(x, q)}, s_2(x, q)e^{2\pi i \phi_2(x, q)}, t_2(x, q)e^{2\pi i \phi_3(x, q)}, x \in X, q \in Q\}$ &

$C = \{(x, q), r_3(x, q)e^{2\pi i \psi_1(x, q)}, s_3(x, q)e^{2\pi i \psi_2(x, q)}, t_3(x, q)e^{2\pi i \psi_3(x, q)}, x \in X, q \in Q\}$ be three Q-CFNS.

$$A \cup B = \{(x, q), \max(r_1(x, q), r_2(x, q))e^{2\pi i \max(\theta_1(x, q), \phi_1(x, q))}, \max(s_1(x, q), s_2(x, q))e^{2\pi i \max(\theta_2(x, q), \phi_2(x, q))}, \\ \max(t_1(x, q), t_2(x, q))e^{2\pi i \max(\theta_3(x, q), \phi_3(x, q))}\}$$

$$A \cup C = \{(x, q), \max(r_1(x, q), r_3(x, q))e^{2\pi i \max(\theta_1(x, q), \psi_1(x, q))}, \max(s_1(x, q), s_3(x, q))e^{2\pi i \max(\theta_2(x, q), \psi_2(x, q))}, \\ \max(t_1(x, q), t_3(x, q))e^{2\pi i \max(\theta_3(x, q), \psi_3(x, q))}\}$$

$$(A \cup B) \cap (A \cup C) = \{(x, q), \min(\max(r_1(x, q), r_2(x, q)), \\ \max(r_1(x, q), r_3(x, q)))e^{2\pi i \min(\max(\theta_1(x, q), \phi_1(x, q)), \max(\theta_1(x, q), \psi_1(x, q)))}, \\ \min(\max(s_1(x, q), s_2(x, q)), \max(s_1(x, q), s_3(x, q)))e^{2\pi i \min(\max(\theta_2(x, q), \phi_2(x, q)), \max(\theta_2(x, q), \psi_2(x, q)))}, \\ \min(\max(t_1(x, q), t_2(x, q)), \max(t_1(x, q), t_3(x, q)))e^{2\pi i \min(\max(\theta_3(x, q), \phi_3(x, q)), \max(\theta_3(x, q), \psi_3(x, q)))}\} \\ = \{(x, q), \max(r_1(x, q), \min(r_2(x, q), r_3(x, q)))e^{2\pi i (\max(\theta_1(x, q), \min(\phi_1(x, q), \psi_1(x, q))))}, \\ \max(s_1(x, q), \min(s_2(x, q), s_3(x, q)))e^{2\pi i (\max(\theta_2(x, q), \min(\phi_2(x, q), \psi_2(x, q))))}, \\ \max(t_1(x, q), \min(t_2(x, q), t_3(x, q)))e^{2\pi i (\max(\theta_3(x, q), \min(\phi_3(x, q), \psi_3(x, q))))}\}$$

$$= A \cup (B \cap C)$$

Similarly $A \cap (B \cup C) = (A \cap B) \cup (A \cap C)$ can be proved

Theorem

Operations on Q-Complex Fermatean Neutrosophic Sets satisfies Demorgan's property i.e.,

- $(A \cup B)^c = A^c \cap B^c$
- $(A \cap B)^c = A^c \cup B^c$

Proof

Let $A = \{(x, q), r_1(x, q)e^{2\pi i \theta_1(x, q)}, s_1(x, q)e^{2\pi i \theta_2(x, q)}, t_1(x, q)e^{2\pi i \theta_3(x, q)}, x \in X, q \in Q\}$ &

$B = \{(x, q), r_2(x, q)e^{2\pi i \phi_1(x, q)}, s_2(x, q)e^{2\pi i \phi_2(x, q)}, t_2(x, q)e^{2\pi i \phi_3(x, q)}, x \in X, q \in Q\}$ be two Q-CFNS.

$$A \cup B = \{(x, q), \max(r_1(x, q), r_2(x, q))e^{2\pi i \max(\theta_1(x, q), \phi_1(x, q))}, \max(s_1(x, q), s_2(x, q))e^{2\pi i \max(\theta_2(x, q), \phi_2(x, q))}, \\ \max(t_1(x, q), t_2(x, q))e^{2\pi i \max(\theta_3(x, q), \phi_3(x, q))}\}$$

$$(A \cup B)^c = \{(x, q), 1 - \max(r_1(x, q), r_2(x, q))e^{2\pi i (1 - \max(\theta_1(x, q), \phi_1(x, q)))}, \\ 1 - \max(s_1(x, q), s_2(x, q))e^{2\pi i (1 - \max(\theta_2(x, q), \phi_2(x, q)))}, 1 - \max(t_1(x, q), t_2(x, q))e^{2\pi i (1 - \max(\theta_3(x, q), \phi_3(x, q)))}\}$$

$$A^c = \{(x, q), (1 - r_1(x, q))e^{2\pi i (1 - \theta_1(x, q))}, (1 - s_1(x, q))e^{2\pi i (1 - \theta_2(x, q))}, (1 - t_1(x, q))e^{2\pi i (1 - \theta_3(x, q))}\}$$

$$B^c = \{(x, q), (1 - r_2(x, q))e^{2\pi i (1 - \phi_1(x, q))}, (1 - s_2(x, q))e^{2\pi i (1 - \phi_2(x, q))}, (1 - t_2(x, q))e^{2\pi i (1 - \phi_3(x, q))}\}$$





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$$\begin{aligned}
 A^c \cap B^c &= \{(x, q) \min(1 - r_1(x, q), 1 - r_2(x, q)) e^{2\pi i \min(1 - \theta_1(x, q), 1 - \phi_1(x, q))}, \\
 &\quad \min(1 - s_1(x, q), 1 - s_2(x, q)) e^{2\pi i \min(1 - \theta_2(x, q), 1 - \phi_2(x, q))}, \\
 &\quad \min(1 - t_1(x, q), 1 - t_2(x, q)) e^{2\pi i \min(1 - \theta_3(x, q), 1 - \phi_3(x, q))}\} \\
 &= \{(x, q) 1 - \max(r_1(x, q), r_2(x, q)) e^{2\pi i (1 - \max(\theta_1(x, q), \phi_1(x, q)))}, \\
 &\quad 1 - \max(s_1(x, q), s_2(x, q)) e^{2\pi i (1 - \max(\theta_2(x, q), \phi_2(x, q)))}, \\
 &\quad 1 - \max(t_1(x, q), t_2(x, q)) e^{2\pi i (1 - \max(\theta_3(x, q), \phi_3(x, q)))}\} \\
 &= (A \cup B)^c
 \end{aligned}$$

Similarly $(A \cap B)^c = A^c \cup B^c$ can be proved

DISCUSSION

Need for study of Q-CFNS

The desire to more accurately reflect complicated and unpredictable information in contemporary mathematical and decision-making situations gives rise to the study of Q-complicated Fermatean Neutrosophic Sets. Conventional models in Neutrosophic Set Theory and Fuzzy Set Theory can depict uncertainty, but they frequently have drawbacks when handling contradicting information, periodic data, or higher degrees of vagueness. These theories are extended by Q-Complex Fermatean Neutrosophic Sets, which satisfy the Fermatean constraint while permitting truth, indeterminacy, and falsity memberships to take complex values. This makes it possible to express uncertain data with more accuracy and flexibility. Therefore, learning about this idea contributes to the development of more robust mathematical tools for applications where ambiguity and partial knowledge are common, like data analysis, artificial intelligence, pattern recognition, and decision-making.

Limitations of Q-CFNS

Q-Complex Fermatean Neutrosophic Sets offer a strong framework for managing uncertainty, but they are not without limitations. The model's mathematical complexity is increased by the use of complex numbers to represent truth, indeterminacy, and falsity membership values, which could make practical interpretation challenging. Furthermore, complex-valued membership computational processes can be laborious and call for sophisticated mathematical tools. Practical applications of Q-Complex Fermatean Neutrosophic Sets are still scarce when compared to current approaches in Fuzzy Set Theory and Neutrosophic Set Theory, and many operational techniques, including aggregation and similarity measurements, are still not fully standardised.

Future Scope of Q-CFNS

Notwithstanding these drawbacks, Q-Complex Fermatean Neutrosophic Sets present a substantial opportunity for further investigation. To increase their utility in challenging decision-making scenarios, future research can concentrate on creating novel aggregation operators, similarity metrics, and distance functions. This idea may potentially be extended by researchers to other mathematical structures including topological spaces, graphs, and algebraic systems. Furthermore, combining this model with cutting-edge technologies like machine learning and artificial intelligence may improve its capacity to handle ambiguous and imprecise data, increasing its application in domains like data analysis, engineering, and intelligent decision-support systems.





CONCLUSION

This work developed the idea of Q-Complex Fermatean Neutrosophic Sets and investigated its basic algebraic and operational properties. By adding complex-valued membership degrees while meeting the Fermatean constraint, the suggested framework expands on current models in Neutrosophic Set Theory and Fuzzy Set Theory. To provide a strong theoretical basis for this model, a number of algebraic operations and structural characteristics were developed and investigated. The findings demonstrate that, in comparison to previous fuzzy frameworks, Q-Complex Fermatean Neutrosophic Sets offer more flexibility in capturing uncertainty, indeterminacy, and inconsistent information. As a result, this work advances the creation of powerful uncertainty models and provides novel opportunities for further investigation, especially in the areas of aggregation operators, decision-making techniques, and other mathematical extensions.

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Antimicrobial Resistance : A Catastrophic Threat

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ABSTRACT

You don't know what you will find, you may set out to find one thing end up by discovering something entirely different"-ALEXANDER FLEMING Antimicrobial resistance (AMR) is a catastrophic threat to the society and to the life on earth. It represents a global threat not only to humans but also to animals, plants and environment sectors. AMR is extricable linked to over prescription of antibiotics in health sector, over the counter availability of the drugs, use of antibiotics in food -animal production, use in agriculture, use in veterinary health sector and poor management of waste. The present article highlights the global perspective of AMR and in detail about the Indian perspective and measures to control the spread of AMR at hospital level, industry level and at individual level as health care professional and patient. This article also gives in sight about the future directions which may stand useful in policy making to combat AMR.

Keywords: Anti microbialresistance, Global Threat, Indian perspective

INTRODUCTION

In an accidental discovery while experimentation, Sir Alexander Fleming noticed a wonder mold which can wipe off the bacteria from old discarded bacteria smeared dishes. He discovered that the active ingredient in the mold was "PENICILLIN"- the first antibiotic in the world.¹ This invention has led to the inception of a new era in the field of medical science. At the Noble prize award winning ceremony in 1945, Sir Alexander Fleming rightly said "The thoughtless person playing with PENICILLIN treatment is morally responsible for the death of man who succumbs



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to infection with PENICILLIN resistant organism” conferring how dangerous a world with excessive consumption of these would be, at the same time the microbes developed ways to counter this threat to their existence called the ANTIMICROBIAL RESISTANCE (AMR).² AMR threatens the prevention and treatment of an increasing range of infection caused by the microbes. Since infectious diseases constantly evolving and developing AMR it becomes imperative to examine the key socioeconomic and political factors that can add to threat of AMR in developing and developed nations.³ Effective antimicrobial drugs are pre-requisite for preventing patients from fatal infections but when the misuse of these drugs occurs, the bacteria change its response to the use of these medicines, thus developing antimicrobial resistance. Antimicrobial resistance is a rapidly evolving global

Health issue, being a catastrophic threat to the society and to the existence of all living beings present on this planet. Currently 7,00,000 people died due to drug resistance (WHO 2018)⁴ and it is estimated that by 2050, AMR could kill two million people per year, more than cancer and diabetes combined (House of Commons, AMR, 2018)⁵. Without urgent action we are heading towards post antibiotic era, in which common infections would once again kill. So, tackling antimicrobial resistance is a high priority on a global platform. Awareness of the seriousness of the situation and the need for urgent action is required at the highest political level globally, country level and above all at individual level. AMR is the crisis that must be managed with utmost urgency and we need to hasten the process of finding solutions. It needs to be mitigated timely.⁶

Historical Prespective

A summary of the historical progression of antimicrobial resistance is presented. (Figure 1) ^{7,8}

What is Antimicrobial Resistance (Amr)

Antimicrobial resistance happens when the germs like (Bacteria, fungi, protozoa, viruses) develop the ability to defeat the drugs. designed to treat them. AMR is a global threat and is crucial health concern for our coming generations.⁹ The death caused by resistant bacteria is more than 75,000 / year globally which is leading to a potential disaster on the future of world. If this post Antibiotics generation comes to pass, by 2050, it would kill more people than cancer daily their fate was predicted more than 70 years ago when the first antibiotic hit the market.

How is Antimicrobial Resistance Different from Antibacterial Resistance?

Antibiotic resistance occurs when bacteria transmute after subjection to an antibiotic used to prevent or treat a bacterial infection. Resistant bacteria cause infections that are difficult to treat than antibiotic -susceptible infections, raising the risk for failure or transmission of disease.¹⁰ In recent times, antibiotic- resistant bacteria have been accountable for infections such as pneumonia, tuberculosis, bacteremia, and gonorrhea becoming difficult and sometimes impossible to treat as antibiotic become less effective. (Figure 2)^{9,10}

Amr and its Types

AMR is broadly divided into two types¹¹

- Intrinsic resistance:¹²

The resistance of microorganism to an antibiotic due to its morphology or structure. It is mainly mediated by

- Activity of multi drug efflux pump
- Cellular envelope impermeability
- Lack of targets for drug action

e.g. Porin channels are required for activation of vancomycin but as gram positive bacteria has no porin channels so they are intrinsically resistant to vancomycin.¹³

- Acquired resistance: Acquired resistance develops when a new trait is expressed, often because of a genetic change that has been selected for in the setting of antibiotic exposure. Bacteria can also mediate tolerance to antibiotics independent of genetic change, such as with persister states or biofilm formation acquired antibiotic resistance can arise by multiple mechanisms but commonly involves altering the target site of the drug, enzymatically inactivating the drug, or preventing the drug from accessing its target. These mechanisms involve new genetic changes in the



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pathogen leading to heritable resistance. AMR can be acquired either by genetic mutation or by conjugation or transformation. In genetic mutation, the cell population is exposed to a drug and only the mutant microorganism survives and now this resistant cell will multiply and resistant population arises.e.g. streptococcus resistance.¹⁴

Antimicrobial Gene Transfer

Resistant gene can be transferred from one bacterium to the other either vertically or horizontally. In vertical transfer Resistant gene is transferred from one generation to another generation by reproduction, Bacteria may transfer resistant gene horizontally among the same species or even between different genus and species. It can occur through conjugation, transformation and transduction. In conjugation two microbial cells are connected to each other through a pilus (bridge) because of close proximity and if one bacterium has resistant plasmid it will transfer to another e.g. Ampicillin resistant gene. In transformation, bacteria encounter a DNA fragment containing a resistant gene e.g. Gram-negative bacteria encounter a fragment of DNA containing gentamycin resistant strain which is released from gram positive bacteria while lysis.¹⁵ Gene transfer is therefore a highly efficient mechanism for bacteria to evolve and adapt.¹⁶

Global Perspective of Amr

Antimicrobial Resistance has increased by 40% between 2000 and 2010. In 2015, world health assembly recognized the importance of antimicrobial resistance affecting public health systems and a Global Action Plan to fight antimicrobial resistance was made with 53 member states.¹⁷ WHO 2019 reported an increased incidence of antimicrobial resistance in low-income countries. At Global level WHO has laid down the formation of Glass AMR surveillance system to make strategies to tackle AMR. There is a growing antibiotic resistance in poultry, livestock, animals, agriculture, sewage and hospital waste water. UK is doing a lot with AMR reducing practices with better surveillance of antimicrobial use, resistance, public campaigns, finding of medicines and diagnosis and development.(AMR House of Commons Library,2017).¹⁸ Two campaigns to reduce inappropriate use of antibiotics were held in France and Belgium. “Antibiotics are not Automatic” campaign was launched in 2001 by France. Central Asian and Eastern European surveillance of Antimicrobial Resistance (CAESER) network by WHO originated in 2012 helps to strengthen AMR surveillance in whole of European region. They conduct technical training and workshops, exchange visits amongst countries; which are part of CAESER network.

Indian Perspective of Amr

India is among the lower socio-economic country group with the highest burden of the bacterial infections.¹⁹The mortality rate from infectious diseases in India is 417 per 1,00,000persons being highest in world. Thus, India has one of the highest rates of resistance to antimicrobial agents used both in humans and food animals. It is estimated that the consumption documented is by 103% from 2000-2015, the highest among low/middle income groups. Thus, India has now been designated as AMR capital in the world.²⁰India has become a part of Global Antimicrobial resistance research and development hub on September 12 2019. AMR is a cause of worry in developing nation like India where the burden of infectious disease is high and healthcare spending is low. Rapid increase in the resistance to the newer and more expensive and rising rate of AMR across multiple pathogens is an alarming situation for our country. Above that the injudicious use of antibiotics in livestock and food animals, poultry industry, and dairy sector has added to the burden of AMR. The need of the hour is to focus on awareness among consumers and providers. India has framed its “National Action Plan” 2017-2021 on April 2017 for sustained efforts against AMR for the coming 5 years. The “One Health Concept” adopted by the country highlights the inter- dependence of Humans, animals and environmental parameters for containment of AMR.²¹ A detailed timeline of antibiotic resistance can be found. (Table 1)²²

How Antimicrobial Resistance Develops

The susceptibility and resistance of a particular microorganism are not necessarily uniform in all the species. Level of resistance vary greatly with in related bacterial groups. Drugs fightmicroorganism and they respond with equal thrush. The strategies they use for the defense against antibiotics are the resistance mechanisms. Every microbe has





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an instruction loaded plasmid with in DNA which help bacteria to develop bacterial resistance and passing the instructions from one germ to another. The mechanisms are discussed in detail below:

- Destruction of antibiotic by enzymatic production: Resistance through beta lactamase enzyme occurs both in gram positive and gram negative.²³
 - In gram negative bacteria- The beta lactamases enter the cell wall through porin channels and destroy the beta lactam molecules before they reach their targets.
 - In gram positive bacteria – beta lactamases excreted extracellularly. inactivating the drug outside the cell.
- Restrict the access of the drug: The cell wall becomes impermeable to antibiotics either by limiting the number of entry ways for the drug or by altered porin channels which hinder the drug entrance.
- Alteration of the target site by mutation: The target site get affected by drugs because of alteration through mutations and cell wall become resistant to presence of efflux pump in the cell that actively exports tetracycline molecules and other drugs out of the cell as fast as they are transported or diffuse into the cell, The antibiotic cannot reach its target.²⁴
- PBP alteration through mutation in G+ve bacteria. The B-lactam can no longer bind to it and the cell becomes resistant to the drug. Also occurs in G-ve bacteria

Other causes:

- Chemical alteration of antibiotic molecule
- Changing metabolic pathways
- Changing membrane permeability
- Altering structural targets
- Infecting specific sites

The major causes of antimicrobial resistance are detailed. (Table 2)

Antimicrobial Resistance Threatens All (Interconnected Web)

Antibiotic usage is also not exclusive to humans. Every day antibiotics are used to treat livestock and fish to prevent infections. Similar to overuse in humans, uncontrolled use of antibiotics creates a reservoir of bacteria that could become resistant, thus rendering the antibiotic useless. The high volume of antibiotics in food-producing animals contributes to the development of antimicrobial-resistant bacteria, particularly in settings of intensive animal production.²⁵ In some countries, the total amount of antibiotics used in animals is 4 times larger than the amount used in humans. In many countries much of the antibiotics used in animals are for growth promotion and prevention of disease, and not to treat sick animals.²⁶

These bacteria can be transmitted from animals to humans via direct contact between animals and humans, or through the food chain and the environment. (Table 3,4) Antimicrobial-resistant infections in humans can cause longer illnesses, increased frequency of hospitalization, and treatment failures that can result in death. Some types of bacteria that cause serious infections in humans have already developed resistance to most or all of the available treatments and we are running out of treatment options for some types of infection. WHO recommends an overall reduction in use of antibiotics in food-producing animals to help preserve their effectiveness for human medicine. Many of the bacteria (such as Salmonella, Campylobacter and Escherichia coli) carried by animals can also cause disease in people. These bacteria, which are frequently antimicrobial-resistant, can contaminate our food supply from farm to fork, such as through slaughtering and processing. Fruits and vegetables may also be contaminated by such bacteria at the farm or later through cross-contamination. We know about this because we can link drug-resistant bacteria isolated from sick people to an agricultural source through DNA fingerprinting.^{25,26} Over 400 000 people die each year from foodborne diseases, with over one-third of these deaths occurring in children under 5 years of age. The vast majority of foodborne illnesses are caused by microbes, including bacteria, according to WHO estimates. If these bacteria become resistant to antibiotics, it will become impossible to treat them and more people will die from foodborne diseases. In common with many important public health issues, due to ethical and technical complexity, there are very few randomized controlled studies that have assessed associations between use of antibiotics in food-producing animals and risks of human exposure to and infection by drug-resistant zoonotic pathogens.²⁷ Most of the





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supporting scientific evidence the best available was collected from epidemiological studies, surveillance programs and observational studies.²⁸(Figure 3)

Possible Ways to Control Amr

Inadequate access to clean water, sanitation, hygiene in community settings (schools, farms), health care facilities, food production, food safety and waste management, diagnostics and vaccines, over prescription of antibiotics, maintenance of self-hygiene are all contributing factors for development and spread of antimicrobial resistance. Stronger Political leadership advocacy, coordination and accountability are needed at all levels. The misuse of antibiotics is putting us all at risk. A collaborative multidisciplinary approach is the need of time to combat AMR. Effective strategies need to be planned at different level - global, national, community, hospital and individual levels.²⁹ Surveillance and research form the base core area to strength knowledge and evidence.

At Hospital Level: The health policy maker makes this a priority in India. Strengthening of infection control in health care facilities marks an important step. The aim is to minimize the disease transmission finally decreasing the transmission of AMR. To prevent AMR spread, control measures must be designed to reduce the spread of resistant pathogens. These measures include:

- Establishment of Infection Control and Prevention Unit (IPC unit).^{30,31} An infection control committee should work on good hygiene practices, rational antimicrobial use, discard of medicines. Display of the revised list of antimicrobials published by WHO 2017 should be there with doctors prescribing the antibiotics in the hospital and the pharmacist dispensing the antibiotics in the hospital. WHO recommends to immediately stop the use of antimicrobials on WHO list of highest priority critically important drugs.
- Surveillance of Antibiotic resistance: - Strengthening surveillance and regulatory framework can help us to achieve our goal. To generate data on antimicrobial use and AMR, which may also improve antimicrobial prescribing habits and standard empirical treatment guidelines.³²
- Diagnostic Stewardship: - Increasing awareness among all stakeholders is the biggest challenge that needs to be addressed. Appropriate use of microbiological diagnosis to guide therapeutic decisions. Good microbiological practice should be followed in the hospital which includes speedy reporting and rapid diagnostics to guide prescribing which can be achieved through direct communication of clinician with lab personnel.³¹
- Others: Hospitals can also launch AMR awareness programmes or NukkadNataks in the reception area where the focus is to increase the awareness of this crisis among the patients visiting the hospital. Hospitals with teaching facilities can serve as game changer as they are the ones which can sensitize the upcoming doctors, pharmacist, nurses, dentist and other health workers regarding the catastrophic threat of AMR. Knowledge of AMR and rationale use of antibiotics could be reinforced as an integral part of their syllabus. Long term research projects can be undertaken by such institutes for the betterment and innovation in the field.³³

At Patient Level³⁰ - The most significant contribution by a patient in this aspect will be to use antibiotics only when prescribed by certified health professional and never self-medicate themselves. Patient education regarding use of established regime for antimicrobial to prevent AMR. Patient should be aware of ineffectiveness of antimicrobial in viral infections, which can limit the inappropriate use of antimicrobials. Empower the public to ask questions regarding the appropriateness of treatment. Compliance can improve infection control, thus directly combating AMR. Celebrity Power can be a big success for awareness among public regarding AMR in India. Importance of hygiene and preventing infection spread to other members in the family by simple measures.

- Preparing food Hygienically
- Avoid close contact with sick
- Practice Safe Sex
- Following WHO five keys to safer food: Safe water, keep raw and cooked food separately, cook thoroughly, safe temperature and safe food





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At Industry level³¹- India has a poorly regulated industrial setup may it be pharmaceutical, food, poultry, animal, agriculture etc.

- Poorly regulated pharmaceutical industry means antibiotics are freely available to those who can afford them. Pharma industry must take it on them to distribute drug in responsible manner. They should emphasize on quality medicine i.e. developing and updating quality standards for medicines and detect and remove substandard antimicrobials from market.
- Antibiotic use in animals –WHO strictly called for legislation to minimize antimicrobial usage in animals. Rampant antibiotics use in Poultry/food industry are often pass on to humans
- Antibiotic in drinking water^{34,35}- Lack of clean water is another contributing factor to AMR. That may be because of improper use of antibiotics in agriculture effluent from hospital waste gets mixed up thus causing transfer of resistance conferring mechanism.
- Antibiotic Innovations- The amount of economic burden will be enormous if the crucial medicines become ineffective. India has to invest in drug innovations to combat AMR so that we can save our future generations. Thus we need to prioritize our national action plan and invest in antibiotic research and development.
- Limit to pharmaceutical promotions of antibiotics³⁶: Promotion should be banned, so that direct consumer connection is not there and advertisement should follow the standard of drug promotion. A list of essential medicine can be laid down according to three categories: - Access, watch, revise.
- Improved surveillance of AMR in agricultural settings for improved understanding of the relationship between antimicrobial drugs and pesticide use. Regulatory framework for antimicrobial drug use in agriculture and veterinary medicine.³⁷

At Healthcare worker level: Healthcare workers may be physician, surgeon, microbiologist, pharmacologist, nurses, dentist are all stakeholders, as they are the one who are in direct contact with the patient and can influence the patient. They play a major role in Preventing and controlling the spread of AMR.

- Education-of the patient and the professional regarding AMR
- Aseptic practices: ensure that their hands, instruments, environment is clean and sterilized.
- Rational use of Antibiotics.³⁸ Antibiotic over prescription is due to poor understanding of its dangers and contribution to AMR.
- AMR Awareness programmes and sensitization programmes
- Make it as a thumb rule for as many cases as possible to give prescription following culture sensitivity only.³⁹
- Must immediately report AMR to surveillance teams
- Practitioners of alternative medicines should not prescribe antibiotics.

At Pharmacist level: A key person to educate patients about the use of antimicrobial is pharmacist. Knowledge of AMR at Pharmacist level directly improves the utilization of Antibiotics. Antibiotics can only be handed over to patient on prescription can play a strong role in pharmacist stewardship program. Pharmacist should never dispense any medicine on their own diagnosis. Instead, they should guide and refer the patient to physician. The global problem of AMR cannot be dealt on country basis or region basis. We live in an interconnected world, so humans, animals, food, microorganisms travel along with us. Thus, to curb the rise of AMR, global action response is necessary.

Organizations in India to Control Amr

National Task Force on AMR containments was formed in 2010 which was followed by the adoption of National policy for containment of AMR in 12th 5-year plan in 2011 at Jaipur.⁴⁰ In 2013, AMR monitoring networks were initiated by the Indian Council of Medical Research (ICMR). The National Centre for Disease Control also initiated their activities to control AMR in India in year 2014.⁴¹ The National Health Policy 2017 calls for a rapid standardization of guidelines regarding antibiotic use, limiting the use of antibiotics as OTC medications, banning or





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restricting the use of antibiotics as growth promoters in animal livestock, and pharmaco-vigilance including prescription audits inclusive of antibiotic usage in the hospital and community.⁴² The political commitment came from the honorable Prime Minister Sh. Narendra Modi Ji himself. Public education came to the forefront with prime minister directly addressing the nation in his 2016 radio address highlighting the issue of antibiotic resistance and the launch of the “Red Line” campaign. A red line on the antibiotic packaging is aimed to draw public attention to the dangers of its misuse and has been lauded internationally.⁴⁰ The Government recently adopted a National Action Plan (NAP) on AMR in 2017. The strategic objectives of NAP-AMR are aligned with the global action plan based on national needs and priorities. In addition to the five priorities of Global Action Plan on AMR, India has a sixth priority dealing with India's leadership on AMR.

Control and Prevention

Strengthen the knowledge and evidence base through surveillance and research detection:

- Conduct studies to assess the relationship between availability of poor- quality medicines and presence of drug-resistant microbes
- Optimize the use of antimicrobial medicines in human and animal health

Prevention:

- Strengthen and optimize registration and market authorization systems within the national medicines regulatory authority
- Promote and operationalize principles of reliance on stringent regulatory authorities and regional harmonization
- Ensure sufficient WHO prequalified sources of medicines
- Ensure compliance with current good manufacturing practices
- Ensure good supply chain practices including proper dispensing
- Procure medicines from WHO prequalified sources

Detection

- Monitor antimicrobial quality through strategic and risk-based post- marketing surveillance programmes
- Strengthen national quality control laboratories to comply with ISO 170125 or WHO prequalification standards
- Ensure routine inspection of products imported and utilize appropriate screening technologies

Response:

- Use data on medicines quality to inform and take regulatory action
- Develop mechanism(s) for communicating notices of poor-quality antimicrobials with relevant stakeholders

What Needs to be Done – Defense Strategies

Antimicrobial resistance has been found in all regions of the world. Modern travel of people, animals, and goods means antimicrobial resistance can easily spread across borders and continents. Fighting this threat is a public health priority. It requires a collaborative global approach across sectors to detect, prevent, and respond to these threats when they occur. Every country can take steps to slow antimicrobial resistance. Commit to setting goals across multiple sectors, including:

- Healthcare
- Food
- Communities (local and global)
- Environment (soil and water)

Create and implement a comprehensive plan with a One Health approach to achieve those goals, and track progress. Every country plan can consider the following actions to prevent resistant infections and their spread:

- Implement infection prevention and control practices
- Improve antibiotic use, including ensuring access



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- Implement data and tracking systems to track resistance, guide prevention strategies, and report results at the local and global level
- Improve lab capacity to identify resistant bacteria

In addition to these important actions, it is also critical to join the global effort to develop new drugs, diagnostics, vaccines, and therapeutics to treat infections.

- Implementing programs in healthcare settings to prevent the spread of resistance (infection prevention and control programs) and support the appropriate use of antimicrobials (antimicrobial stewardship programs)
- Enhancing laboratory capacity to detect and report resistance that have global health implications
- Establishing or strengthening national tracking systems to respond rapidly to outbreaks, identify emerging pathogens, and track trends
- Supporting a national network of travel clinics to better understand the spread of resistance across the U.S. to ultimately improve the health of international travelers

Six strategic priorities have been identified under the NAP-AMR⁴⁰:

- Improving awareness and understanding of AMR through effective communication, education, and training;
- Strengthening knowledge and evidence through surveillance;
- Reducing the incidence of infection through effective infection prevention and control;
- Optimizing the use of antimicrobial agents in health, animals, and food;
- Promoting investments for AMR activities, research, and innovations; and
- Strengthening India's leadership on AMR.

Future Directions and Suggestions

- All the stakeholders such as policy makers, planners, practitioners, pharmacists and dispensers, institution managers, pharmaceutical industries, department of animal husbandry, faculty members and students of medical colleges must adopt an integrated approach to effectively prevent the antimicrobial resistance.
- Medical practitioners can play important role while prescribing suitable antibiotics to their patients.
- Pharmacist can help by dispensing appropriate antibiotic to the patients.
- Implementation of proper surveillance mechanisms by government agencies.
- Every healthcare organization must form their guidelines to combat these issues.
- Patients must also be informed by their physicians about the harmful effects of antibiotics and its self-medication.
- Promotion about AMR among general population through television commercials and radio channels will be beneficial.
- Faculty members in medical colleges can create guidelines for their institution or at department level for appropriate usage of antibiotics.
- There must be monitoring at district level and state levels by conducting regular surveys and this data must be shared among all the stakeholders.
- Legal actions must be implemented on the defaulters.

CONCLUSION

Microbes adapt to environment and change for their survival. Microbes, not humans or animals became resistant to antibiotics. AMR crisis demands immediate action as there is a rapid increase in global incidence of infectious diseases. Amr leads to higher medical costs, prolonged stay in hospital, increased length of treatment and increased mortality. AMR is one health problem which is not only connected to the health of the people but also of animals and environment.





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Table 1: Time line of antibiotic resistance

Drug	Year of release	Year of resistance
Pencillin	1941	1942
Streptomycin	1947	1947
Tetracycline	1952	1956
Vancomycin	1958	1988
Amphotericin	1959	2016
Methicillin	1960	1961
Nalidixic acid	1964	1966
Gentamycin	1967	1969
Vancomycin	1972	1978
Cephalosporins	1980	1983
Azithromycin	1980	2011
Imipenem	1985	1996
Ciprofloxacin	1987	2007
Fluconazole	1988	1988





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Linezolid	1998	1999
Caspofungin	2001	2004
Ceftazimide	2015	2015

Table 2: Major Causes of Antimicrobial Resistance

Major causes of antimicrobial resistance
1. Using antibiotics in viral infections
2. Inappropriate or mis use of antibiotics
3. Exposure from food source
4. Not completing the course of antibiotics as prescribed

Table 3: Spread Of Antibiotic Resistance In Humans

Spread of antibiotic resistance in humans
Patient to patient
Health care staff to patient
Patient to other people
Health care staff to other people

Table 4: Spread Of Antibiotic Resistance From Animals To Humans

Spread of antibiotic resistance from animals to humans
Animal products
Through environment
Contaminated water and soil
Prepared food through contaminated surfaces

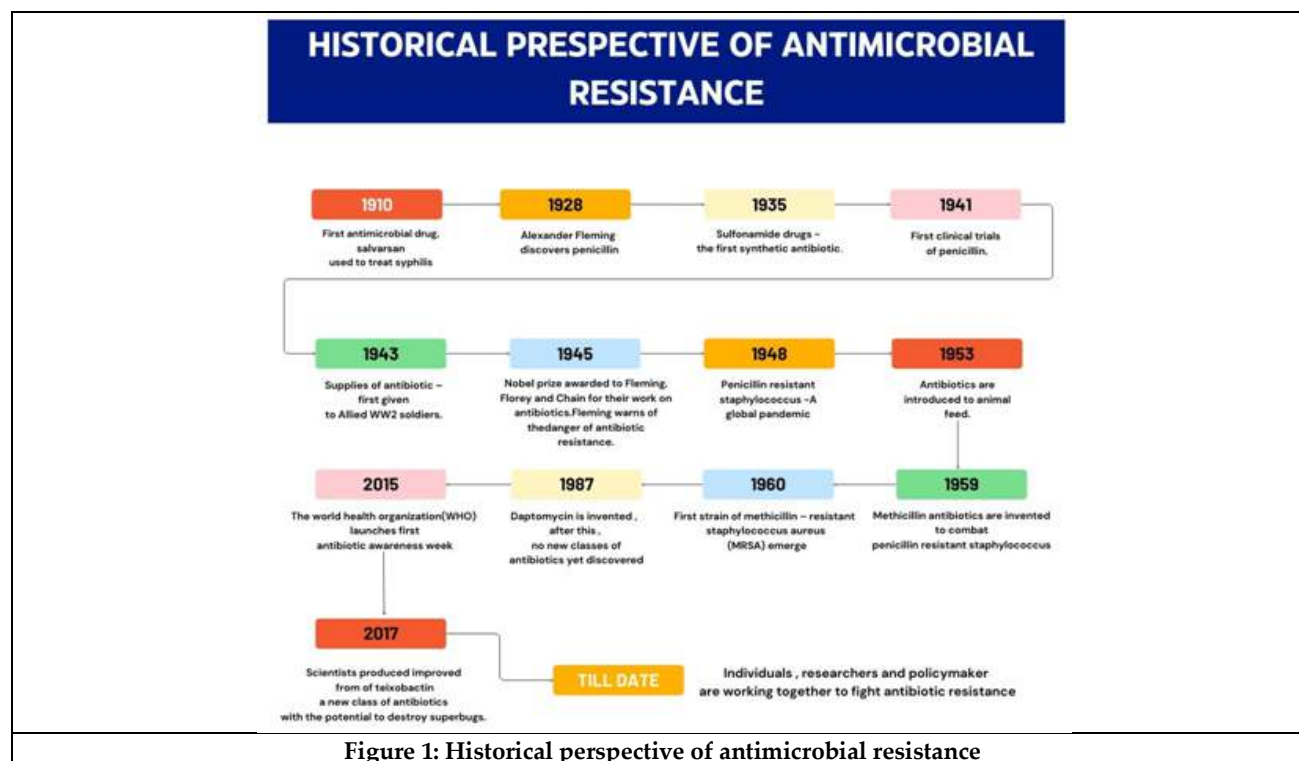


Figure 1: Historical perspective of antimicrobial resistance





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Characteristics	Antibacterial	Antimicrobial
Definition	An agent that destroys bacteria and fungi, suppresses their growth or their ability to reproduce.	An agent that destroys microorganisms, suppresses their growth or their ability to reproduce.
Types	Antibiotics and chemotherapeutics.	Antibacterial agents, antivirals, antimycotic agents, antiparasitic agents, essential oils, disinfectants and, antiseptics.
Use	Used in infections with bacterial or mycotic etiology.	Used for the treatment of bacterial, viral, fungal, and parasitic diseases, for disinfection of skin, mucous membranes, medical instruments, clothing, water, etc.
Examples	Aminoglycosides, amphenicols, glycopeptide antibiotics, carbapenems, macrolides, penicillins, quinolones, etc.	Carbapenems, macrolides, penicillins, quinolones, oseltamivir, rimantadine, amantadine, ketoconazole, fluconazole, etc.

Figure 2: Antimicrobial vs anti-Bacterial resistance

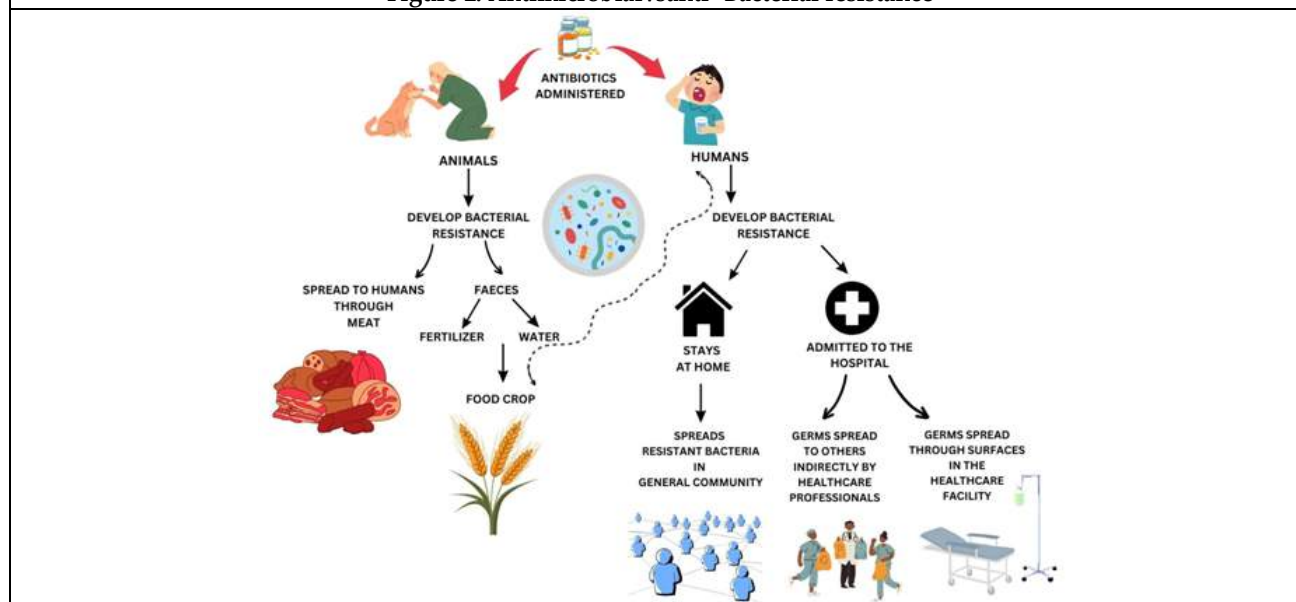


Figure 3: Interconnected web of amr

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RESEARCH ARTICLE

A New Perspective Way on Approaching Chatterjea Mapping in Multiplicative Modular Metric Space

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ABSTRACT

This paper brings a new approach that is establishing the concept of connecting metric and modular into multiplicative modular metric spaces. this is a extension work of Elif Kaplan et al., and Satit Saejung which is originally defined distances between points and images using only positive real numbers. And applying well-established contraction of Chatterjea contraction, using the methodology of Banach's successfully proved the existence and uniqueness of fixed point. This significant research not only provides a robust theoretical foundation but also demonstrates the practical applicability of these theorems, marking a notable advancement in the field of metric spaces.

Keywords: Unique Fixed point, Chatterjea Mapping, Cauchy Sequence, Two mappings, Convergent, Complete Multiplicative Modular Metric Space.

INTRODUCTION

The Banach Fixed Point Theorem is a foundational tenet of analysis, serves as the progenitor for a vast lineage of fixed point theorems within the domain of metric spaces. Its elegant and constructive proof, which guarantees a unique fixed point for any contraction mapping on a complete metric space, laid the groundwork for an expansive eld of inquiry. The conceptual metamorphosis from linear spaces to modular spaces was pioneered by W. Orlicz, who posited that a linear space could be imbued with the structure of a modular space through the adherence to four axiomatic properties. A seminal contribution came from J. Musielak et al., who formally introduced modular





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functional denoted by φ_{pq} within a real linear space X . Their work also delineated the conditions for introducing an F -norm in specific subspaces of X . A pivotal advancement was made by Vyacheslav V. Chistyakov et al., who articulated the notion of a modular on an arbitrary set, thereby inaugurating the theory of modular metric spaces. This conceptual leap facilitated the development of a novel metric space for functions of bounded generalized variation, with their range residing in metric semi-groups and abstract convex cones. In a direct extension of this paradigm, Kitima Kuaket et al. expounded upon the ideas of Kirk and Xu, meticulously examining asymptotic pointwise contractions within the modular metric space framework. Concurrently, Parin Chaiparya et al. established Geraghty-type fixed point theorems for these spaces, furnishing a definitive solution for a non-homogeneous linear parabolic partial differential equation. Subsequent to this, they also elucidated foundational properties of subsets within modular metric spaces and presented

several fixed point theorems for multi valued contraction mappings. The practical utility of these theoretical constructs was evinced by Umit Aksoy et al., who successfully applied the modular metric space setting to address anti-periodic boundary value problems for nonlinear first-order differential equations of Carbohydrate's type. The same researchers, Umit Aksoy et al., introduced Meir-Keeler type contraction mappings to the evolving lexicon of modular metric spaces. Multiplicative metric spaces were introduced by Bashirov et al. After that many researchers worked on multiplicative metric spaces and introduced many ideas in that space; see more ideas about multiplicative metric spaces. Taking metric and modular into multiplicative modular metric space and given a contemporary and notable contribution by Elif Kaplan et al. Unveiled a ground breaking concept the w -multiplicative modular metric space. This novel paradigm represents a synthesis of two distinct metric spaces. Capitalizing on this innovation, After that some corrections and clarifications given by Saejung, S we have extended their inquiry to encompass Chatterjea contractions, presenting new fixed point theorems that build upon and significantly augment preceding work.

RESULTS AND DISCUSSION

Definition 1. Assume Ω be a non void set then $\mu : (0, \infty) \times \Omega \times \Omega \rightarrow [1, \infty)$ be a function this fulfils the succeeding characteristic. for all $\Omega_1, \Omega_2, \Omega_3 \in \Omega$ and $\zeta, \vartheta > 0$

- $\mu(\zeta, \Omega_1, \Omega_2) \geq 1$ when $\mu(\zeta, \Omega_1, \Omega_2) = 1$ and $\Omega_1 = \Omega_2$
- $\mu(\zeta, \Omega_1, \Omega_2) = \mu(\zeta, \Omega_2, \Omega_1)$
- $\mu(\zeta\vartheta, \Omega_1, \Omega_2) \leq \mu(\zeta, \Omega_1, \Omega_3) \cdot \mu(\vartheta, \Omega_3, \Omega_2)$

then (Ω, μ) is said to be multiplicative modular metric spaces (MMMS).

Definition 2. Assume $\zeta > 0$ and (Ω, μ) be a MMMS. A open ball $\varpi(\zeta, c, \epsilon)$ with radius $\epsilon > 1$ and center $c \in \Omega$ is defined as

$$\varpi(\zeta, c, \epsilon) = \{G \in \Omega, \mu(\zeta, c, G) < \epsilon\}.$$

Likewise, a closed ball can be trace as

$$\varpi(\zeta, c, \epsilon) = \{G \in \Omega, \mu(\zeta, c, G) \leq \epsilon\}.$$

Definition 3. Let $\zeta > 0$ and (Ω, μ) be a MMMS. Take $c \in \Omega$. If there exists $\epsilon > 1$ such that $\varpi(\zeta, c, \epsilon) \subset C$, then $c \in C$ is called a interior point of C . The set of all interior points of C , and it is specified by $\text{int}(C)$.

Definition 4. Let (Ω, μ) be a MMMS. A point $c \in \Omega$ is said to be a cluster points and $D \subset \Omega$ if and only if

$$\varpi(\zeta, c, \epsilon) \setminus \{c\} \cap D \neq \emptyset \text{ for every } \epsilon > 1.$$

The set of all limit points of D is denoted by D' .

Definition 5. Assume a MMMS (Ω, μ) . A set $\mathfrak{d} \subset \Omega$ is stated to be closed in (Ω, μ) if $\mathfrak{d}$ consists all of its limit points.

Definition 6. Let (Ω, μ_{Ω_1}) , and (Ω, μ_{Ω_2}) be two MMMS and $E : \Omega \rightarrow \Omega$ be a function. If τ fulfils the condition that for each $\epsilon > 1$ and there exists $\delta > 1$ such that





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$$\mathfrak{E}(\varpi(\zeta, c, \delta)) \subset \varpi(\zeta, \mathfrak{E}c, \epsilon),$$

using this condition we know that τ is a continuous at $c \in \Omega$.

Definition 7. Assume a MMMS (Ω, μ) with a sequence $\{c_n\}$ in Ω and an member $c \in \Omega$. The sequence $\{c_n\}$ is said to be convergent to c , is formulated as $c_n \rightarrow c$ ($n \rightarrow \infty$), if for any open ball $\varpi(\zeta, c, \epsilon)$ there exists a natural number N then $n \geq N$ leads to $c_n \in \varpi(\zeta, c, \epsilon)$.

Definition 8. Let $\{c_0\}$ be a sequence in Ω , and let (Ω, μ) be a MMMS. The sequence $\{c_0\}$ is called a Cauchy sequence if and only if $\mu(\zeta, c_0, \Omega_1) \rightarrow 1$ as $\nu, \Omega_0 \rightarrow \infty$.

Definition 9. Let (Ω, μ) be a MMMS. If every Cauchy sequence in Ω is said to be converges to a point of Ω , then Ω is called a complete space.

Definition 10. Let (Ω, μ) be a MMMS. Define $\mathfrak{E}_\mu = \{\mathfrak{C} \subset \Omega : c \in \mathfrak{C} \iff \exists \zeta > 0, \epsilon > 1 \text{ such that } \varpi(\zeta, c, \epsilon) \subset \mathfrak{C}\}$. Then $(\Omega, \mathfrak{E}_\mu)$ is a topological space

Definition 11. Let (Ω, μ) be a MMMS. If for any $c, \mathfrak{G} \in \Omega$ and $\zeta \in (0, \infty)$ then there exists a unchanging number $\xi \in [0, 1)$ then

$$\mu(\zeta, \mathfrak{E}c, \mathfrak{E}\mathfrak{G}) \leq [\mu_\zeta(c, \mathfrak{G})]^\xi$$

then the function $\mathfrak{E} : \Omega \rightarrow \Omega$ is termed as multiplicative modular contraction (MMC).

Definition 12. Let (Ω, μ) be a MMMS. If for any $c, \mathfrak{G} \in \Omega$ and $\zeta \in (0, \infty)$ then there exists a real stationary point $\xi \in [0, 1)$ such that

$$\mu(\zeta, \mathfrak{E}c, \mathfrak{E}\Omega_1) \leq [\mu(\zeta, c, \mathfrak{E}\Omega_1)\mu(\zeta, \Omega_1, \mathfrak{E}c)]^\xi \text{ for all } \nu, \Omega_1 \in \Omega,$$

then the mapping $\mathfrak{E} : \Omega \rightarrow \Omega$ is called a multiplicative modular Chatterjea contraction.

Theorem 1.

Consider $\mu : (1, \infty) \times \Omega \times \Omega \rightarrow [1, \infty]$ is a(MMMS) on a nonvoid set Ω and the space (Ω, μ) is complete. And $\mathfrak{E} : \Omega \rightarrow \Omega$ is Chatterjea contraction then there exists a constant $\xi \in (0, 1/2)$ for all $\Omega_1, p \in \Omega$ and all $\zeta > 1$:

$$\mu(\zeta, \mathfrak{E}\Omega_1, \mathfrak{E}p) \leq (\mu(\zeta, \Omega_1, \mathfrak{E}c) \cdot \mu(\zeta, c, \mathfrak{E}\Omega_1))^\xi.$$

Then the counterparts are true :

- when $\Omega_0 \in \Omega$ such that $\sup\{\mu(\zeta, \Omega_0, \mathfrak{E}^n\Omega_0) : n \geq 0\} < \infty$ for all $\zeta > 1$.
- if μ takes only finite value then $\mathfrak{E}$ has unique fixed point.

Proof. We prove the equivalence in two parts.

(ii) $\Rightarrow$ (i)

Assume that statement (ii) holds true. That is, $\mathfrak{E}$ has a fixed point.

Then there exists some point $\nu \in \Omega$ such that $\mathfrak{E}\nu = \nu$.

We now need to show that statement (i) holds true.

That is, we must find a point $\Omega_0 \in \Omega$ such that for every $\zeta > 1$, and $\sup\{\mu(\zeta, \Omega_0, \mathfrak{E}^n\Omega_0) : n \geq 0\}$ is finite.

Choose $\Omega_0 = \nu$.

Since ν is a fixed point of $\mathfrak{E}$,

we have $\mathfrak{E}\nu = \nu$.

So applying $\mathfrak{E}$,

$$\mathfrak{E}^n\Omega_0 = \mathfrak{E}^n\nu = \nu \text{ for all } n \geq 0.$$

Now compute the modular distance

$$\mu(\zeta, \Omega_0, \mathfrak{E}^n\Omega_0) = \mu(\zeta, \nu, \nu).$$

By def of 5, this statement shows $\mu(\zeta, \Omega_1, \Omega_1) = 1$ for all $\Omega_1 \in \Omega$ and all $\zeta > 1$, we have

$$\mu(\zeta, \nu, \nu) = 1.$$

So every $n \geq 0$ and $\zeta > 1$, $\mu(\zeta, \Omega_0, \mathfrak{E}^n\Omega_0) = 1$.





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The set $\{\mu(\zeta, \Omega_0, \mathfrak{E}^n \Omega_0) : n \geq 0\} = \{1, 1, 1, \dots\}$.

The supremum of this set is 1, which is finite

$$\sup\{\mu(\zeta, \Omega_0, \mathfrak{E}^n \Omega_0) : n \geq 0\} = 1 < \infty.$$

Since this holds for every $\zeta > 1$, condition (i) is satisfied.

So (ii) $\Rightarrow$ (i) is proved

(i) $\Rightarrow$ (ii)

Assume that statement (i) holds true. That is, there exists a point $\Omega_0 \in \Omega$ such that for every $\zeta > 1$

$$(\Omega_0, \zeta) := \sup\{\mu(\zeta, \Omega_0, \mathfrak{E}^n \Omega_0) : n \geq 0\} < \infty.$$

Take a sequence $\{\Omega_n\}_{n=0}^\infty$ in Ω by

$$\Omega_n = \mathfrak{E}^n \Omega_0.$$

So, Ω_0 is the starting point,

$$\Omega_1 = \mathfrak{E} \Omega_0$$

$$\Omega_2 = \mathfrak{E}^2 \Omega_0$$

$$\Omega_3 = \mathfrak{E}(\Omega_1),$$

And so on

We now show that this sequence $\{\Omega_n\}$ is of Chatterjea contraction.

That is, for every $\zeta > 1$, there exists $\xi \in (0, 1/2)$ such that for all $n, m \geq 0$

$$\mu(\zeta, \Omega_{n+1}, \Omega_{m+1}) \leq (\mu(\zeta, \Omega_n, \Omega_{m+1}) \cdot \mu(\zeta, \Omega_m, \Omega_{n+1}))^\xi.$$

By definition, $\Omega_{n+1} = \mathfrak{E}(\Omega_n)$ and $\Omega_{m+1} = \mathfrak{E}(\Omega_m)$.

Since $\mathfrak{E}$ is a Chatterjea contraction we have

$$\mu(\zeta, \mathfrak{E} \Omega_n, \mathfrak{E} \Omega_m) \leq (\mu(\zeta, \Omega_n, \mathfrak{E} \Omega_m) \cdot \mu(\zeta, \Omega_m, \mathfrak{E} \Omega_n))^\xi.$$

Substituting $\mathfrak{E} \Omega_m = \Omega_{m+1}$

and $\mathfrak{E} \Omega_n = \Omega_{n+1}$, we get

$$\mu(\zeta, \Omega_{n+1}, \Omega_{m+1}) \leq (\mu(\zeta, \Omega_n, \Omega_{m+1}) \cdot \mu(\zeta, \Omega_m, \Omega_{n+1}))^\xi.$$

We now show that $\{\Omega_n\}$ is a Cauchy sequence.

Take $\lim_{n, m \rightarrow \infty} \mu(\zeta, \Omega_n, \Omega_m) = 1$ for all $\zeta > 1$.

From assumption (i),

we know that

$$\mu(\zeta, \Omega_0, \Omega_1) = \mu(\zeta, \Omega_0, \mathfrak{E} \Omega_0)$$

$$\leq (\Omega_0, \zeta) < \infty$$

for all $\zeta > 1$.

we proved $\mu(\zeta, \Omega_0, \Omega_1) < \infty$ for all $\zeta > 1$, then the sequence is Cauchy.

Therefore, $\{\Omega_n\}$ is Cauchy. Since (Ω, μ) is complete, every Cauchy sequence converges to a point in Ω . So there exists a point $\mathfrak{o} \in \Omega$ such that

$$\lim_{n \rightarrow \infty} \mu(\zeta, \Omega_n, \mathfrak{o}) = 1 \text{ for all } \zeta > 1.$$

We now prove that $\mathfrak{o}$ is a fixed point of $\mathfrak{E}$,

i. e., $\mathfrak{E} \mathfrak{o} = \mathfrak{o}$

We must show that $\mu(\zeta, \mathfrak{o}, \mathfrak{E} \mathfrak{o}) = 1$ for all $\zeta > 1$.

Fix an arbitrary $\zeta > 1$. Consider the parameter $\zeta^2 > 1$. By the triangle inequality

$$\mu(\zeta^2, \mathfrak{o}, \mathfrak{E} \mathfrak{o}) \leq \mu(\zeta, \mathfrak{o}, \Omega_{n+1}) \cdot \mu(\zeta, \Omega_{n+1}, \mathfrak{E} \mathfrak{o}).$$

Take $\limsup$ as $n \rightarrow \infty$ on both sides. Since n independent we prove that

$$\mu(\zeta^2, \mathfrak{o}, \mathfrak{E} \mathfrak{o}) \leq \limsup_{n \rightarrow \infty} [\mu(\zeta, \mathfrak{o}, \Omega_{n+1}) \cdot \mu(\zeta, \Omega_{n+1}, \mathfrak{E} \mathfrak{o})].$$

$$\leq \left(\limsup_{n \rightarrow \infty} \mu(\zeta, \mathfrak{o}, \Omega_{n+1}) \right) \cdot \left(\limsup_{n \rightarrow \infty} \mu(\zeta, \Omega_{n+1}, \mathfrak{E} \mathfrak{o}) \right)$$

Since $\Omega_n \rightarrow \mathfrak{o}$, the subsequence Ω_{n+1} also converges to $\mathfrak{o}$. Therefore

$$\lim_{n \rightarrow \infty} \mu(\zeta, \mathfrak{o}, \Omega_{n+1}) = 1$$





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$$\Rightarrow \limsup_{n \rightarrow \infty} \mu(\zeta, v, \Omega_{n+1}) = 1$$

Take $\Omega_{n+1} = \mathbb{E}(\Omega_n)$, so

$$\mu(\zeta, \Omega_{n+1}, \mathbb{E}v) = \mu(\zeta, \mathbb{E}\Omega_n, \mathbb{E}v).$$

Apply the Chatterjea contraction to Ω_n and v

$$\begin{aligned} \mu(\zeta, \mathbb{E}\Omega_n, \mathbb{E}v) &\leq (\mu(\zeta, \Omega_n, \mathbb{E}v) \cdot \mu(\zeta, v, \mathbb{E}\Omega_n))^\xi \\ &= (\mu(\zeta, \Omega_n, \mathbb{E}v) \cdot \mu(\zeta, v, \Omega_{n+1}))^\xi. \end{aligned}$$

Take the *limsup* as $n \rightarrow \infty$

$$\begin{aligned} \limsup_{n \rightarrow \infty} \mu(\zeta, v, \Omega_{n+1}, \mathbb{E}v) &\leq \limsup_{n \rightarrow \infty} [(\mu(\zeta, \Omega_n, \mathbb{E}v) \cdot \mu(\zeta, v, \Omega_{n+1}))^\xi] \\ &\leq \left(\left(\limsup_{n \rightarrow \infty} \mu(\zeta, \Omega_n, \mathbb{E}v) \right) \cdot \left(\limsup_{n \rightarrow \infty} \mu(\zeta, v, \Omega_{n+1}) \right) \right)^\xi. \end{aligned}$$

We already know $\limsup_n \mu(v, v, \Omega_{n+1}) = 1$.

So $\limsup_n \mu(\zeta, \Omega_n, \mathbb{E}v)$, apply the triangle inequality

$$\mu(\zeta, \Omega_n, \mathbb{E}v) \leq \mu(\zeta, \Omega_n, v) \cdot \mu(\zeta, v, \mathbb{E}v).$$

$$\begin{aligned} \limsup_{n \rightarrow \infty} \mu(\zeta, \Omega_n, \mathbb{E}v) &\leq \limsup_{n \rightarrow \infty} \mu(\sqrt{\zeta}, \Omega_n, v) \cdot \mu(\sqrt{\zeta}, v, \mathbb{E}v) \\ &= 1 \cdot \mu(\sqrt{\zeta}, v, \mathbb{E}v). \end{aligned}$$

$$\begin{aligned} \limsup_{n \rightarrow \infty} \mu(\zeta, \Omega_{n+1}, \mathbb{E}v) &\leq \left((\mu(\sqrt{\zeta}, v, \mathbb{E}v) \cdot 1) \right)^\xi \\ &= (\mu(\sqrt{\zeta}, v, \mathbb{E}v))^\xi \end{aligned}$$

Add every thing

$$\mu(\zeta^2, v, \mathbb{E}v) \leq 1 \cdot \mu(\zeta, v, \mathbb{E}v)^\xi.$$

Let

$$\mu(\zeta^2, v, \mathbb{E}v) \geq 1$$

$$\mu(\sqrt{\zeta}, v, \mathbb{E}v) \geq 1$$

$$\mu(\zeta^2, v, \mathbb{E}v) \leq \mu(\sqrt{\zeta}, v, \mathbb{E}v)^\xi.$$

But similarly, we can apply the same logic to $\mu(\sqrt{\zeta}, v, \mathbb{E}v) \leq (\mu(\zeta^{\frac{1}{4}}, v, \mathbb{E}v))^\xi$ and so on.

Taking up to k iterations, we get

$$\mu(\zeta^2, v, \mathbb{E}v) \leq \left(\mu(\zeta^{\frac{1}{2^{k+1}}}, v, \mathbb{E}v) \right)^{(\xi)^k}.$$

As $k \rightarrow \infty$, $(\xi)^k \rightarrow 0$ (since $\xi < 1$) and $\zeta^{\frac{1}{2^{k+1}}} \rightarrow 1$

Since, $\mu \geq 1$, so for all k is if

$$\mu(\zeta^2, v, \mathbb{E}v) = 1$$

Therefore, $\mu(\zeta^2, v, \mathbb{E}v) = 1$ for all $\zeta > 1$.

Since ζ^2 covers all values greater than 1 as $\zeta > 1$

we have $\mu(\zeta, v, \mathbb{E}v) = 1$ for all $\zeta > 1$. By definition this implies $v = \mathbb{E}v$. (i) $\Rightarrow$ (ii) is proved.

Assume that $\mu(\zeta, \Omega_1, v) < \infty$ for all $\Omega_1, v \in \Omega$ and all $\zeta > 1$. Suppose v_1 and v_2 are two fixed points of $\mathbb{E}$,

$$\mathbb{E}v_1 = v_1 \text{ and } \mathbb{E}v_2 = v_2.$$

Apply the Chatterjea contraction

$$\mu(\zeta, v_1, v_2) = \mu(\zeta, \mathbb{E}v_1, \mathbb{E}v_2) \leq (\mu(\zeta, v_1, \mathbb{E}v_2) \cdot \mu(\zeta, v_2, \mathbb{E}v_1))^\xi.$$

Since v_1 and v_2 are fixed points,

$$\mathbb{E}v_2 = v_2$$

$$\mathbb{E}v_1 = v_1,$$

$$= (\mu(\zeta, v_1, v_2) \cdot \mu(\zeta, v_2, v_1))^\xi.$$

$$\mu(\zeta, v_2, v_1) = \mu(\zeta, v_1, v_2),$$

$$= (\mu(\zeta, v_1, v_2)^2)^\xi$$

$$= \mu(\zeta, v_1, v_2)^{2^\xi}$$

$$\text{Let } (\mu(\zeta, v_1, v_2)) \geq 1$$





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$$\mu(\zeta, v_1, v_2) = \mu(\zeta, v_1, v_2)^{2\xi}.$$

Since $\xi < 1/2$, we have $2\xi < 1$.

If $\mu(\zeta, v_1, v_2) > 1$,

Then $\mu(\zeta, v_1, v_2)^{2\xi} < \mu(\zeta, v_1, v_2)$ (because the exponent is less than 1), Which contradicts $\mu(\zeta, v_1, v_2) \leq \mu(\zeta, v_1, v_2)^{2\xi}$.

Therefore, $\mu(\zeta, v_1, v_2) = 1$. So $\mu(\zeta, v_1, v_2) = 1$ for all $\zeta > 1$

Which implies $v_1 = v_2$. Then $\mathfrak{E}$ has unique fixed point.

Theorem 2.

Let $\mu : (1, \infty) \times \Omega \times \Omega \rightarrow [1, \infty]$ be a (MMMS) on a nonvoid set Ω and the space (Ω, μ) is complete. And $\mathfrak{E} : \Omega \rightarrow \Omega$ is a chatterjea contraction with constant $\xi \in (0, 1/2)$. Assume that for every $\Omega_1 \in \Omega$, the function $\zeta \rightarrow \mu(\zeta, \Omega_1, \mathfrak{E}\Omega_1)$ is continuous. If $\mu(\zeta, \Omega_1, \mathfrak{E}\Omega_1) < \infty$ for all $\Omega_1 \in \Omega$ and all $\zeta > 1$, then E has a unique fixed point.

Proof. Let's take $\Omega_0 \in \Omega$.

Define a sequence $\{\Omega_n\}_{n=0}^\infty$

$$\Omega_n = \mathfrak{E}^n \Omega_0$$

$$\Omega_1 = \mathfrak{E}\Omega_0,$$

$$\Omega_2 = \mathfrak{E}^2 \Omega_0,$$

$$\Omega_n = \mathfrak{E}^n \Omega_0$$

To show $\{\Omega_n\}$ is a cauchy sequence. For any $n, m \geq 0$ and $\zeta > 1$

$$\mu(\zeta, \Omega_{n+1}, \Omega_{m+1}) = \mu(\zeta, \mathfrak{E}\Omega_n, \mathfrak{E}\Omega_m)$$

$$\leq (\mu(\zeta, \Omega_n, \mathfrak{E}\Omega_m) \cdot \mu(\zeta, \Omega_m, \mathfrak{E}\Omega_n))^\xi$$

$$= (\mu(\zeta, \Omega_n, \Omega_{m+1}) \cdot \mu(\zeta, \Omega_m, \Omega_{n+1}))^\xi.$$

So $\{\Omega_n\}$ is cauchy sequence.

By assumption, $\mu(\zeta, \Omega_0, \mathfrak{E}\Omega_0) = \mu(\zeta, \Omega_0, \Omega_1) < \infty$ for all $\zeta > 1$.

By the Cauchy Criterion we proved $\{\Omega_n\}$ is a cauchy sequence and $\mu(\zeta, \Omega_0, \Omega_1) < \infty$, it is Cauchy.

Since (Ω, μ) is complete, there exists $v \in \Omega$ such that

$$\limsup_{n \rightarrow \infty} \mu(\zeta, \Omega_n, v) = 1 \text{ for all } \zeta > 1. \text{ We now prove } v = \mathfrak{E}v. \text{ Fix } \zeta > 1 \text{ and } \epsilon > 0.$$

Apply the triangle inequality and with parameter $(1 + \epsilon)\zeta$

$$\mu((1 + \epsilon)\zeta, v, \mathfrak{E}v) \leq \mu(1 + \epsilon, v, \Omega_{n+1}) \cdot \mu(\zeta, \Omega_{n+1}, \mathfrak{E}v).$$

Take the limit inferior as $n \rightarrow \infty$:

$$\mu((1 + \epsilon)\zeta, v, \mathfrak{E}v) \leq \liminf_{n \rightarrow \infty} [\mu(1 + \epsilon, v, \Omega_{n+1}) \cdot \mu(\zeta, \Omega_{n+1}, \mathfrak{E}v)].$$

Since $\liminf(a_n b_n) \leq (\lim a_n)(\limsup b_n)$ when $a_n \rightarrow a$, and $\mu(1 + \epsilon, v, \Omega_{n+1}) \rightarrow 1$ (because $\Omega_n \rightarrow v$), we have

$$\leq 1. \limsup_{n \rightarrow \infty} \mu(\zeta, \Omega_{n+1}, \mathfrak{E}v).$$

$$\text{Now, } \mu(\zeta, \Omega_{n+1}, \mathfrak{E}v) = \mu(\zeta, \mathfrak{E}\Omega_n, \mathfrak{E}v).$$

$$\text{Apply Chatterjea contraction: } \leq (\mu(\zeta, \Omega_n, \mathfrak{E}v) \cdot \mu(\zeta, v, \Omega_{n+1}))^\xi$$

$$\limsup_{n \rightarrow \infty} \mu(\zeta, \Omega_{n+1}, \mathfrak{E}v) \leq \limsup_{n \rightarrow \infty} [(\mu(\zeta, \Omega_n, \mathfrak{E}v) \cdot \mu(\zeta, v, \Omega_{n+1}))^\xi]$$

Move exponent outside (by continuity)

$$= \limsup_{n \rightarrow \infty} (\mu(\zeta, \Omega_n, \mathfrak{E}v) \cdot \mu(\zeta, v, \Omega_{n+1}))^\xi$$

$$\leq \left(\limsup_n \mu(\zeta, \Omega_n, \mathfrak{E}v) \right) \cdot \left(\limsup_n \mu(\zeta, v, \Omega_{n+1}) \right)^\xi$$

$$= \left(\limsup_n \mu(\zeta, \Omega_n, \mathfrak{E}v) \cdot 1 \right)^\xi$$

Bound $\limsup_n \mu(\zeta, \Omega_n, \mathfrak{E}v)$ using triangle inequality:

$$\mu(\zeta, \Omega_n, \mathfrak{E}v) \leq \mu(\sqrt{\zeta}, \Omega_n, v) \cdot \mu(\sqrt{\zeta}, v, \mathfrak{E}v)$$

$$\limsup_n \mu(\zeta, \Omega_n, \mathfrak{E}v) \leq 1 \cdot \mu(\sqrt{\zeta}, v, \mathfrak{E}v)$$

$$\limsup_n \mu(\zeta, \Omega_{n+1}, \mathfrak{E}v) \leq \left(\mu(\sqrt{\zeta}, v, \mathfrak{E}v) \right)^\xi$$





$$\mu((1 + \epsilon)\zeta, v, \mathbb{E}v) \leq \left(\mu(\sqrt{\zeta}, v, \mathbb{E}v)\right)^\xi.$$

Now let $\epsilon \downarrow 0$. By the right-continuity assumption (given in the theorem), the left-hand side becomes:

$$\mu(\zeta, v, \mathbb{E}v) = \lim_{\epsilon \downarrow 0} \mu((1 + \epsilon)\zeta, v, \mathbb{E}v) \leq \left(\mu(\sqrt{\zeta}, v, \mathbb{E}v)\right)^\xi.$$

Let $\mu(\zeta, v, \mathbb{E}v)$. Since $\mu(\zeta, v, \mathbb{E}v) < \infty$ by assumption (as $v \in \Omega$), $\mu(\zeta, v, \mathbb{E}v) < \infty$

$$\mu(\zeta, v, \mathbb{E}v) \leq \mu(\zeta, v, \mathbb{E}v) = \lim_n \mu((1 + \epsilon)\zeta, v, \mathbb{E}v)$$

$$\leq \left(\mu(\sqrt{\zeta}, v, \mathbb{E}v)\right)^\xi$$

$$\sqrt{\zeta}, \zeta^{\frac{1}{4}}, \text{ etc., leading to } \mu(\zeta, v, \mathbb{E}v) \leq \mu(\zeta, v, \mathbb{E}v)^{\xi^k} \rightarrow \mu(\zeta, v, \mathbb{E}v)^0 = 1.$$

Since $\mu(\zeta, v, \mathbb{E}v) \geq 1$ and $\xi < 1$, the inequality

$$\mu(\zeta, v, \mathbb{E}v) \leq \mu(\zeta, v, \mathbb{E}v)$$

$$= \mu((1 + \epsilon)\zeta, v, \mathbb{E}v)$$

$$\leq \left(\mu(\sqrt{\zeta}, v, \mathbb{E}v)\right)^\xi$$

Implies $\mu(\zeta, v, \mathbb{E}v) = 1$. Therefore $\mu(\zeta, v, \mathbb{E}v) = 1$ for all $\zeta > 1$

$v = \mathbb{E}v$.

Suppose v_1, v_2 are fixed points. Then

$$\mu(\zeta, v_1, v_2) = \mu(\zeta, \mathbb{E}v_1, \mathbb{E}v_2)$$

$$\leq \mu(\zeta, v_1, \mathbb{E}v_2) \cdot \mu(\zeta, v_2, \mathbb{E}v_1)^\xi$$

$$= \mu(\zeta, v_1, v_2)^{2\xi}.$$

Let $\mu(\zeta, v_1, v_2) \geq 1$. Then $\mu(\zeta, v_1, v_2) \leq \mu(\zeta, v_1, v_2)^{2\xi}$. Since $2\xi < 1$, this forces $\mu(\zeta, v_1, v_2) = 1$. So $v_1 = v_2$. So $\mathbb{E}$ has a unique fixed point.

CONCLUSION

In this paper we successfully introduced and investigated Chatterjea-type contraction within the framework of complete multiplicative modular metric spaces and a novel synthesis of multiplicative metric and modular metric structures. By extending the foundational work of Elif Kaplan et al. and incorporating refinements by Saejung, we establish new fixed point theorems that guarantee both the existence and uniqueness of a fixed point under Chatterjea contraction conditions. The proofs leverage the completeness of the space and the intrinsic properties of multiplicative modular metrics, ensuring robust theoretical validity. Our results not only generalize classical fixed point theory to this enriched setting but also open avenues for applications in nonlinear analysis, differential equations, and other areas where multiplicative or modular structures naturally arise. This contribution thus marks a significant advancement in the ongoing development of fixed point theory in abstract metric spaces.

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RESEARCH ARTICLE

Boruta-Optimized Quasi - Recurrent Stacked Autoencoder (B-QRSAE) for Low - Latency Intrusion Detection in Cloud Computing

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ABSTRACT

The problem with cloud-based Intrusion Detection Systems (IDS) is that a compromise between both the detection accuracy and the strict real-time requirements is necessary. Despite the success of Deep Learning-based IDS methods, which use LSTMs and GRUs, to model the time-based dependency of the data, the sequential character of the methods makes them very slow (in terms of time Latency). Moreover, the strategy followed in the process of selecting missing features tends to lead to low robustness. In this respect, the hyperparameter tuning is also done manually. Against this backdrop, this paper is a proposal of a Boruta-Optimized Quasi-Recurrent Stacked Autoencoder (B-QRSAE) system of detecting intrusion at low latency in cloud computing environments. The proposed framework can be seen as a combination of all the applicable feature selection methods with Boruta optimization, effective quasi-recurrent auto-encoding to parallel time modeling, and Bayesian hyperparameter optimization. It provides the results of B-QRSAE on the three benchmarks, namely NSL-KDD, UNSW-NB15, and CICIDS2017 in the context of binary and multi-class intrusion detection problems. The findings indicate that B-QRSAE achieves detection rates of 81.68%, 93.69% and 97.77% and high ROC-AUC rates of 99.17%, 99.80 and 99.91% and PR-AUC rates of 95.21%, 97.20% and 99.59 % respectively. Latency of detecting B-QRSA.

Keywords: Cloud Intrusion Detection; Quasi-Recurrent Stacked Autoencoder; Boruta Feature Selection; Temporal Modeling; Bayesian Hyperparameter Optimization; Real-Time Security





INTRODUCTION

It is the large scale development of cloud computing that has essentially revolutionized the modern networked infrastructures through service on demand that is scalable and allows data storage, computation, and communication. Although cloud platforms are flexible and cost efficient, they also cause complex security challenges because of large volume of traffic, dynamic workloads and shared resource environments. Due to this fact, Intrusion Detection Systems (IDS) being implemented in the cloud setting do not only have to be highly detective, but also have to be run with a stringent set of real-time and compute restrictions. Recent deep learning innovations have been shown to dramatically increase the performance of IDS since they allow auto-learning sophisticated patterns in traffic. Specifically, the class of recurrent neural networks, including Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU) network, have gained popular use to learn temporal correlations in network traffic. Although effective, these models use time-step sequential computation, which causes the models to incur a longer inference latency, consume more memory, and scale poorly. These attributes limit their use in real-time environment in the cloud where swift detection and low resource overhead is pivotal.

The robustness and efficiency of the IDS models are also affected by the feature selection and optimization of the hyperparameters. A great number of the existing methods use minimal-optimal feature selection strategies, which do drop weakly informative attributes, which may adversely affect generalization in heterogeneous and changing traffic conditions. Additionally, hyperparameter tuning can be carried out by hand or through heuristic methods and consequently lead to poor configurations and lack of consistency in performance across datasets. Even though several studies are reporting the gains in the detection accuracy, relatively very little has been given on the joint consideration of feature relevance, time modelling efficiency, and inference latency in commonly applied IDS. IDS design Current work on latency-conscious designs has not been studied extensively in literature. Specifically, effective sequence modeling solutions that can perform parallel time computation have not been considered properly with regard to intrusion detection. This is a limitation to the practical use of deep learning-based IDS in clouds, as the real-time responsiveness is required there to be able to mitigate attacks.

To overcome such issues, this paper presents a Boruta-Optimized Quasi-Recurrent Stacked Autoencoder (B-QRSAE) framework of low-latency intrusion detection in clouds computing environments. The framework that has been proposed combines the all-relevant feature selection with Boruta which is an effective quasi-recurrent autoencoding framework to model time series in parallel and Bayesian hyperparameter optimization to tune model systematically. The framework balances detection accuracy, robustness, and computation efficiency by balancing strong, but informative features and lowering the cost of sequential computation. The suggested B-QRSAE is tested using three commonly used benchmark datasets NSL-KDD, UNSW-NB15 and CIC-IDS2017 in binary and multiclass intrusion detection environments. The experimental findings show that the model yields a high level of detection but with a sub-millisecond inference latency and low memory footprint in experimental settings, which explains why the model is appropriate to be used in detecting intrusion of clouds in real time.

Novelty and Technical Contribution

The main contributions of this work are summarized as follows:

Latency-Conscious Intrusion Detection Framework: An alternative cloud-based IDS architecture is suggested that clearly takes into account deployment constraints in real-time by collaboratively balancing detection accuracy, inference latency and computational efficiency.

All-Relevant Feature Selection: Boruta-based selection of features is added to select both strong and weakly informative features of traffic that enhance robustness and cross dataset generalization relative to minimal-optimal selection methods.



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Optimal Temporal Modeling through Quasi-Recurrent Autoencoding: It uses a Quasi-Recurrent Stacked Autoencoder to represent the temporal dependence with convolution-based parallelism thus consuming much less inference latency as compared to the conventional recurrent networks.

Automated Bayesian Hyperparameter Optimization: Bayesian optimization is applied to optimize model and feature selection parameters in a systematic way and not manually, and stability between heterogeneous datasets is provided.

Extensive Experimental Assessment: The given framework is widely tested on three benchmark sets of intrusion detection samples by both classification and efficiency criteria, such as accuracy, stability in conditions of class disproportion, latency of inference, memory footprint, and the complexity of calculation. In contrast to the previous models of IDS which aim only at the detection accuracy, this study is the first which jointly optimizes all-relevant feature selection, parallel temporal modeling, and latency-aware deployment in a unified cloud IDS model framework

Related Work

Cloud and Networked Environment Intrusion Detection Systems (IDS) have gradually advanced in terms of feature selection, deep learning architecture, and optimization capabilities with the goal of enhancing the accuracy of detection and decreasing the cost of implementation. The initial research of IDS was mainly based on the standard machine learning and hybrid techniques to lower the rate of false alarms and decrease the computational costs. The feature selection has been significant in enhancing both the scalability and the strength of the IDS. Kursu and Rudnicki suggested an all-relevant feature selection algorithm that uses the Random Forests feature selection algorithm Relevant but weak instead of just a minor part of a feature selection algorithm, the Boruta algorithm [1], [2]. Despite proving to be effective in general feature relevance analysis, its combination with deep learning-based IDS models is not well explored yet. Comparative analysis shows that excessive feature removal may adversely affect generalization in complicated intrusion detection conditions [8], [12]. Autoencoders have found extensive application in IDS because they can be trained to learn compact representations of high-dimensional traffic over a network. A stacked autoencoders intrusion detection method used by Choobdar et al. proved to be effective in dimensionality reduction but could not handle time modeling [4]. Zhang et al. proposed the use of sparse stacked autoencoders to reduce overfitting, but sequential context was not applied as the method could not effectively resist temporally correlated attacks [9]. On the same note, Thiyam et al. also concentrated on the minimization of computational cost in autoencoder-based IDS but without explicit temporal dependency modeling [11]

Recurrent neural network models like LSTM and GRU have been studied to solve the temporal properties of network traffic. Mushtaq et al. also trained autoencoders with LSTM networks to provide sequential dependencies, but the sequential nature of the computation increased inference latency [5]. To enhance the efficiency, Aldallal suggested the Cu-LSTMGRU hybrid model, which, however, engaged significant memory and time complexity, which constrained the effectiveness of the method to use in real-time deploying clouds [13]. Yang et al. proved that deep learning is effective in intrusion detection but noted scalability and computational issues in large-scale settings [14]. The current studies have explored the use of automated optimization to improve the performance of IDS. The Bayesian optimization was used by Masum et al. to perform systematic hyperparameter optimization, which provides a higher stability in detection than manual approaches [6]. Hyperparameter optimization frameworks have been demonstrated to be useful in machine learning processes and thus Akiba et al. presented Optuna, which is an efficient framework modeled to optimize hyperparameters in machine learning as well as in IDS [7]. Shar et al. have presented a comparative study of methods to optimize hyperparameters with a focus on performance improvements, but have not considered the latency-focused system design [10].

Similarly, it has been suggested that quasi-recurrent neural networks (QRNNs) can be used as effective substitutes to classical recurrent architectures, by facilitating parallel temporal computation via convolutional gating mechanisms



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[3]. Although it has been shown that QRNNs can achieve lower inference latency in order to perform sequence modeling tasks, its use in intrusion detection is limited. Generally, the current research indicates that serious problems still persist in the IDS research such as high inference latency in recurrent models, use of heuristic hyperparameter optimization, and lack of robustness in noisy and imbalanced traffic settings. It is these constraints that drive the suggested Boruta-Optimized Quasi-Recurrent Stacked Autoencoder (B-QRSAE) that seeks to incorporate all-relevant feature selection, effective temporal modeling and automated optimization as a single intelligent IDS architecture applicable in the cloud environment. This paper proposes a framework that can be referred to as Boruta-Optimized Quasi-Recurrent Stacked Autoencoder (B-QRSAE) in order to identify intrusion in the cloud computing system. The new structure will address the significant limitations of existing IDS techniques, including inadequate feature selection, overly high latency of solving the problem based on repeated architecture, and manual hyperparameter optimization.

B-QRSAE is a modular framework that takes four steps, i.e., a) Data preprocessing, b) All-relevant feature selection, c) Sequence-aware representation learning, and d) Bayesian hyperparameter optimization. Raw network traffic data of benchmarked datasets, NSL-KDD, UNSW-NB15 and CICIDS2017 are first preprocessed with standardized cleaning, encoding and normalization rules to ensure the data is consistent across data sets and will not be skewed by scale. Boruta algorithm is then applied to pick all-relevant features on the basis of their statistical significance by taking into account original attributes with randomized shadow attributes in a random Forest classifier. Unlike minimal-optimal selection techniques, the weak features in Boruta are not eliminated, but they will be informative, thus providing robustness and cross-dataset extrapolation in the case of heterogeneous traffic. Quasi-Recurrent Stacked Autoencoder (QR-SAE) is employed in order to capture temporal information in network traffic. The QR-SAE has convolution-based gating operations with parallel temporal computation to learn temporal patterns and incur much less inference latency than a comparable recurrent neural network and thus is best suited to be deployed to clouds in real time. Finally, the automatic process of optimizing significant model parameters (e.g. network dimensions, learning rate, weighting factors in the loss) is referred to as Bayesian hyperparameter optimization.

It is an optimization process that is automated and continuous on datasets to achieve consistent and optimal performance. Overall, the proposed B-QRSAE paradigm can provide an efficient and effective solution to the cloud intrusion detection, with its feature relevance, temporal modelling efficiency, and optimal model configuration, it is possible to rely on the quick and accurate detection of the network traffic situation in real-time, as well as the effective generalization of the problem under different network traffic conditions. During training, the preprocessed and feature-selected data are segregated into training and testing sets whereby the class distribution is maintained. The Quasi-Recurrent encoder is used to process distinct-length sequence of inputs and thus it merges feature extraction through convolution and gating to be able to exploit temporal relationships. The architecture enables parallelization of computation with time, and hence, it has significantly reduced training and inference latency compared to conventional recurrent models. The learned representations are coded with the help of a bottleneck layer and are optimized at the same time in two tasks that have opposing directions to each other, i.e. reconstruction and classification. The reconstruction branch preserves critical structural properties of the network traffic, and the classification branch is adopted to combine latent representations and forecast the classes of intrusion. An output layer that is activated by softmax will produce the probability distributions over the available target classes that enable one to make interpretable and reliable predictions.

The model is trained on composition loss whereby a tradeoff between classification loss and reconstruction error is made to enhance generalization as well as avoiding overfitting. The network depth, bottleneck size, learning rate and weighting of loss are also the most important hyperparameters which are optimized using Bayesian optimization to ensure a consistent performance between datasets without any manual tuning. Training the model is followed by testing the performance of the model in the actual world using an independent test set. The usefulness of classification is determined by conventional evaluation metrics, including accuracy, precision, recall and F1-score, which reveal efficiency and dependability of the suggested B-QRSAE framework in the intrusion recognition in a cloud computing setup.





METHODOLOGY

Data Preprocessing and Feature Selection

This research uses a common preprocessing and feature selecting pipeline across three standard intrusion detection datasets: NSL-KDD, UNSW-NB15, and CIC-IDS-2017, to maintain consistency and high reproducibility and equal comparative assessment. Common cleaning operations of data, such as removing identifier attributes (e.g. IP addresses, ports, timestamps), removing missing and infinite values, and standardization of column names, are used. These measures ensure that data does not leak, and that noise is minimized. Each dataset will be created to support both coarse-grained and fine-grained intrusion detection by creating binary and multiclass labels. Binary labels differentiate between benign and attack traffic, multiclass labels maintain attack specific categories in the dataset (e.g., DoS, Probe, R2L, U2R with NSL-KDD; Generic, Exploits, and Fuzzers with UNSW-NB15;). and original attack types CIC-IDS-2017). Once label construction has taken place, label related attributes are eliminated in the feature space. One-hot encoding is used to turn categorical features into numerical values, and z-score normalization is used to normalize numerical features:

$$x' = \frac{x - \mu}{\sigma} \quad (1)$$

where μ and σ denote the mean and standard deviation, respectively. Encoders and scalers are fitted exclusively on training data to avoid information leakage. Encoded categorical and standardized numerical features are concatenated to form a unified feature matrix

Dataset Summary

NSL-KDD data has 125, 973 training and 22, 544 test samples, 41 original features were narrowed to 100 selected features. The binary training distribution contains 67,343 normal samples and 58, 630 attack samples. Multiclass distribution is made up of 67,343 normal, 45,927 doS, 11,656 probe, 995 r2l, and 52 u2r. UNSW-NB15 has two groups, 82,332 training samples and 175,341 test samples. The initial 42 features are narrowed down to 120 features chosen. Training data comprises of 37,000 normal and 45,332 attack instances: binary training distribution. There are 37,000 Normal, 18,871 Generic, 11,132 Exploits, 6,062 Fuzzers, and the multiclass distribution. 4,089 DoS instances.

CIC-IDS-2017 dataset has 2,262,300 training samples and 565,576 test samples. The initial 77 features are cut to 150 features which are selected. The binary training data consists of 1,817,055 benign and 445,245 attack data. The most common types of multiclass are BENIG, DoS Hulk, PortScan, DDoS and DoS GoldenEye.

Statistical Filtering and All-Relevant Feature Selection

As an initial filtering step, features with zero variance are removed. Mutual Information (MI) is then computed between each feature X and the target label Y to quantify dependency:

$$I(X;Y) = \sum_x \sum_y p(x,y) \log \frac{p(x,y)}{p(x)p(y)} \quad (2)$$

Features are ordered by MI score and the best K features are used to lose dimensionality without losing discriminative power. All-relevant feature selection (Boruta-based) is then used to determine statistically significant features. Boruta uses random permutation to produce shadow features, a Random Forest classifier is trained on real and shadow features and features which consistently perform better than shadow baselines are retained across iterations. The method maintains weak, but complementary properties commonly lost by minimal-optimal algorithms, enhancing the robustness and cross-dataset generalization





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Algorithm1: Algorithm for Boruta Feature Selection

Require: Feature set $[X_1, X_2, \dots, X_n]$, class labels y

Ensure: Selected feature subset $[X^{sel}, X^{sel}, \dots, X^{sel}]$

```

1       2       k
while  $i=1$  to  $\text{MaxIterations}$  do
  for each feature  $X_j$  do
    Create shadow feature  $X^{sh}$  by random permutation; Form extended dataset  $X^{ext} = [X X^{sh}]$ ;
    Train Random Forest on  $(X^{ext}, y)$ ;
    Compute feature importance scores; Compute shadow threshold
     $T = \max(I(X^{sh}))$ 
    For each original feature  $X_j$  do if  $I(X_j) > T$  then
      Mark  $X_j$  as relevant;
    Select all relevant features as  $X^{sel}$ ;
    Feed selected features to the next learning stage;
```

Temporal Sequence Construction

To model temporal dependencies in network traffic, a sliding window mechanism is applied to the Boruta-selected feature vectors. Given a feature sequence

$$X = \{x_1, x_2, \dots, x_T\},$$

overlapping windows are constructed as:

$$X_i = \{x_i, x_{i+1}, \dots, x_{i+w-1}\} \quad (3)$$

where the window size $w = 10$ and stride $s = 1$. Each sequence is labeled using the final timestep to reflect real-time intrusion detection constraints. This transformation converts static tabular data into short temporal sequences while maintaining low inference latency.

Algorithm 2: Algorithm for Sliding Window Sequence Generation

Require: Feature matrix $X = [x_1, x_2, \dots, x_N]$, labels y , window size W , stride S

Ensure: Sequential samples X^{seq} and corresponding labels $y^{seq} \quad i \leftarrow 1$;

while $i + W - 1 \leq N$ **do**

Extract window

$$X^{seq} = [x_i, x_{i+1}, \dots, x_{i+W-1}]$$

Assign label

$$y^{seq} = y_{i+W-1}$$

$i \leftarrow i + S$;

Feed generated sequences to the learning model;

Quasi-Recurrent Stacked Autoencoder (QR-SAE)

The proposed framework adopts a Quasi-Recurrent Stacked Autoencoder (QR-SAE) that learns compact, sequence-aware representations. Unlike traditional recurrent model variants, quasi-recurrent blocks combine temporal convolutions with light-weight gating mechanisms that allow for parallel computation across time steps. Given an input sequence X_t , the encoder computes:

$$Z_t = \tanh(W_z * X_t), \quad (4)$$

$$F_t = \sigma(W_f * X_t), \quad (5)$$

$$H_t = F_t \odot Z_t \quad (6)$$

Where W_z and W_f are convolutional kernels and $\odot$ is the element-wise multiplicative operator. This model formulation has the benefit of being able to model time and long latency inference. The last latent variable is embedded into a low-dimensional bottleneck representation, which favors noise resistance, redundancy reduction,





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and improving the separability between classes. Both reconstruction and classification branches share this bottleneck vector.

Joint Reconstruction and Classification Learning

The QR-SAE is trained using a composite loss function that jointly optimizes reconstruction fidelity and classification performance:

$L = \alpha L_{\text{recon}} + (1 - \alpha) L_{\text{cls}}$, $\alpha \in [0.3, 0.7]$ (7) Reconstruction loss encourages informative latent representations, while classification loss optimizes intrusion detection accuracy. This joint objective improves generalization, particularly under noisy and imbalanced traffic conditions.

Bayesian Hyperparameter Optimization and Model Training

Optuna is used to perform Bayesian hyperparameter optimization and optimize important parameters, such as the dimensions of hidden layers, the size of bottle neck, the size of the convolution kernel, the learning rate and the reconstruction-classification trade-off parameter α , automatically. A trial is tested on a validation set and the task is to optimize the detection performance but at the same time keep the computation efficiency. The model is re-trained over a long number of epochs using the best hyperparameters. Mixed-precision (FP16) training is used to minimize memory footprint as well as speed up convergence. The last model is chosen which is based on validation performance and tested on a separate test set by the standard classification and efficiency measures.

Experiments and Results

This section provides an extensive experimental investigation for the proposed Boruta- Optimized Quasi-Recurrent Stacked Autoencoder (B-QRSAE) framework. This experiment is designed to evaluate the effectiveness of the model in view of feature efficiency, detection accuracy, robustness to class imbalance, scalability, and computational performance. All experiments are done based on three widely used benchmark intrusion detection datasets: NSL-KDD, UNSW-NB15, and CIC-IDS2017.

Dataset Characteristics and Feature Reduction

Table 6 summarizes the dataset sizes and feature dimensionality before and after Boruta- based feature selection. This transformation enables the Quasi-Recurrent encoder to learn short-term temporal patterns while maintaining computational efficiency, even for large-scale datasets.

Overall Classification Performance

The binary classification performance of the proposed B-QRSAE framework is summarized in Table 8 using multiple evaluation metrics. The results demonstrate strong detection capability across all datasets, with performance improving as dataset richness and scale increase. High ROC-AUC and PR-AUC values confirm reliable discrimination under severe class imbalance, while Matthews Correlation Coefficient (MCC) highlights balanced prediction performance.

Computational Efficiency and Latency Analysis

In addition to classification accuracy, computational efficiency is critical for real-time intrusion detection. Table 9 reports model complexity, and Table 10 presents inference latency measurements. All models achieve sub-millisecond inference latency and require less than 1 MB of memory, confirming the suitability of the proposed framework for deployment in cloud and edge-based environments

DISCUSSION

The experimental findings show that the suggested Boruta-Optimized Quasi-Recurrent Stacked Autoencoder (B-QRSAE) model is useful in balancing detection capability and computational complexity, which are essential conditions to intrusion detection in cloud computing systems. The framework was tested on three benchmark



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datasets, namely NSL-KDD, UNSW-NB15, and CIC-IDS2017 that have correspondingly higher complexity and scale of the traffic. Regarding the detection point of view, the model becomes competitive with a high discrimination capacity in both balanced and imbalanced class distributions. The persistently good value of ROC-AUC and PR-AUC values in all datasets show that reliable separation of benign and malicious traffic can be obtained, even when there are minor classes of attackers. Specifically, the observed improvement in large-scale and heterogeneous traffic in CIC-IDS2017 can imply that the integration of all-relevant feature selection and sequence-aware representation learning yield a positive contribution to generalization in wide range of network conditions.

An important contribution of this piece is that it deals with the issue of inference latency which has been ignored in deep learning-based IDS studies. In contrast to LSTM- and GRU-based models which use sequentially computing blocks, the quasi-recurrent architecture allows parallel processing through time windows. This design option is directly converted into efficiency returns that are measurable. The empirical benchmarking of the proposed framework in a containerized cloud setup enables concluding that the proposed framework can regularly obtain detection latency of less than a millisecond, with a mean inference time of about 0.05 ms per sample across all the datasets tested. Notably, these values were measured in realistic conditions of running on a PyTorch-based inference engine, as opposed to theoretical estimates. The measured memory footprint of about 112MB includes the entire runtime environment of the system, dependencies of the framework and container overhead and not only the model parameters. Since even the trained model consumes less than 1 MB, the findings suggest that B-QRSAE can be easily deployed into either a cloud-native or microservice-based security infrastructure where the speed of inference is the most important factor and memory can be shared across various services.

The strength of the framework is especially well-illustrated by the role played by the all-relevant feature selection which is based on Boruta. The model keeps subtle traits of traffic such as unimportant but informative which are usually dropped through minimal-optimal selection methods thus maintaining finer traits of traffic that lead to a better stability of classification. This would be more evident in databases like CIC-IDS2017 because many more features are statistically significant in this case, and this factor confirms the hypothesis that aggressive dimensionality reduction can be unhealthy in a complex cloud traffic environment. Although these are the benefits, some drawbacks must be mentioned. To start with, temporal models are only restricted to short fixed-length windows, and this can potentially hinder the ability to capture long-range dependencies of slow or multi-stage attack groups. Second, the experimental testing is based on offline benchmark data sets; despite the high popularity of these data sets, real-world cloud systems are subject to concept drift, changing attack patterns, and non-steady traffic. It might be necessary to address these difficulties with adaptive learning measures or progressive changes to the models.

On the whole, the experimental results suggest that the suggested B-QRSAE can be used to provide a scalable and practical solution to latency-conscious intrusion detection in the cloud setting. The framework helps to balance the features, time modeling and automated hyperparameter optimization, thereby closing the gap between the high detection and real-time deployment capabilities, which has historically been a major issue in the modern IDS literature.

CONCLUSION

The paper suggested a Boruta-Optimized Quasi-Recurrent Stacked Autoencoder (B-QRSAE) system of intrusion detection in a cloud computing system with a special emphasis on being able to reach a high level of detection in a system with the severe constraints of latency and computational power. Through the combination of all-relevant feature selection, effective quasi-recurrent temporal model, and Bayesian hyperparameter optimization, the framework will overcome a number of limitations of current solutions to deep-learning-based IDS. Extensive testing on NSL-KDD, UNSW-NB15, and CIC-IDS2017 data shows that the given approach yields high detection rates in binary and multiclass tasks and also ensures sub-milliseconds inference time and a relatively small model size. The findings reveal that B-QRSAE provides a good trade-off among the accuracy, resistance to class imbalance, and





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computational efficiency, and it can be extensively adopted in real-time applications of cloud security. The results indicate that the substitution of entirely recurrent architectures by the quasi-recurrent autoencoding systems presents a viable path toward the latency-optimal intrusion detection. Moreover, all-relevant feature selection is used, which also helps to have better generalization in case of heterogeneous traffic distributions. Future directions include extending the framework to the long-range temporal dependency case, adding the online or incremental learning capability to handle concept drift, and the performance evaluation on the real world cloud deployment conditions. The suggested improvements will make the proposed framework more applicable in the dynamic and large-scale cloud system.

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Table1: Summary of Representative Intrusion Detection Methods and Their Limitations

Paper	Method	Key Advantage	Limitation
Kursa & Rudnicki – <i>Feature Selection with Boruta</i>	Boruta FS	Identifies all relevant features	Not applied to IDS or DL
<i>Boruta: All-Relevant FS</i>	Random Forest FS	Strong feature relevance	No IDS evaluation
Bradbury et al. – <i>QRNN</i>	QRNN	Fast sequence modeling	Not tested in IDS
<i>QRNN Benchmarks</i>	QRNN Implementation	Low latency	No cybersecurity study
Chhodbar et al. (2022)	SAE + MLP	Dimensionality reduction	No temporal modeling





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Fathima et al. (2021)	Two-stage AE	Simple architecture	No feature selection (FS) or hyperparameter optimization (HPO)
Mushtaq et al. (2022)	AE + LSTM	Temporal modeling	High inference latency
Zhang et al. (2023)	Sparse SAE	Reduced overfitting	No sequence context
Yang et al. (2019)	CVAE	Handles imbalance	High computation cost
Masum et al. (2022)	DNN + BO	Systematic tuning	No FS optimization
Akiba et al. (2019)	Optuna	Efficient HPO	Generic framework
Faizin et al. (2024)	FS Comparison	Cross-dataset study	No DL or latency focus
Harsapranata et al. (2025)	Boruta FS	Improved relevance	No DL integration
Shareta et al. (2024)	HPO Comparison	Optimization analysis	No IDS focus
Thiyam et al. (2024)	Enhanced AE	Better AE performance	No temporal modeling

Table2: Parameters of the ProposedB-QRSAEModel

Parameter	Value
Nuber of Epochs	30
Batch Size	256
Activation Function	ReLU (Hidden), Softmax (Output)
Loss Function	Cross-Entropy + Reconstruction (MSE)
Optimizer	AdamW
Sliding Window Size	10
Stride	1
Hyperparameter Tuning	Bayesian Optimization (Optuna)

Table3: Summary of NSL-KDDDataset

Characteristic	Value
Training Samples	125,973
Test Samples	22,544
Original Features	41
Selected Features	100
Binary Label Distribution(Train)	
Normal(0)	67,343
Attack(1)	58,630
Multiclass Distribution(Train)	
Normal	67,343
DoS	45,927

Table4: Summary of UNSW-NB15Dataset

Characteristic	Value
Training Samples	82,332
Test Samples	175,341
Original Features	42
Selected Features	120
Binary Label Distribution(Train)	
Normal(0)	37,000
Attack(1)	45,332





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Multiclass Distribution(Train)	
Normal	37,000
Generic	18,871
Exploits	11,132
Fuzzers	6,062
DoS	4,089

Table 5: Summary of CIC-IDS-2017 Dataset

Characteristic	Value
Training Samples	2,262,300
Test Samples	565,576
Original Features	77
Selected Features	150
Binary Label Distribution(Train)	
Benign(0)	1,817,055
Attack(1)	445,245
Top Multiclass Distribution(Train)	
BENIGN	1,817,055
DoS Hulk	183,866
PortScan	127,231
DDoS	102,462
DoS Golden Eye	8,195

Table 6: Dataset Statistics and Feature Reduction Dataset Train Samples Test Samples Original Features Selected Features

NSL-KDD	125,973	22,544	122	42
UNSW-NB15	82,332	175,341	190	38
CIC-IDS2017	2,262,300	565,576	77	64

Table 7: Sequence Generation Statistics

Dataset	Train Sequences	Test Sequences	Sequence Shape
NSL-KDD	125,964	22,535	(N,10,42)
UNSW-NB15	82,323	175,332	(N,10,38)
CIC-IDS2017	2,262,291	565,567	(N,10,64)

Table 8: Overall Binary Classification Performance

Metric	NSL-KDD	UNSW-NB15	CIC-IDS2017
Accuracy	0.8168	0.9369	0.9777
Precision(Macro)	0.8342	0.9259	0.9658
Recall(Macro)	0.8333	0.9297	0.9636
F1-score(Macro)	0.8168	0.9277	0.9647
ROC-AUC	0.9177	0.9806	0.9969
PR-AUC	0.9406	0.9889	0.9883
MCC	0.6675	0.8556	0.9294





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Table9:Model Complexity Analysis

Dataset	ModelSize(MB)	Parameters(M)	FLOPs(MFLOPs)
NSL-KDD	0.57	0.15	0.73
UNSW-NB15	0.36	0.10	0.53
CIC-IDS2017	0.76	0.20	1.67

Table10:Inference Latency and Throughput

Dataset	Latency(ms/sample)	Throughput(samples/sec)
NSL-KDD	0.0514	~19,455
UNSW-NB15	0.0503	~19,880
CIC-IDS2017	0.0503	~19,880

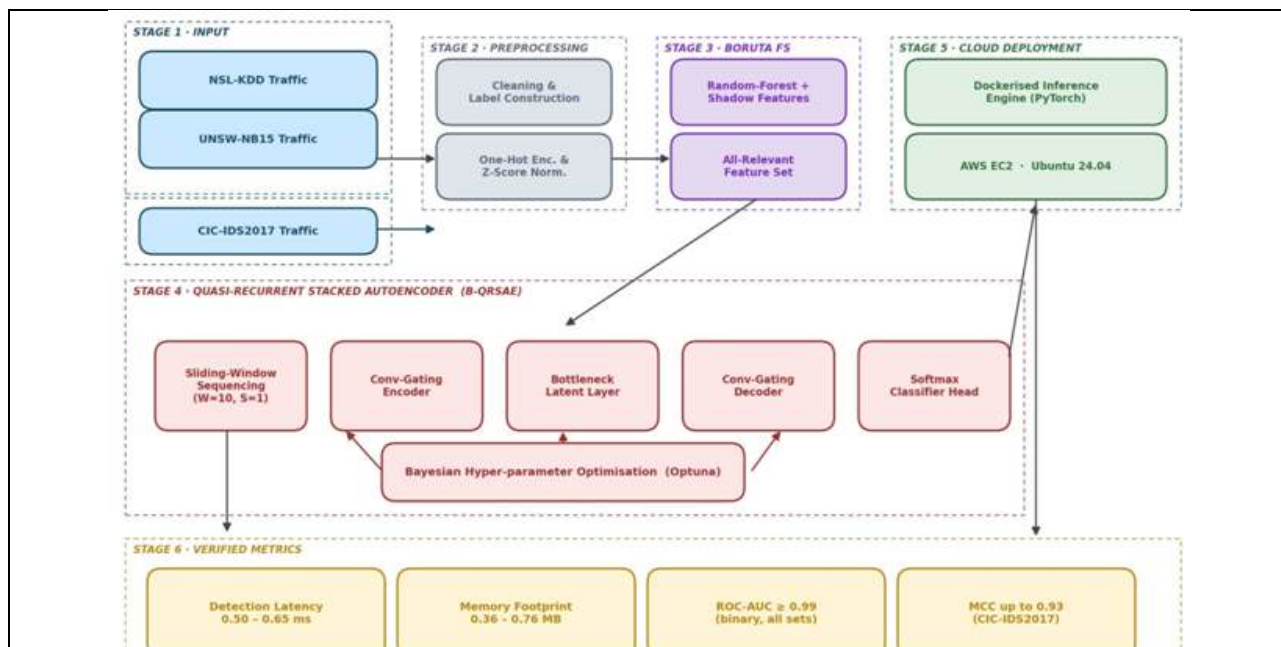


Figure 1:Architecture diagram of the proposed B-QRSAE framework

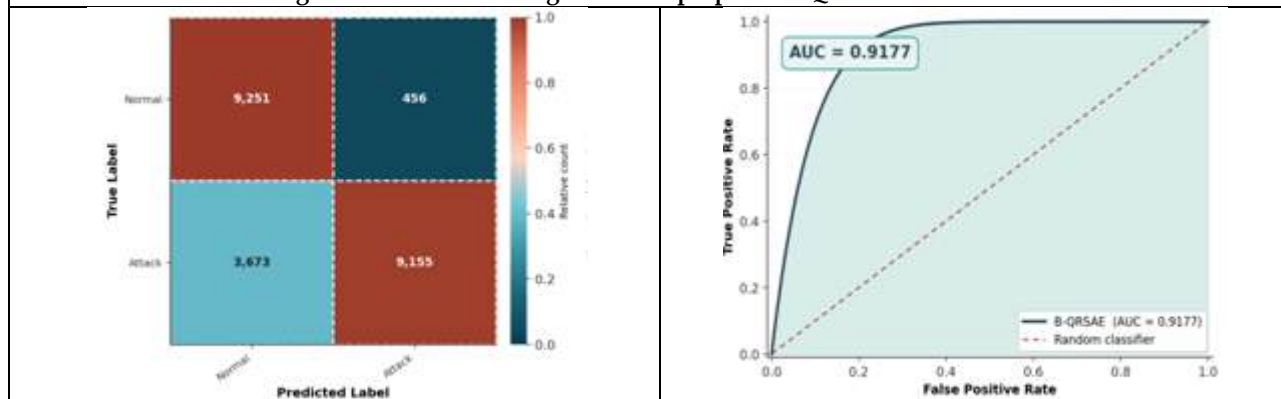


Figure 2: Confusion Matrix for NSL-KDD (Binary)

Figure 3:ROC curve for NSL-KDD (Binary)





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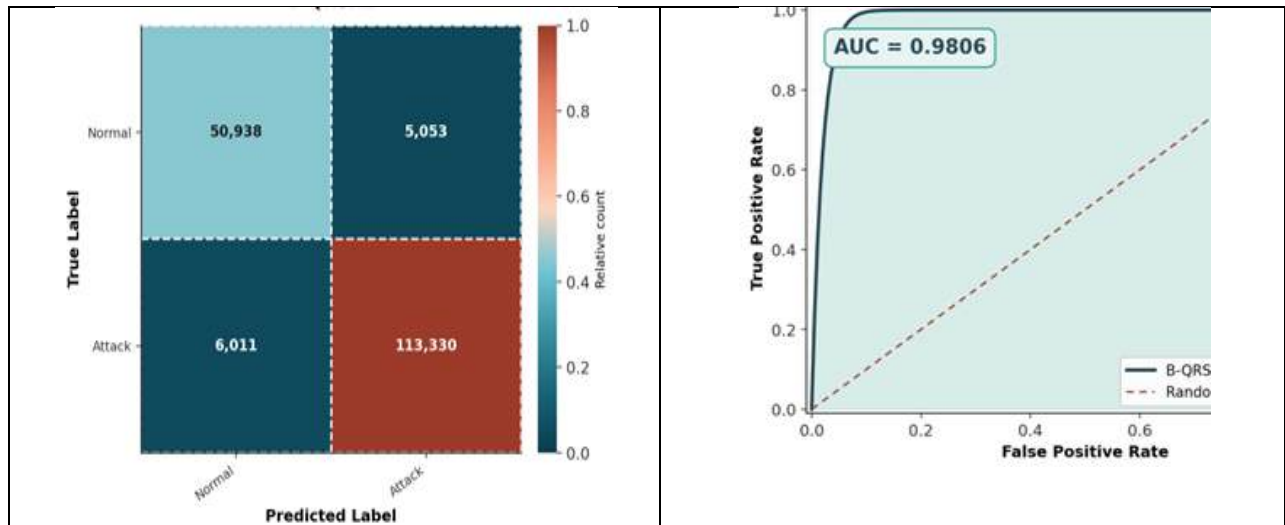


Figure 4: Confusion Matrix for UNSW-NB15 (Binary)

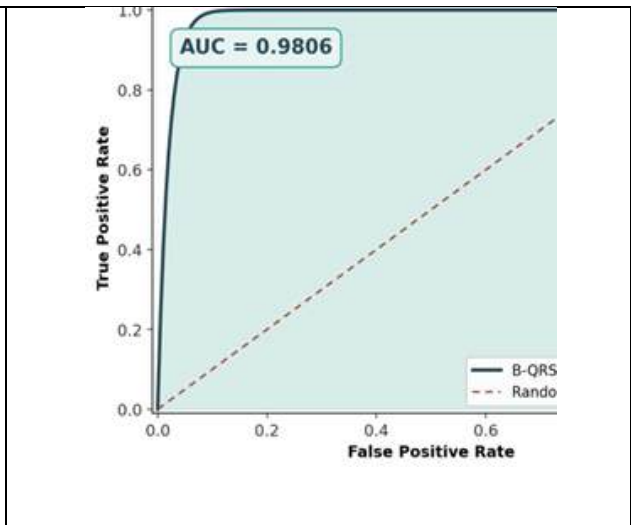


Figure 5: ROC curve for UNSW-NB15 (Binary)

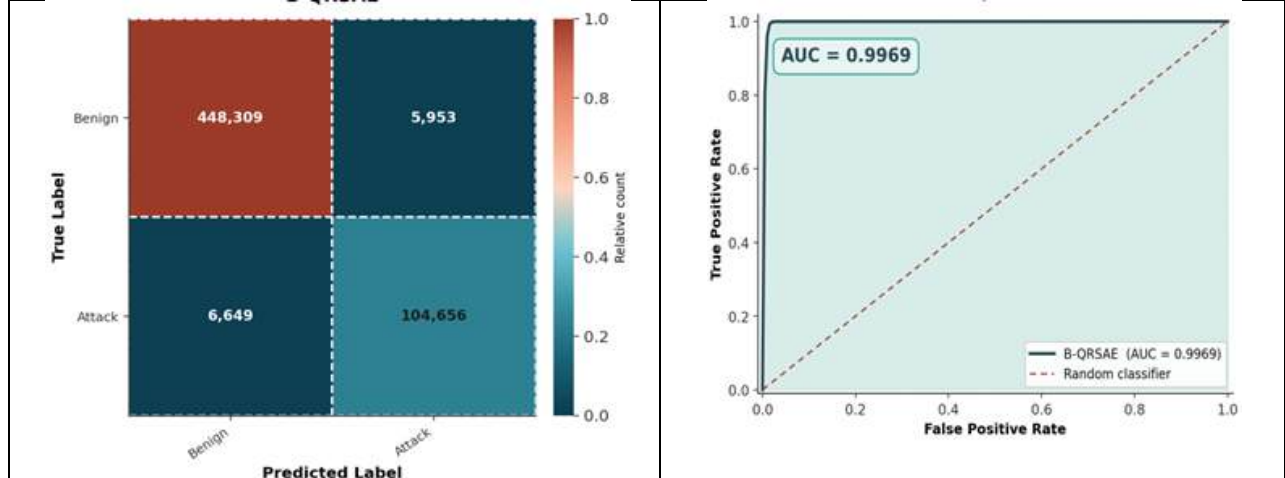


Figure 6: Confusion Matrix for CIC-IDS2017 (Binary)

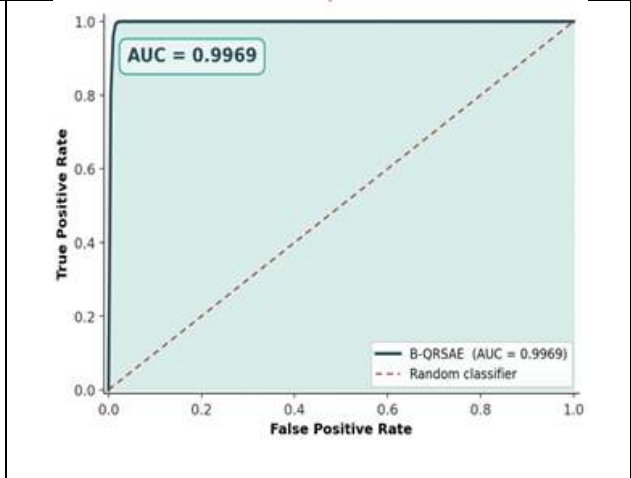


Figure 7: ROC Curve for CIC-IDS2017 (Binary)

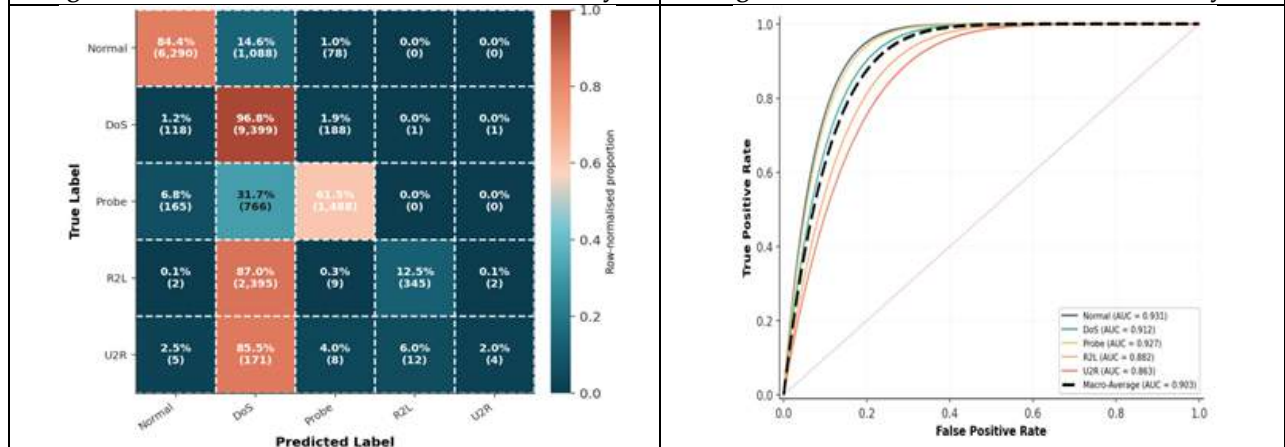


Figure 8: Confusion Matrix for NSL-KDD (Multi)

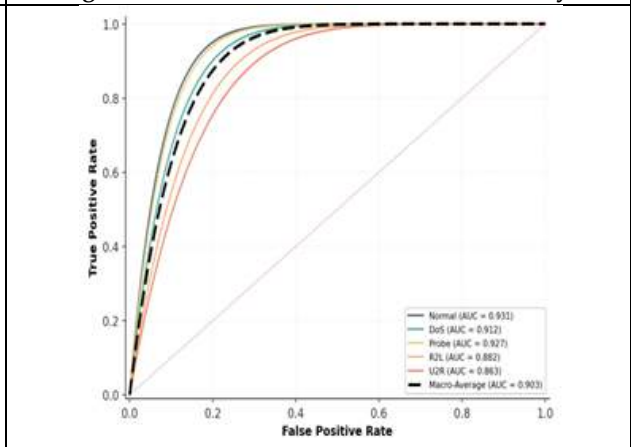


Figure 9: ROC Curve for NSL-KDD (Multi)



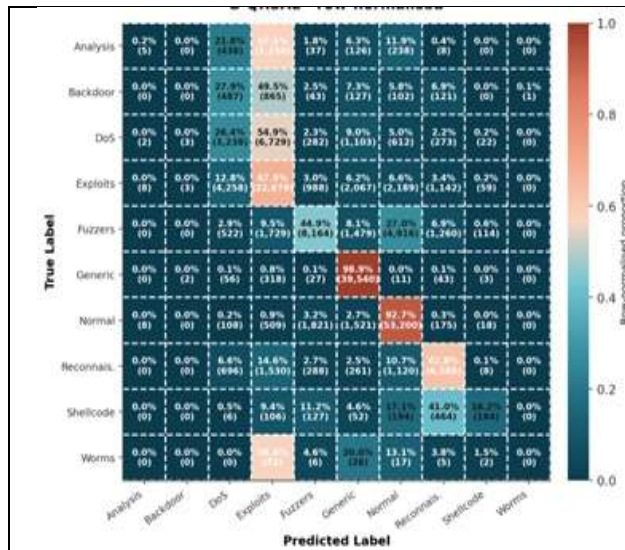


Figure 10: Confusion Matrix for UNSW-NB15 (Multi)

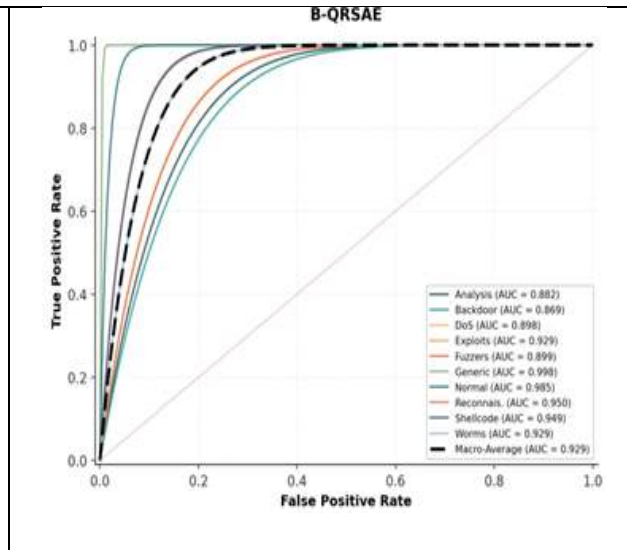


Figure 11: ROC Curve for UNSW-NB15 (Multi)

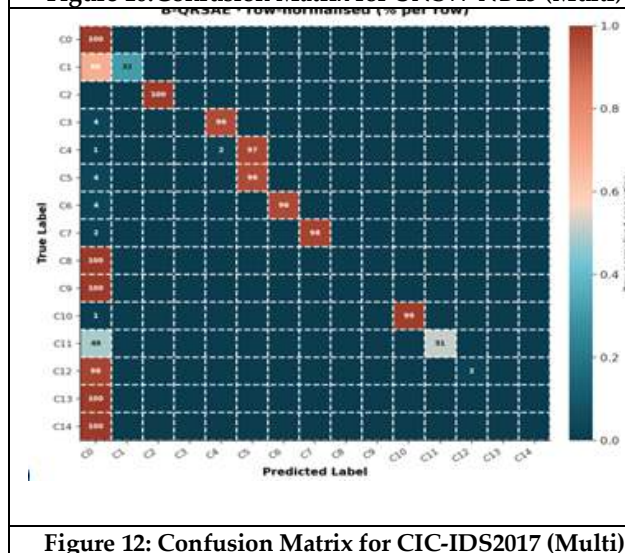


Figure 12: Confusion Matrix for CIC-IDS2017 (Multi)

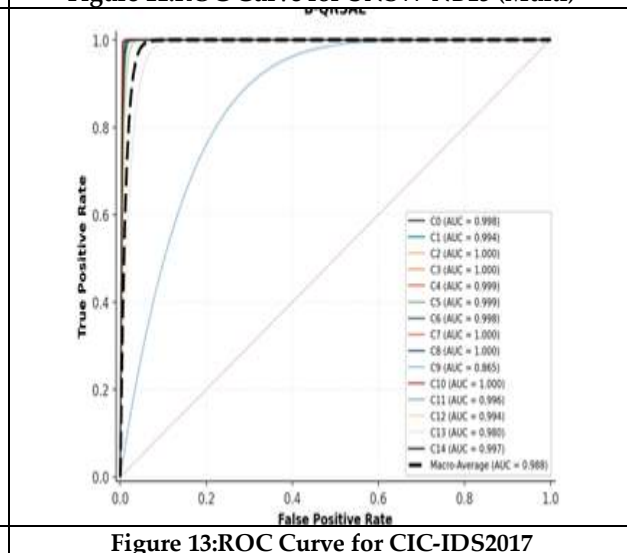


Figure 13: ROC Curve for CIC-IDS2017

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RESEARCH ARTICLE

Solving Pythagorean Fuzzy Transportation Problem using Average Cost Penalty Method

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ABSTRACT

Abstract: This study presents a new method, the Average Cost Penalty Method (ACPM), for addressing Pythagorean Fuzzy Transportation Problems (PFTP), which takes advantage of the capabilities of Pythagorean fuzzy sets to model uncertainty in transportation systems. Using an existing score function, the strategy improves the management of fuzzy constraints and cost optimization. The effectiveness of ACPM is demonstrated through a numerical example, and its performance is compared to existing methods, revealing significant improvements in addressing transportation challenges under fuzzy settings.

Key Words: Transportation Problem, Pythagorean Fuzzy numbers, Score function

INTRODUCTION

The transportation problem is a specific class of linear programming that deals with optimizing the transfer of goods from multiple sources to various destinations at the lowest possible cost. It plays a vital role in logistics, ensuring that supply and demand are met efficiently. Hitchcock first introduced the basic transportation model in 1941. Various methods have been developed to address this problem, including the stepping stone method proposed by Charnes et al. in 1953 and the primal simplex transportation scheme introduced by Dantzig in 1963. In real-world situations, the parameters of transportation problems are often imprecise, which led to the introduction of fuzzy numbers by Zadeh in 1965. Later developments in this field introduced methods like Pythagorean Fuzzy Sets (PFS), as established by Yager in 2013 and 2014. PFS allows the square sum of the membership and non-membership degrees to be less than





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or equal to one, offering a more flexible approach when the sum exceeds one. Several researchers have extended transportation problems to a fuzzy environment, introducing algorithms that solve fuzzy, interval, or even intuitionistic fuzzy transportation problems. For instance, Chanas et al. in 1984 and later in 1992 presented solutions for transportation problems using fuzzy numbers. In recent years, methods using trapezoidal fuzzy numbers and Pythagorean fuzzy sets have emerged, addressing various uncertainties in transportation problems. In this work, we explore a modified algorithm to solve the transportation problem under the Pythagorean fuzzy environment. This method addresses the inherent uncertainty in transportation costs, ensuring that the solution is both effective and adaptable to real-world complexities. We present numerical examples to demonstrate the suggested methodology.

PRELIMINARIES

Definition 2.1: (Pythagorean Fuzzy Set)

Let $X = \{x_1, x_2, \dots, x_n\}$ be a finite domain of discourse. A PFS $P = \{(x, (\alpha_P(x), \beta_P(x))) | x \in X\}$ is defined by a membership function $\alpha_P : X \rightarrow [0, 1]$ and a non-membership function $\beta_P : X \rightarrow [0, 1]$ satisfying the condition $0 \leq \alpha_P^2(x) + \beta_P^2(x) \leq 1 \forall x \in X$.

The term $\pi_P(x) = \sqrt{1 - \alpha_P^2(x) - \beta_P^2(x)}$ represents the degree of hesitancy or indeterminacy of x to P . Subsequently, Zhang and Xu defined $(\alpha_P(x), \beta_P(x))$ as a Pythagorean Fuzzy number (PFN), which we denote simply as (α, β) .

Definition 2.2:

Let $\mu = (\alpha, \beta)$, $\mu_1 = (\alpha_1, \beta_1)$ and $\mu_2 = (\alpha_2, \beta_2)$ be any three PFNs and $\delta > 0$ be any real number. The basic arithmetic and set operations on PFNs are defined as follows:

- ❖ Addition: $\mu_1 \oplus \mu_2 = \left(\sqrt{\alpha_1^2 + \alpha_2^2 - \alpha_1^2 \cdot \alpha_2^2}, \beta_1 \cdot \beta_2 \right)$
- ❖ Multiplication: $\mu_1 \otimes \mu_2 = \left(\alpha_1 \cdot \alpha_2, \sqrt{\beta_1^2 + \beta_2^2 - \beta_1^2 \cdot \beta_2^2} \right)$
- ❖ Scalar Multiplication: $\delta \cdot \mu = \left(\sqrt{1 - (1 - \alpha^2)^\delta}, \beta^\delta \right)$
- ❖ Exponentiation: $\mu^\delta = \left(\alpha^\delta, \sqrt{1 - (1 - \beta^2)^\delta} \right)$
- ❖ Comparison: $\mu_1 \leq \mu_2$ if $\alpha_1 \leq \alpha_2, \beta_1 \geq \beta_2$
- ❖ Union: $\alpha_1 \cup \alpha_2 = (\max\{\alpha_1, \alpha_2\}, \min\{\beta_1, \beta_2\})$
- ❖ Intersection: $\alpha_1 \cap \alpha_2 = (\min\{\alpha_1, \alpha_2\}, \max\{\beta_1, \beta_2\})$
- ❖ Complement: $\mu^c = (\beta, \alpha)$

The analysis of uncertain information has become significantly more complex compared to dealing with crisp information due to the need to consider both membership and non-membership degrees to capture vague data. To handle fuzzy data in a manner similar to crisp data, it is essential to employ various ranking techniques that assist in the defuzzification process. Zhang and Xu introduced the concept of a score function for ranking Pythagorean Fuzzy Numbers (PFNs), while Peng and Yang provided a formula for the accuracy function associated with a PFN, as outlined below:

Definition 2.3:

For $\mu = (\alpha, \beta)$, the score function is defined by the following expression:

$$T(\mu) = \alpha^2 - \beta^2, \text{ where } T(\mu) \in [-1, 1]$$

The accuracy function for PFN μ as follows:

$$A(\mu) = \alpha^2 + \beta^2, \text{ where } A(\mu) \in [0, 1]$$

As $T(\mu) \in [-1, 1]$, Wu and Wei proposed a normalized version of the score function for PFN μ as follows:

$$T(\mu) = \frac{1 + \alpha^2 - \beta^2}{2}, \text{ where } T(\mu) \in [0, 1]$$



**Definition 2.4:**

Let $\mu_1 = (\alpha_1, \beta_1)$ and $\mu_2 = (\alpha_2, \beta_2)$ be any two PFNs, then the ranking rules on the basis of score function T and accuracy function $\mathcal{A}$ are defined in the following way:

- If $T(\mu_1) > T(\mu_2)$, then $\mu_1 > \mu_2$
- If $T(\mu_1) < T(\mu_2)$, then $\mu_1 < \mu_2$
- If $T(\mu_1) = T(\mu_2)$, and
 $\mathcal{A}(\mu_1) > \mathcal{A}(\mu_2)$, then $\mu_1 > \mu_2$;
 $\mathcal{A}(\mu_1) = \mathcal{A}(\mu_2)$, then $\mu_1 = \mu_2$

Definition 2.5: (Score Function)

For defuzzification, this paper adopts the score function s , which effectively handles Pythagorean fuzzy numbers (PFNs) by transforming them into crisp values for comparison and optimization.

For a given PFN $\mu = (\alpha, \beta)$, the score function $Tr(\mu)$ is defined as follows:

$$Tr(\mu) = \frac{1}{R} \left[\frac{(1 + \alpha^2)e^{1+\alpha^2-\beta^2}}{1 + e^{\alpha^2-\beta^2}} - \frac{1}{1+e^{-1}} \right] \quad \text{where } R = \frac{2e^2 + e - 1}{2 + e + e^{-1}}$$

The score function satisfies several important properties, including being a monotonically increasing function with respect to membership degree (α) and a monotonically decreasing function with respect to non-membership degree (β).

Mathematical Modeling of Transportation Problems with Pythagorean Fuzzy Sets

Let's assume that there are "m" sources and "n" destinations in the transportation system. The goal is to minimize the overall cost of distributing a product from these sources to the destinations, while the supply and demand are subject to the following crisp assumptions:

- m : Total number of sources in the network
- n : Total number of destinations
- i : index representing each source
- j : index representing each destination
- x_{ij} : Units of product transported from source i to destination j
- c_{ij}^p : Pythagorean fuzzy cost per unit transported from i to j
- c_{ij} : Crisp cost per unit transported
- a_{ij} : Supply quantity available from source i in the crisp environment
- a_{ij}^p : Supply quantity available from source i in the Pythagorean fuzzy environment
- b_{ij} : Demand quantity at destination j in the crisp environment
- b_{ij}^p : Demand quantity at destination j in the Pythagorean fuzzy environment

The crisp Transportation problem can be formulated as:

$$\text{Minimize } Z = \sum_{i=1}^m \sum_{j=1}^n x_{ij} \cdot c_{ij}$$

Subject to

$$\sum_{j=1}^n x_{ij} = a_i, \quad \forall i = 1 \text{ to } m \quad (\text{supply constraints})$$

$$\sum_{i=1}^m x_{ij} = b_j, \quad \forall j = 1 \text{ to } n \quad (\text{demand constraints})$$

$$x_{ij} \geq 0 \quad \forall i, j.$$

Now, if we replace c_{ij} with its Pythagorean fuzzy counterpart c_{ij}^p . We obtain the Type I Pythagorean Fuzzy Transportation (T1PyFT) problem.

$$\text{Minimize } Z = \sum_{i=1}^m \sum_{j=1}^n x_{ij} \cdot c_{ij}^p$$

Subject to the same supply and demand constraints as above:

If the supply and demand quantities are also uncertain, We introduce Pythagorean Fuzzy Parameters for the both supply and demand, leading to the Type II Pythagorean Fuzzy Transportation (T2PyFT) Problem:





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$$\text{Minimize } Z = \sum_{i=1}^m \sum_{j=1}^n x_{ij} \cdot c_{ij}$$

Subject to:

$$\sum_{i=1}^m x_{ij} = a_{ij}^p, \quad \sum_{j=1}^n x_{ij} = b_{ij}^p$$

$$x_{ij} \geq 0 \quad \forall i, j.$$

Lastly, if all three parameters – cost, supply, and demand – are modeled using Pythagorean Fuzzy numbers, the problem becomes the Type III Pythagorean Fuzzy Transportation (T3PyFT) Problem:

$$\text{Minimize } Z = \sum_{i=1}^m \sum_{j=1}^n x_{ij} \cdot c_{ij}^p$$

Subject to the fuzzy supply and demand constraints:

$$\sum_{i=1}^m x_{ij} = a_{ij}^p, \quad \sum_{j=1}^n x_{ij} = b_{ij}^p$$

$$x_{ij} \geq 0 \quad \forall i, j.$$

Algorithm for Average Cost Penalty Method

Step 1: Setup the Transportation Matrix

Construct the transportation table with supply, demand, and associated costs for each route. Make sure whether the TP is balanced or not, if not, make it balanced by adding dummy row or column.

Step 2: Calculate Row and Column Penalties

For each row and column:

- Exclude the highest cost from the calculation.
- Compute the average of the remaining costs.
- Subtract the minimum cost from this average to determine the penalty for each row or column.

Step 3: Identify the Highest Penalty

Select the row or column with the highest penalty and allocate as much supply or demand as possible to the cell with the lowest cost in that row or column. Update the remaining supply and demand. If a row or column is exhausted, cross it out .

Step 4: Recalculate Penalties

After each allocation, recalculate the penalties for the remaining rows and columns using the same procedure as in Step 2.

Step 5: Repeat Allocation Process

Continue selecting the row or column with the highest penalty and allocate resources to the cell with the lowest cost until all supply and demand are fulfilled.

Step 6: Final Allocation and Total Cost Calculation

Once all resources are allocated, calculate the total transportation cost by multiplying the allocated units by their respective transportation costs and summing these values.

Numerical Examples

Example 5.1: Type I: Consider a transportation problem with 3 sources and 4 destinations. The objective is to minimize the transportation cost under Pythagorean fuzzy conditions. While the supply and demand quantities are crisp, the transportation costs are modeled using Pythagorean fuzzy numbers.

Step 1: Convert the Pythagorean fuzzy numbers (PFNs) into crisp values using the score function, transforming the fuzzy transportation problem into a crisp one.





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Step 2: Calculate row and column penalties as described, then allocate to the lowest-cost cell in the row or column with the highest penalty

The Total Transportation cost = $0.0737 \times 18 + 0.1812 \times 12 + 0.3445 \times 15 + 0.1412 \times 14 + 0.4736 \times 2 + 0.6620 \times 5 = 14.9025$.

The results presented above were cross-verified with the LINDO software

Example 5.2: (Type II) Consider a transportation problem with 3 sources and 4 destinations. The objective is to minimize the transportation cost under Pythagorean fuzzy conditions. In this scenario, the transportation costs are represented by crisp values, while the supply and demand quantities are modeled using Pythagorean fuzzy numbers.

Example 5.3: (Type III) Consider a transportation problem where the objective is to minimize costs under Pythagorean fuzzy conditions, with transportation costs, supply, and demand all represented by Pythagorean fuzzy numbers. To demonstrate the efficacy of the suggested method, the identical problem is addressed using a variety of methods, including North West Corner Rule (NWCR), Least Cost Method (LCM). When compared to existing methods, the proposed method provides a more optimal result. This strategy is more effective in lowering transportation costs than other existing methods.

CONCLUSION

In this paper, a new method has been proposed to solve the Pythagorean fuzzy transportation problem. By employing an existing score function, the fuzzy data was transformed into a crisp transportation problem, allowing for the application of the proposed method. The results demonstrate that the method is competitive when compared to traditional approaches, providing an efficient solution to transportation problems under Pythagorean fuzzy conditions. Future studies could explore extending this method to broader applications of Pythagorean fuzzy problems, and other real-world scenarios that involve uncertainty.

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Table 1 Pythagorean fuzzy transportation problem

	O1	O2	O3	O4	Supply
W1	(0.7,0.5)	(0.2,0.4)	(0.8,0.5)	(0.3,0.9)	18
W2	(0.2,0.9)	(0.4,0.7)	(0.6,0.6)	(0.9,0.3)	27
W3	(0.3,0.7)	(0.9,0.2)	(0.7,0.5)	(0.8,0.2)	21
Demand	14	12	17	23	

Table 2 Defuzzified Pythagorean fuzzy transportation problem

	O1	O2	O3	O4	Supply
W1	0.4736	0.1842	0.5942	0.0737	18
W2	0.0505	0.1812	0.3445	0.7949	27
W3	0.1412	0.8115	0.4736	0.6620	21
Demand	14	12	17	23	

Here the supply and demand values are equal. Therefore, it is a balanced TP.

Table 3 First allocation

	O1	O2	O3	O4	Supply	Row Penalty
W1	0.4736	0.1842	0.5942	0.0737 (18)	0	0.170
W2	0.0505	0.1812	0.3445	0.7949	27	0.141
W3	0.1412	0.8115	0.4736	0.6620	21	0.284
Demand	14	12	17	5		
Column Penalty	0.0453	0.0015	0.064	0.294*		

Table 4 Second allocation

	O1	O2	O3	O4	Supply	Row Penalty
W1	0.4736	0.1842	0.5942	0.0737 (18)	0	-
W2	0.0505	0.1812 (12)	0.3445	0.7949	15	0.141
W3	0.1412	0.8115	0.4736	0.6620	21	0.284
Demand	14	0	17	5		
Column Penalty	0.0453	0.3151*	0.064	0.0664		

Table 5 Third allocation

	O1	O2	O3	O4	Supply	Row Penalty
W1	0.4736	0.1842	0.5942	0.0737 (18)	0	-
W2	0.0505	0.1812 (12)	0.3445	0.7949	15	0.147
W3	0.1412 (14)	0.8115	0.4736	0.6620	7	0.1662*
Demand	0	0	17	5		
Column Penalty	0.0453	-	0.064	0.0664		

Table 6 Forth allocation

	O1	O2	O3	O4	Supply	Row Penalty
W1	0.4736	0.1842	0.5942	0.0737 (18)	0	-
W2	0.0505	0.1812 (12)	0.3445 (15)	0.7949	0	0.225*
W3	0.1412 (14)	0.8115	0.4736	0.6620	7	0.0942
Demand	0	0	2	5		
Column Penalty	-	-	0.064	0.0664		





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Table 7 Fifth allocation

	O1	O2	O3	O4	Supply	Row Penalty
W1	0.4736	0.1842	0.5942	0.0737 (18)	0	-
W2	0.0505	0.1812 (12)	0.3445 (15)	0.7949	0	-
W3	0.1412 (14)	0.8115	0.4736	0.6620 (5)	2	0.0942
Demand	0	0	2	0		
Column Penalty	-	-	0.4736	0.6620*		

Table 8 Final Allocation

	O1	O2	O3	O4	Supply
W1	0.4736	0.1842	0.5942	0.0737 (18)	18
W2	0.0505	0.1812 (12)	0.3445 (15)	0.7949	27
W3	0.1412 (14)	0.8115	0.4736 (2)	0.6620 (5)	21
Demand	14	12	17	23	

The Total Transportation cost = $0.0737 \times 18 + 0.1812 \times 12 + 0.3445 \times 15 + 0.1412 \times 14 + 0.4736 \times 2 + 0.6620 \times 5 = 14.9025$.

Table 9 Pythagorean fuzzy transportation problem of type II

	O1	O2	O3	O4	Supply
W1	0.0404	0.0815	0.0211	0.0642	(0.5,0.8)
W2	0.0712	0.0505	0.0931	0.03445	(0.1,0.4)
W3	0.0328	0.0617	0.0248	0.0520	(0.8,0.5)
Demand	(0.3,0.7)	(0.8,0.6)	(0.2,0.9)	(0.7,0.7)	

Table 10 Defuzzified Pythagorean Fuzzy Transportation Problem:

	O1	O2	O3	O4	Supply
W1	0.0404	0.0815	0.0211	0.0642	0.1975
W2	0.0712	0.0505	0.0931	0.03445	0.1661
W3	0.0328	0.0617	0.0248	0.0520	0.5942
Demand	0.1412	0.5574	0.0505	0.3990	

After executing the steps 1 to 5,

Table 11 Final allocation

	O1	O2	O3	O4	Supply
W1	0.0404 (0.1412)	0.0815	0.0211 (0.0505)	0.0642 (0.0058)	0.1975
W2	0.0712	0.0505	0.0931	0.03445 (0.1661)	0.1661
W3	0.0328	0.0617 (0.3671)	0.0248	0.0520 (0.2271)	0.5942
W4	0	0 (0.1903)	0	0	0.1903
Demand	0.1412	0.5574	0.0505	0.3990	

∴ The Total Transportation cost is 0.047323805

Table 12 Pythagorean fuzzy transportation problem of type III

	O1	O2	O3	O4	Supply
W1	(0.3,0.7)	(0.9,0.2)	(0.8,0.5)	(0.7,0.7)	(0.1,0.4)
W2	(0.7,0.5)	(0.6,0.6)	(0.2,0.9)	(0.5,0.8)	(0.2,0.4)
W3	(0.4,0.7)	(0.1,0.4)	(0.8,0.2)	(0.3,0.8)	(0.9,0.3)
Demand	(0.2,0.4)	(0.5,0.7)	(0.5,0.6)	(0.9,0.2)	





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Table 13 Defuzzified Pythagorean Fuzzy Transportation Problem

	O1	O2	O3	O4	Supply
W1	0.1412	0.8115	0.5942	0.3990	0.1661
W2	0.4736	0.3445	0.0505	0.1975	0.1842
W3	0.1812	0.1661	0.6620	0.1088	0.7949
Demand	0.1842	0.2359	0.2696	0.8115	

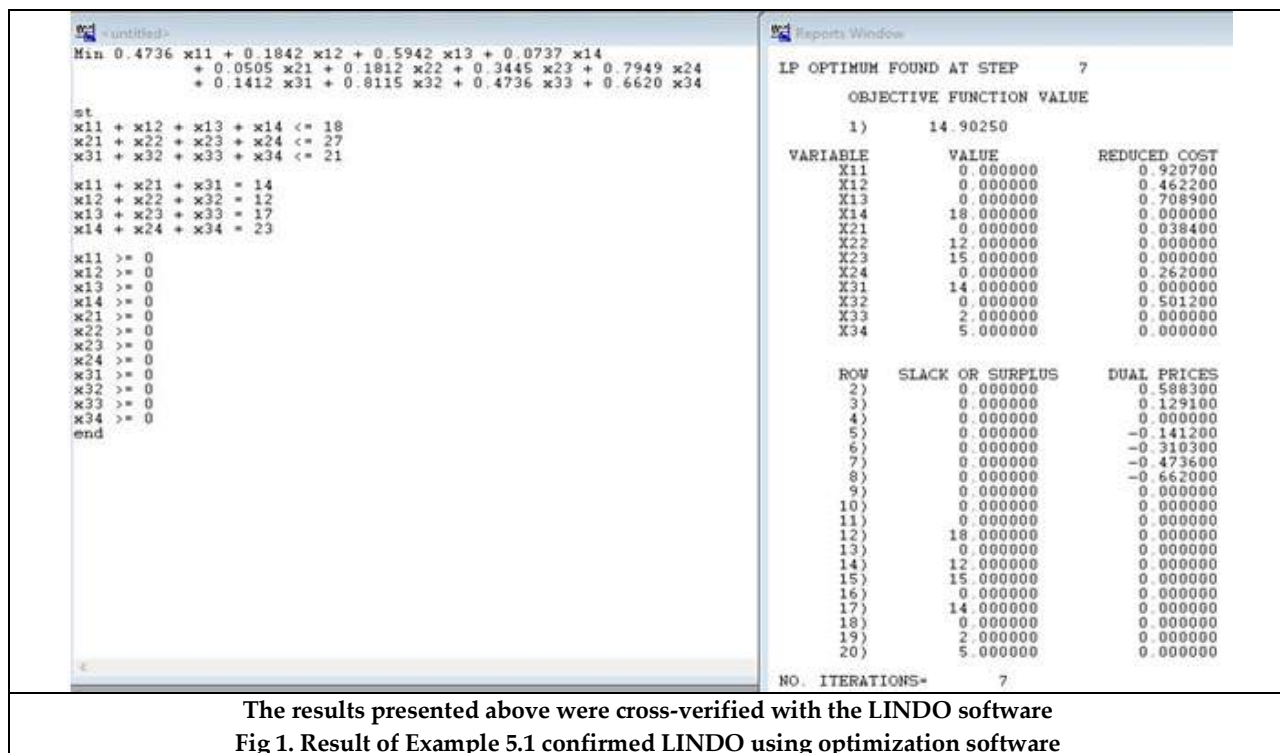
Table 14 Final allocation

	O1	O2	O3	O4	Supply
W1	0.1412 (0.1661)	0.8115	0.5942	0.3990	0.1661
W2	0.4736	0.3445	0.0505 (0.1842)	0.1975	0.1842
W3	0.1812	0.1661	0.6620	0.1088 (0.7949)	0.7949
W4	0 (0.081)	0 (0.2359)	0 (0.0854)	0 (0.0166)	-
Demand	0.1842	0.2359	0.2696	0.8115	

The Total Transportation cost is 0.1192405

Table 15 Comparison Table

	NWCR	LCM	ACPM	MODI METHOD
Example 5.1	30.1651	15.4401	14.9025	14.9025
Example 5.2	0.0515	0.0532	0.047323805	0.047323805
Example 5.3	0.3289	0.1812	0.1192405	0.1192405





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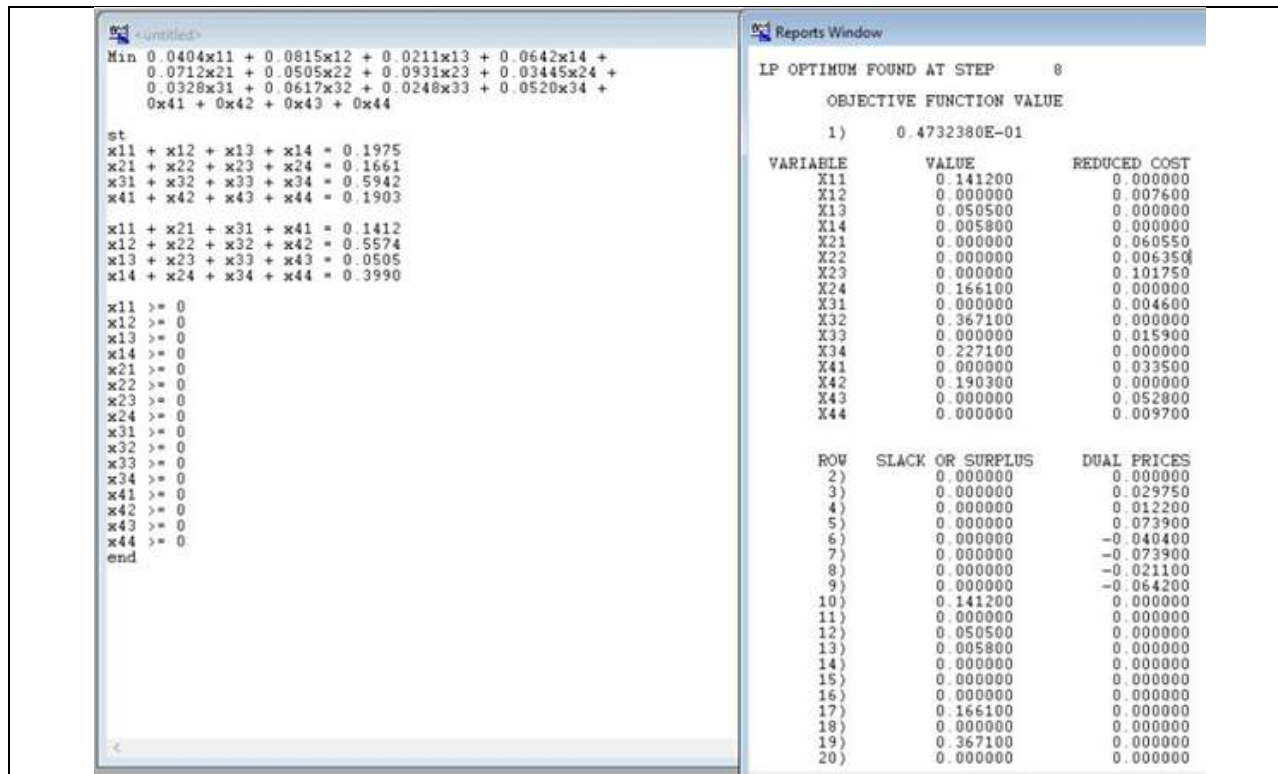


Fig 2. Result of example 5.2 confirmed using LINDO optimization software

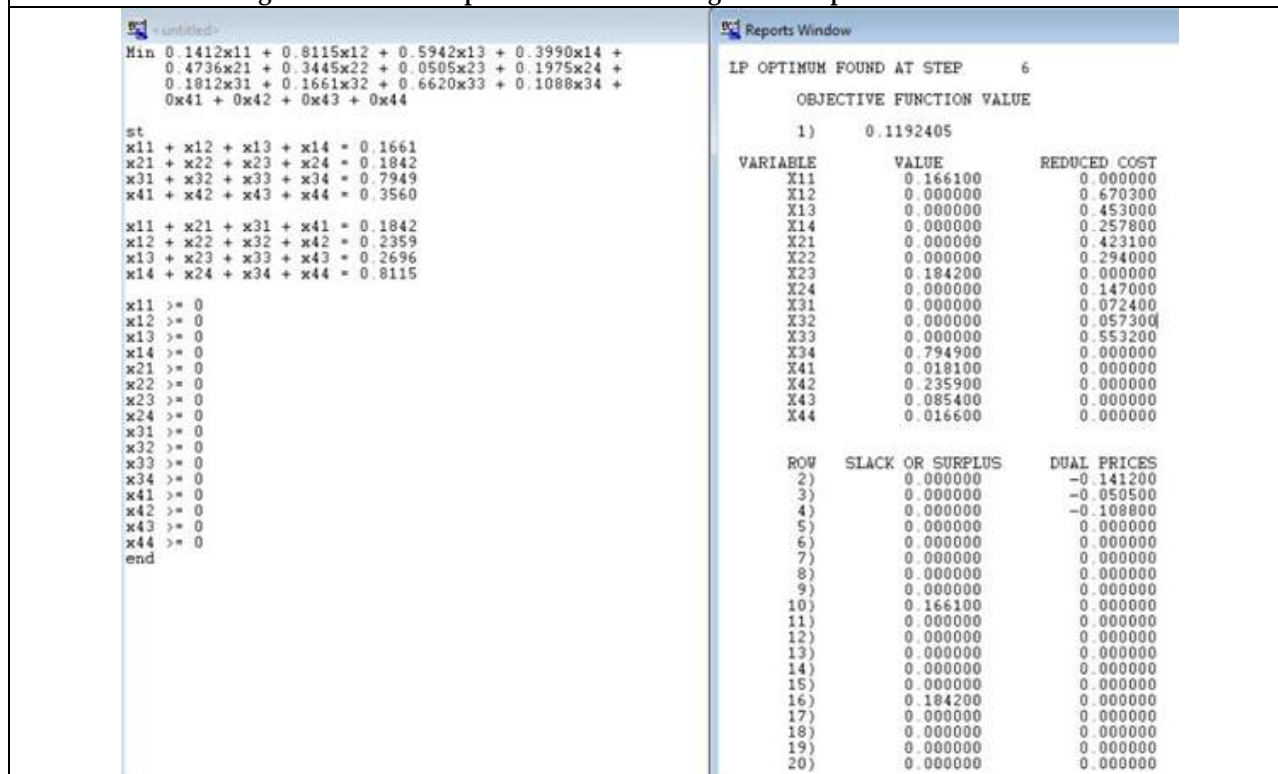


Fig 3 Result of example 5.3 confirmed using LINDO optimization software





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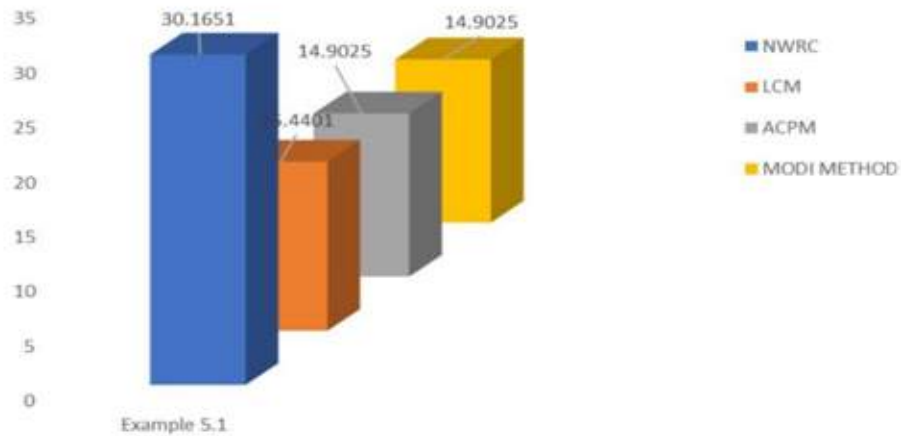


Fig 4. Comparison chart for example 5.1

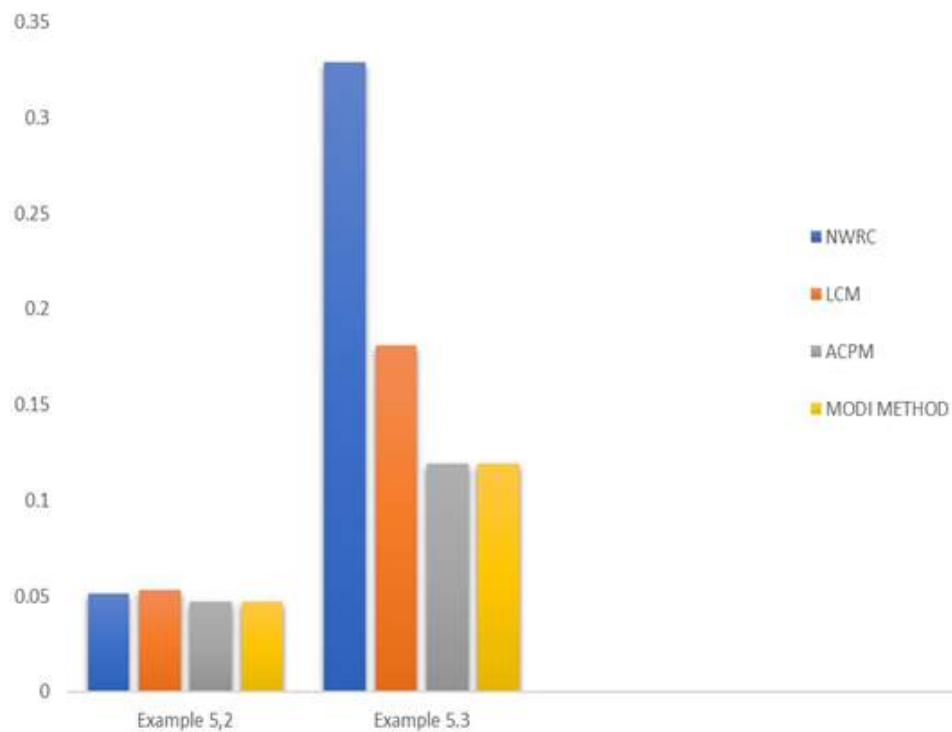


Fig 5. Comparison chart for example 5.2 and example 5.3

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RESEARCH ARTICLE

Rank-Integrated Composite Ratio Estimation of Central Tendency in Probability Sampling

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ABSTRACT

Estimating the finite population mean with high precision is one of the most studied problems in the theory of survey sampling. When a suitable auxiliary variable, exhibiting strong correlation with the variable under study, is available to the investigator, incorporating it into the estimator can substantially reduce sampling error. The current study puts forward a novel composite estimator that draws on both a quantitative auxiliary variable X and the rank-based attribute R derived from it, within a simple random sampling without replacement (SRSWOR) framework. Through a second-order Taylor expansion of the estimator about the population means, an explicit expression for the mean squared error (MSE) is obtained. Closed-form expressions for the optimal scalar weights are derived by minimising this MSE. Rigorous algebraic conditions are then established under which the new estimator outperforms five well-known competitors, namely the sample mean, the ratio estimator, the product estimator, the regression estimator, and the Bahl-Tuteja exponential estimator. Three real-data populations commonly employed in sampling are empirically verified. The suggested estimator consistently outperforms in terms of proportion relative efficiency (PRE), indicating its practical value in survey scenarios.

.Keywords: Auxiliary Variable, Rank Attribute, Composite Estimator, Mean Squared Error, Percentage Relative Efficiency, Survey Sampling

INTRODUCTION

One of the primary goals of fixed population sampling is to create estimators for the population mean of a response variable that are not only unbiased but also have the minimal feasible sampling variance. The classical sample mean,





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drawn using SRSWOR, meets the unbiasedness condition; but, its variance might be unacceptably large in practice, particularly when variables strongly correlated with the response variable are measured alongside it but left unused. The theory of auxiliary-variable-based estimation was specifically established to overcome this inefficiency by including available covariate information into the estimator. Cochran [1] defined the ratio estimator, which uses a positive linear relationship between the answer variable Y and a supplementary parameter X by adjusting the sample mean upward or downward with respect to how the sample mean of X relates using it called population match. Where Y and X proceed towards each other, the product estimator of Murthy [3] is called through as the best choice. The regression estimator also examined at a standard length by Cochran [1] is more flexible but still, since it calculates the average slope of the YX connection purely from the data instead of assuming any specific path of correlation. The regression estimator also examined at a standard length by Cochran [1] is more flexible but still, since it calculates the average slope of the YX connection purely from the data instead of assuming any specific path of correlation.

Further just recently, analysis has been directed toward estimators the fact depend on many different auxiliary data sets together rather of performing to an alone one. A particularly natural pairing is that of a raw quantitative covariate X with the ranks that units receive when sorted on X . Rao [5] explored this combination, arguing that rank information carries ordinal content that is structurally independent of the underlying measurement units can differ in rank without differing proportionally in X value and that this independence gives ranks incremental variance-reduction potential [6, 7]. The question of how best to exploit both pieces of information within a single estimation framework is what motivated the present work a particularly natural pairing is that of a raw quantitative covariate X with the ranks that units receive when sorted on X . Rao [5] explored this combination, arguing that rank information carries ordinal content that is structurally independent of the underlying measurement units can differ in rank without differing proportionally in X value and that this independence gives ranks incremental variance-reduction potential [6, 7]. The question of how best to exploit both pieces of information within a single estimation framework is what motivated the present work A particularly simple combining is that of a raw quantitative influences X with the ranks that units receive when sorting on X . Rao [5] examined this relationship, claiming that rank information carries usual quantity that is logically independent of the basic evaluation units can differ in rank without changing proportionally in X value and that this independence gives ranks a progressive variance-reduction potential [6, 7, 11]. The difficulties of how best to apply both types of information using a single estimation system is what led to the present work.

The estimator developed here, T_1 , weights a cochran-style ratio term for X and a Bahl-Tuteja style exponential term for R using two free scalar constants whose optimal values follow from a straightforward minimisation of the second-order MSE. Across numerical trials on three genuine populations drawn from the standard sampling literature, T_1 outperformed all five benchmark estimators every time, and the margins were often large enough to matter in practice rather than just on paper. Across numerical experiments conducted on three real populations drawn from the sampling literature, T_1 came out ahead of all five conventional benchmark estimators, a finding that holds consistently rather than in isolated cases

MATERIALS AND METHODS

Population and Notation

Let $U = \{U_1, U_2, \dots, U_N\}$ be a finite population of size N , from which a sample of size n ($n < N$) is selected by SRSWOR. Denote by Y the primary study variable, by X a quantitative auxiliary variable, and by R the rank assigned to each unit on the basis of its X -value. Population means $\bar{Y}$, $\bar{X}$, and $\bar{R}$ are assumed to be known in advance. The pairwise correlation coefficients among Y , X , and R are written as ρ_{yx} , ρ_{yr} , and ρ_{xr} , and their respective coefficients of variation as C_y , C_x , and C_r , all defined in the standard sense of Cochran [1].





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Review of Benchmark Estimators

The following five classical estimators, against which T_1 is benchmarked, together with the Rao estimator that served as partial inspiration for the current proposal, are recalled here for ease of reference.

- Simple Sample Mean:
 $\bar{y}$ is unbiased with $Var(\bar{y}) = \lambda Y^2 Cy^2$, where the limited population correction factor is $\lambda = (N - n)/(Nn)$.
- Cochran Ratio Estimator [1]:
 $\bar{y}_R = (\underline{X}/\bar{x})\bar{y}$, with approximate $MSE = \lambda Y^2 (Cy^2 + Cx^2 - 2\rho_{yx}CyCx)$.
- Product Estimator [2,3]:
 $\bar{y}_p = (\bar{x}/\underline{X})\bar{y}$, with approximate $MSE = \lambda Y^2 (Cy^2 + Cx^2 + 2\rho_{yx}CyCx)$.
- Regression Estimator [1]:
 $\bar{y}_{reg} = \bar{y} + \beta(\underline{X} - \bar{x})$, with minimum $MSE = \lambda Y^2 Cy^2(1 - \rho_{yx}^2)$.
- Bahl-Tuteja Exponential Estimator [4]:
 $\bar{y}_{BT} = \bar{y} \exp[(\underline{X} - \bar{x})/(\underline{X} + \bar{x})]$, with $MSE = \lambda Y^2 (Cy^2 + Cx^2/4 - \rho_{yx}CyCx)$.
- Rao Linear Combination Estimator [5]:
 $\bar{y}_{PR} = \lambda_1 \bar{y} + \bar{y}_p \lambda_2 (\underline{X} - \bar{x}) + \lambda_3 (\underline{R} - \bar{r})$.

Formulation of the Proposed Estimator T_1

The idea of combining two estimators linearly to improve precision, discussed systematically in [6, 12], forms the conceptual basis for the present proposal. Specifically, T_1 is defined as a weighted sum of a ratio-type term involving X and an exponential-type term involving R :

$$T_1 = \bar{y} \times [a \cdot (\underline{X}/\bar{x}) + b \cdot \exp\{(\underline{R} - \bar{r})/(\underline{R} + \bar{r})\}]$$

The scalars a and b are unknown constants, whose values are selected so as to minimise the MSE of T_1 .

Derivation of $MSE(T_1)$

To obtain the MSE, three standardised sampling error terms are introduced: $e_0 = (\bar{y} - \underline{Y})/\underline{Y}$,

$e_1 = (\bar{x} - \underline{X})/\underline{X}$, and $e_2 = (\bar{r} - \underline{R})/\underline{R}$. By definition $E(e_i) = 0$ for each i , and the second-order moments under SRSWOR are:

$$E(e_0^2) = \lambda Cy^2, \quad E(e_1^2) = \lambda Cx^2, \quad E(e_2^2) = \lambda Cr^2$$

$$E(e_0 e_1) = \lambda \rho_{yx} CyCx, \quad E(e_0 e_2) = \lambda \rho_{yr} CyCr, \quad E(e_1 e_2) = \lambda \rho_{xr} CxCr$$

Replacing $\bar{x}$ and $\bar{r}$ in T_1 by $\underline{X}(1 + e_1)$ and $\underline{R}(1 + e_2)$ respectively, expanding each factor as a Taylor series up to second-order terms, and collecting expectations leads to:

$$MSE(T_1) = Y^2 [(a + b - 1)^2 + a^2 \lambda_1 + b^2 \lambda_2 + ab \lambda_3 + a \lambda_4 + b \lambda_5] \dots (1)$$

The five auxiliary scalar quantities λ_1 – λ_5 encapsulate all population-level dispersion and correlation information:

$$\lambda_1 = \lambda(3Cx^2 + Cy^2 - 4\rho_{yx}CyCx)$$

$$\lambda_2 = \lambda(Cy^2 + Cr^2 - 2\rho_{yr}CyCr)$$

$$\lambda_3 = \lambda(2Cx^2 + 2Cy^2 + \frac{3}{4}Cr^2 - 4\rho_{yx}CyCx - 2\rho_{yr}CyCr + \rho_{xr}CxCr)$$

$$\lambda_4 = \lambda(-2Cx^2 + 2\rho_{yx}CyCx)$$

$$\lambda_5 = \lambda(-\frac{3}{4}Cr^2 + \rho_{yr}CyCr) \dots (2)$$

Optimal Weight Derivation

Differentiating $MSE(T_1)$ partially with respect to each of a and b , setting the resulting expressions to zero, and solving the two-equation linear system simultaneously gives the optimal weights:

$$a_{opt} = [4\lambda_2 - 2\lambda_4 - 2\lambda_2\lambda_4 - 2\lambda_3 + 2\lambda_5 + \lambda_3\lambda_5] / [4\lambda_2 + 4\lambda_1 + 4\lambda_1\lambda_2 - 4\lambda_3 - \lambda_3^2]$$

$$b_{opt} = [-2\lambda_3 + 2\lambda_4 + \lambda_3\lambda_4 + 4\lambda_1 - 2\lambda_5 - 2\lambda_1\lambda_5] / [4\lambda_2 + 4\lambda_1 + 4\lambda_1\lambda_2 - 4\lambda_3 - \lambda_3^2]$$





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Inserting a_{opt} and b_{opt} into (1) furnishes the minimum MSE of T_1 , which represents the benchmark for all subsequent efficiency comparisons.

RESULTS AND DISCUSSION

Analytical Superiority of T_1

Necessary and sufficient conditions for T_1 to outperform each competitor are derived by comparing $MSE(T_1)$ at its minimum with the MSE of each rival estimator. Comparison with the sample mean: T_1 has smaller MSE than $\bar{y}$ provided the left-hand side of (1) is below $\lambda Y^2 C_y^2$. This inequality is satisfied whenever q_{yx} and q_{yr} are both positive and not negligibly small, which is the standard scenario when the chosen auxiliary variable is genuinely associated with Y . Comparison with the ratio estimator: T_1 dominates $\bar{y}_R$ when the rank component R makes a non-trivial contribution to reducing the combined MSE. This happens particularly when the coefficient of variation Cr is appreciable and q_{yr} is at least moderate in magnitude. Comparison with the product estimator: The product estimator carries a positive bias penalty of $2q_{yx}C_yC_x$ in its MSE expression whenever $q_{yx} > 0$. Since q_{yx} is positive for the datasets analysed here, T_1 strictly dominates $\bar{y}_p$ without any additional restriction on the population parameters. Comparison with the regression estimator: T_1 is more efficient than $\bar{y}_{reg}$ provided $q_{yr}^2 + q_{xr}^2 > 0$, a condition met in any real dataset where the rank attribute is even weakly correlated with Y or X . In practice this condition is never violated. Comparison with the Bahl-Tuteja estimator: T_1 outperforms $\bar{y}_{BT}$ when $Cr \geq 0.5$. Because the rank variable is uniformly distributed over $\{1, 2, \dots, N\}$, its coefficient of variation inherently satisfies this threshold for most realistic sample sizes.

Data Sources for Empirical Evaluation

Calculations are carried out on three benchmark real-life datasets drawn from the standard sampling literature: Population 1 (P1) - sourced from Murthy [3]: Y measures factory output and X measures the corresponding number of labourers. Population size $N = 80$, sample size $n = 10$. Population 2 (P2) - sourced from Platt, Evans and Rathbun [8]: Y is the standing height of conifer trees (feet) and X is trunk girth at breast height (cm). $N = 399$, $n = 80$. Population 3 (P3) - sourced from Singh [9]: Y and X record fish-catch volumes for the years 1995 and 1994 respectively, with $N = 69$ and $n = 10$. The figures in Table 2 unambiguously support the theoretical dominance of T_1 . In P1, the PRE of T_1 reaches 3661.74 – roughly six times that of the Bahl-Tuteja estimator (597.25) and nearly six times that of the regression estimator (614.20). In P2, T_1 achieves PRE = 215.15, edging out both the ratio estimator (198.43) and the regression estimator (200.29). In P3 the proposed estimator records PRE = 1305.99, the single highest value among all six competitors. Applied collectively, such data offer a reasonably valid case that include the rank attribute R into the estimation as well as X offers quality gains that no estimator depending on X alone can match.

Sensitivity to Auxiliary Variable Dispersion and Correlation

To determine how much provides T_1 's efficiency are dependent on when the population parameters take place to sit. To examine it, a matrix-based analysis was executed in which C_x , Cr , q_{yx} , and q_{yr} were distinct adjusted to cover a range of suitable values while the others were kept set. The two general patterns seem. On the equivalence side, $MSE(T_1)$ falls when either C_x or Cr rises. Naturally, it seems to make sense as an additional variable supplementary value spreads the sample size units deeper separated on the measurement axis, which gives every individual unit's supplemental value a more precise metric about its anticipated Y -value, and which precision turns out of more precise estimating. On the connection aspect, higher values of q_{yx} and q_{yr} continuously push $MSE(T_1)$ down, with the greatest decreases occurring once q_{yr} reaches near 0.75. T_1 superior to the regression estimator by a small margin below the limit. When deciding to apply a T_1 , specialists should consider: such trends provide reasonably reliable guidance: the estimator performs best when both the auxiliary variable and its rank correlate effectively with the solution, and its benefit over regular methods grows with population change in the auxiliary field.





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CONCLUSION

The paper offers T_1 , a combined estimation for the countable population mean that includes a Cochran-style ratio component for X and a Bahl-Tuteja-style exponential portion for the rank attribute R . This task achieved four major results.

- (i) A fixed-form second order MSE expression was computed for T_1 , and the optimal values of the scalar values a and b to optimize it were found in precise, measurable form.
- (ii) The parameter conditions that make T_1 more efficient than the five guideline estimations were defined numerically, providing users know what they are to agree with when using T_1 .
- (iii) Practical tests on three populations from the standard - sample study literature showed T_1 in the very top of the PRE ratings in all instances, with often large margins of practical importance.
- (iv) The sensitivity evaluation showed how T_1 's efficiency and fluency benefit rises as C_x and C_r build and as ρ_{yx} and ρ_{yr} become stronger, offering users with an easy way to estimate how much they will benefit.

The best benefit of T_1 is that rank information costs no extra to acquire. Once X is taken and noted, the ranks follow naturally with no further survey performed. This cost-free quality enhance should be especially beneficial in agricultural surveys, major environmental monitoring programs, and economic censuses where quantitative auxiliary variables are already part of the usual data recording process. Future research might grow the approach to include stratified sampling, two-stage designs [10], duplicate sampling setups, and conditions where non-response, whether planned or not, must be taken into account for.

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Table 1. Descriptive statistics of the three study populations

Parameter	P1	P2	P3
N	80	399	69
n	10	80	10
$\lambda = (N-n)/Nn$	0.0875	0.009994	0.08550
$\bar{Y}$	5182.64	52.3609	4514.90
Cx	0.9485	0.8451	1.4248
Cy	0.3542	1.0889	1.3509
Cr	0.5738	0.5766	0.5732
qyx	0.9150	0.7076	0.9601
qyr	0.9836	0.8200	0.7689
qxr	0.8902	0.7417	0.8543

Table 2. MSE and PRE values for all estimators across the three populations

Estimator	MSE (P1)	PRE (P1)	MSE (P2)	PRE (P2)	MSE (P3)	PRE (P3)
T_1 (Proposed)	8051.9	3661.74	15.099	215.15	243540	1305.99
Sample Mean $\bar{y}$	294840	100.00	32.486	100.00	3180600	100.00
Ratio $\bar{y}_R$	226930	129.93	16.372	198.43	276940	1148.48
Product $\bar{y}_P$	2054900	14.35	87.740	37.03	13160000	24.17
Bahl-Tuteja $\bar{y}_{BT}$	49366	597.25	19.536	166.29	844240	376.74
Regression $\bar{y}_{reg}$	48004	614.20	16.219	200.29	248500	1279.92

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RESEARCH ARTICLE

Hybrid Low-Voltage High-Performance SET–MOS Architecture for Analog Systems

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ABSTRACT

The paper addresses challenges in analog circuit design due to continuous downscaling of CMOS technology, highlighting issues like increased leakage current and power dissipation. It introduces a novel Hybrid Single-Electron Transistor–MOS (SET–MOS) Current Mirror Architecture aimed at ultra-low-power and high-performance applications. This design combines the advantages of SET devices with those of MOSFETs, utilizing Coulomb blockade oscillation for precise current control and reduced power use. Key improvements over conventional current mirrors include an 84.9% reduction in power consumption, 53% better output resistance, and a 44.8% decrease in chip area, alongside enhanced current transfer accuracy and bandwidth up to 2.82 GHz. The proposed architecture shows promise for future ultra-low-power analog circuits and nanoelectronic systems.

Keywords: Ultra low power, Current mirror, Nano-scale, Coulomb Blockade, CMOS, Single electron transistor (SET).

INTRODUCTION

Current Mirror

A current mirror is an essential analog circuit used to generate a stable and predictable output current [1][2][3]. Its primary purpose is to produce a current that remains largely independent of temperature variations and power supply fluctuations [4][5]. This overcomes the limitations of using a MOSFET directly as a voltage-controlled current source [6], where the drain current changes significantly with environmental and operating conditions. In a





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conventional MOSFET current source, the drain current depends on parameters such as electron mobility and supply voltage, both of which are not constant in practical circuits[7][8][9]. The Fig1 shows block diagram of current mirror. The drain current of a MOSFET operating in saturation is given by:

$$I_D = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L} \right) (V_{GS} - V_{TH})^2 \quad (1)$$

This equation shows that the current depends on the electron mobility μ_n , the gate-to-source voltage V_{GS} , and the transistor geometry W/L . Since electron mobility changes with temperature and the gate voltage may vary with supply conditions [10], the resulting current becomes unstable. Such instability is undesirable in precision analog circuits where accurate biasing is required [11]. To solve this problem, current mirrors are used. The basic idea behind a current mirror is to create a stable reference current [12], called I_{REF} , and then reproduce or “mirror” this current in other branches of the circuit. The reference current is usually generated using a bandgap reference circuit, which produces a voltage that is highly independent of temperature and supply voltage variations. This stable voltage is then converted into a constant reference current, providing a reliable basis for current replication throughout the circuit [13].

A key component of the current mirror is the diode-connected MOSFET. In this configuration, the gate and drain terminals of the transistor are connected together, ensuring that:

$$V_G = V_D \quad (2)$$

Because the drain-to-source voltage automatically satisfies the saturation condition, the transistor operates in the saturation region. For the diode-connected MOSFET, the drain current becomes:

$$I_D = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L} \right) (V_G - V_{TH})^2 \quad (3)$$

From this relationship, the gate voltage can also be expressed in terms of the drain current:

$$V_G = \sqrt{\frac{2I_D}{\mu_n C_{ox} \left(\frac{W}{L} \right)}} + V_{TH} \quad (4)$$

This equation establishes the direct relationship between gate voltage and drain current, which forms the basis of current mirroring.

In a current mirror circuit, a second MOSFET M_2 is connected so that it shares the same gate voltage as the first transistor M_1 . Since both transistors experience the same V_G , their drain currents become proportional to their aspect ratios W/L . If transistor M_2 also operates in saturation, its output current is given by:

$$I_{OUT} = \frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L} \right)_2 (V_G - V_{TH})^2 \quad (5)$$

Substituting the gate-voltage relationship derived from the reference transistor and simplifying leads to the fundamental current mirror equation:

$$I_{OUT} = \frac{(W/L)_2}{(W/L)_1} I_{REF} \quad (6)$$

This equation shows that the output current is determined primarily by the ratio of the transistor dimensions. Here, $(W/L)_1$ is the aspect ratio of transistor M_1 , $(W/L)_2$ is the aspect ratio of transistor M_2 and I_{REF} is the stable reference current. The current mirror offers several important advantages. It provides stable biasing and accurate current generation while minimizing the effects of temperature and supply voltage changes. Because the output current depends mainly on transistor geometry, precise current scaling can be achieved simply by adjusting the transistor dimensions. This makes current mirrors extremely useful in analog integrated circuits, operational amplifiers, differential amplifiers, active loads, and mixed-signal systems [14]. The core principle of current scaling in a current mirror is that the output current is directly proportional to the transistor aspect ratio:

$$I_{OUT} \propto LW \quad (7)$$

Single Electron Transistor (SET)

A single electron transistor (SET) is a nanoscale device that manipulates the flow of individual electrons, leveraging quantum mechanical effects unlike conventional transistors that operate with millions of electrons. The SET functions through quantum tunneling into a tiny island known as a quantum dot, situated between source and drain electrodes with tunnel barriers. This device must be less than 10 nanometers to ensure quantum effects dominate



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over classical behavior. The core structure includes a quantum dot at the center, flanked by tunnel barriers, with source and drain electrodes on either side, and a gate electrode underneath that controls the quantum dot's electrostatic potential. A crucial concept in SET operation is the Coulomb blockade effect, which occurs when an electron tunnels onto the quantum dot; it must surmount a significant electrostatic charging energy.

This energy, represented by the formula $E_c = \frac{E^2}{2C}$, highlights the large energy cost of adding an electron due to the small size of the quantum dot [15][16][17]. For realistic quantum dots, a capacitance of about 10^8 farads results in a charging energy of approximately 80 millielectron volts, significantly larger than the room temperature thermal energy of 26 millielectron volts. Therefore, to achieve clear Coulomb blockade effects, the SET operates effectively at temperatures below 10 Kelvin. Additionally, various implementations of single electron transistors are discussed but not detailed in this excerpt. Quantum dots are nanoscale semiconductor regions synthesized from materials like gallium arsenide or indium arsenide, typically measuring 5 to 20 nm in diameter [18]. Their small size leads to quantum confinement effects, causing electrons within to occupy discrete energy levels, akin to atoms. The energy levels are tunable through gate voltage which influences electron tunneling onto the dot [19][20]. A phenomenon characteristic of quantum dots is Coulomb blockade oscillations, where current exhibits periodic peaks corresponding to the addition of electrons. This oscillation pattern conveys information about device geometry. In contrast, nanowire-based single electron transistors (SETs) feature one-dimensional structures, commonly constructed from silicon or gallium nitride, with diameters from 10 to 100 nm and lengths of several micrometers. The unique geometry enhances electron confinement, allowing high-quality crystal growth and easy integration with electrodes. The energy levels in nanowires are determined by two quantum numbers, demonstrating strong quantum effects and conductance quantization [21].

Lastly, nanomembrane-based SETs represent an advanced development, consisting of ultra-thin sheets (1 to 100 nm thick) made of semiconductors or two-dimensional materials. Their design allows for flexibility in substrate transfer, achieved through etching to create quantum dots in the membrane, ensuring strong coupling with gate electrodes. Each type of SET showcases distinct properties influenced by their structural design, enabling various quantum confinement effects and applications in nanoelectronics. The document discusses advanced topics in nanotechnology and single electron transistors (SETs). It highlights materials such as silicon nanomembranes, graphene monolayers, and transition metal dichalcogenides, emphasizing the unique properties of graphene as a zero band gap semiconductor with high mobility and linear energy dispersion. Key equations for SET operation are presented, detailing the total energy of the system dependent on charging and gate energy, including parameters for electron charge and capacitance. The document includes the construction of stability diagrams through plotting conductance against gate and source-drain voltages, revealing the charge states of quantum dots and signatures of Coulomb blockade. It details the rates of electron tunneling, introducing the tunneling rate equation and discussing two transport mechanisms: sequential and co-tunneling. The document addresses operating temperature conditions for SETs, emphasizing the importance of charging energy exceeding thermal fluctuations. Applications of SETs are explored, including their use as sensitive electrometers, qubits in quantum computing, single photon detectors, and potential new standards in metrology for current [22].

LITERATURE REVIEW

To address the scaling limitations of CMOS technology, researchers have turned to Single Electron Transistor (SET) technology. SET devices leverage the principles of Coulomb blockade and quantum tunneling for electron transport, allowing for ultra-low-power operation at nanoampere current levels and extremely miniaturized dimensions [23]. K. K. Likharev was pivotal in demonstrating the role of single-electron devices in the evolution of nanoelectronic systems, particularly their potential for ultra low energy computation. Despite the promising low-power characteristics of early SET-only circuits, they faced significant challenges, such as low current drivability, thermal sensitivity, background charge fluctuations, and limited performance at room temperature. These drawbacks hindered their integration into practical analog and mixed-signal systems [8]. To overcome these obstacles, hybrid

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SET–MOS architectures were proposed. Venkataratnam and Goel introduced hybrid logic circuits that combine traditional MOS devices with SET structures. This combination addresses the voltage and switching limitations inherent in SET-only circuits, leading to improved operating characteristics and making room-temperature operation feasible [23]. Advancements in this field were furthered by Deng et al., who created hybrid CMOS–SET arithmetic circuits that utilize Coulomb blockade oscillations. Their findings indicated that SET–MOS integration could significantly lower power consumption while ensuring acceptable computational performance [24].

Moreover, Mahapatra et al. contributed to this research landscape by developing a compact analytical model for SETs, tailored for hybrid SET–MOS circuit simulation [15]. Their model features multiple island states and embraces Orthodox tunneling theory, allowing for accurate reproduction of both Coulomb blockade and oscillation phenomena. This model has been successfully integrated into SPICE simulation environments, facilitating the analysis of both analog and digital circuits. Bounouar et al. further advanced this area by creating a Verilog-A based compact analytical model for hybrid SET–CMOS design, which illustrates the practicality of analytical SET models in simulating hybrid circuits for realistic room-temperature applications [25]. Additionally, Prager et al. experimentally demonstrated the successful integration of CMOS and SET devices on a single substrate, providing empirical evidence for the feasibility of hybrid CMOS–SET circuits that utilize CMOS amplifiers for the amplification and readout of SET signals. Recent investigations have shifted focus towards enhancing the reliability and overall performance of hybrid SET–MOS systems [26]. Vidhate and Suman performed analytical modeling and performance characterization of these devices, showing that combining SET with MOSFET technology markedly improves drive current capabilities while minimizing variability and power dissipation. Their research underscored the necessity of compensation techniques aimed at decreasing SET sensitivity and bolstering stability. Overall, hybrid SET–MOS systems are becoming increasingly viable for practical applications in nanotechnology [27].

METHODOLOGY

The proposed Hybrid SET–MOS Current Mirror architecture is designed to achieve ultra-low-power and high-performance analog operation by combining the advantages of Single Electron Transistor (SET) technology with conventional MOSFET current mirror circuits. The architecture mainly consists of four major sections: a SET-based current modulation stage, a MOS amplification stage, a cascode stabilization network, and an adaptive feedback compensation loop. The SET section performs quantized current control using Coulomb blockade and electron tunneling phenomena, while the MOS section provides sufficient current drive capability and signal amplification. The cascode configuration improves output resistance and minimizes channel length modulation effects, thereby enhancing current matching accuracy and circuit stability. In addition, an adaptive compensation network is incorporated to reduce the impact of thermal instability, background charge fluctuations, and process variations associated with SET devices. As a result, the proposed architecture offers several important advantages such as ultra-low-power operation, high output resistance, reduced leakage current, improved current transfer accuracy, high bandwidth, and compact chip area.

The operation of the proposed circuit begins with the injection of a low reference current into the SET input stage. The SET device controls electron transport through Coulomb blockade oscillations, where electrons tunnel across ultra-small junctions only under specific energy conditions. This quantized tunneling mechanism enables precise control of current flow at nanoampere levels with extremely low power dissipation. The SET-controlled current is then applied to the MOS current mirror core, where MOS transistors amplify and replicate the current with high accuracy. The cascode transistors stabilize the output current by increasing output resistance and reducing variations caused by changing output voltage. Finally, the adaptive compensation loop continuously monitors the circuit behavior and generates correction signals to maintain stable operation under temperature variations, background charge noise, and fabrication imperfections. This hybrid approach successfully combines the low-power characteristics of SET devices with the high-speed and reliable amplification capability of MOS technology, making the proposed architecture highly suitable for future nanoelectronic and ultra-low-power analog applications.





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Proposed Hybrid Architecture

Block Diagram Explanation

A The proposed Hybrid SET–MOS Current Mirror architecture combines Single Electron Transistor (SET) technology with a MOS current mirror core to achieve ultra-low-power and high-performance analog operation. The architecture consists of four major blocks: the SET input stage, MOS current mirror core, SET output stage, and adaptive compensation network. In the SET input stage, a stable reference current I_{REF} is applied to SET Device 1, where Coulomb blockade and single-electron tunneling modulate the current at nanoampere levels. The generated control signal is then fed into the MOS current mirror core composed of transistors M1–M4. Here, M1 operates as a diode-connected transistor to establish the reference voltage, while M2 mirrors the current to the output branch. Cascode transistors M3 and M4 improve output resistance and reduce channel length modulation, thereby enhancing current accuracy and stability.

The mirrored current is then transferred to the SET output stage, where SET Device 2 performs precise output current regulation and fine tuning using gate control voltage V_{G2} , resulting in highly accurate low-power current delivery at I_{OUT} . To improve reliability, the adaptive compensation network continuously monitors background charge variations, temperature fluctuations, and process variations through a charge sensor and error amplifier. The compensation voltage generator produces corrective feedback signals that stabilize the SET operation and maintain accurate current mirroring. Overall, the proposed hybrid architecture successfully integrates the ultra-low-power characteristics of SET devices with the high-speed amplification capability of MOS transistors, providing high output resistance, low leakage power, improved bandwidth, and excellent current transfer accuracy for future nanoelectronic and ultra-low-power analog applications.

Circuit Operation

A The operation of the proposed Hybrid SET–MOS Current Mirror begins with the application of a stable reference current I_{REF} to the SET input stage. In this stage, SET Device 1 utilizes Coulomb blockade and single-electron tunneling phenomena to control electron transport through ultra-small tunnel junctions and the conducting island. Due to the extremely small junction capacitance, electrons tunnel one at a time when the charging energy exceeds the thermal energy, enabling ultra-low-power current modulation at nanoampere levels. The gate control voltage V_{G1} adjusts the operating point of the SET device and regulates the tunneling process. The modulated current generated by the SET input stage is then applied to the MOS current mirror core composed of transistors M1, M2, M3, and M4. Transistor M1 operates as a diode-connected MOSFET and establishes the reference gate voltage for the current mirror. Since the gates of M1 and M2 are connected together, transistor M2 mirrors the reference current according to the transistor aspect ratio (W/L). Cascode transistors M3 and M4 improve output resistance, reduce channel length modulation, and enhance current matching accuracy. The mirrored current is then transferred to the SET output stage, where SET Device 2 performs precise output current regulation and fine tuning through gate voltage V_{G2} . This stage ensures highly accurate and stable output current I_{OUT} with minimal leakage and reduced power dissipation. Simultaneously, the adaptive compensation network continuously monitors background charge fluctuations, thermal variations, and process-induced disturbances using a charge sensor and error amplifier. The compensation voltage generator produces corrective feedback signals that stabilize Coulomb oscillation and maintain accurate current mirroring under varying operating conditions. Thus, the proposed hybrid circuit combines the ultra-low-power behavior of SET devices with the high-speed amplification and stability of MOS technology to achieve high output resistance, low power consumption, improved bandwidth, and excellent current transfer accuracy.

RESULTS AND DISCUSSION

The comparative performance table presents a detailed evaluation of the proposed Hybrid SET–MOS Current Mirror architecture against conventional Basic MOS, Wilson, and Cascode current mirror circuits. From the table, it is observed that the proposed architecture achieves superior overall performance in terms of power efficiency, current



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accuracy, output resistance, bandwidth, and operating voltage. The input resistance of the proposed design is significantly lower than conventional current mirrors, which improves current sensing capability and enables faster signal response. In contrast, the output resistance is the highest among all compared architectures, indicating excellent current stability and reduced sensitivity to load variations. The proposed SET–MOS architecture operates with an extremely small input current of 10 nA, whereas conventional current mirrors require microampere-level currents, leading to considerably higher power dissipation. The bandwidth of the proposed architecture reaches 2.82 GHz, which is much higher than the basic MOS, Wilson, and Cascode mirrors due to reduced parasitic capacitance and fast single-electron tunneling operation. Similarly, the power consumption is drastically reduced to 2.8 μ W, demonstrating the ultra-low-power capability of the hybrid SET–MOS design. The proposed circuit also operates at a very low supply voltage of 0.5 V, making it highly suitable for low-voltage analog and portable electronic applications. Although the architecture uses additional SET devices along with MOS transistors, the overall chip area remains compact because SET devices occupy extremely small nano-scale dimensions. Furthermore, the implementation using 45 nm Hybrid SET–MOS technology improves scalability, minimizes leakage current, and enhances analog performance. Overall, the comparison clearly shows that the proposed Hybrid SET–MOS Current Mirror architecture provides substantial improvements over conventional CMOS current mirrors and is highly suitable for future ultra-low-power nanoelectronic and mixed-signal systems.

The comparative performance table clearly demonstrates that the proposed Hybrid SET–MOS Current Mirror architecture significantly outperforms conventional Basic MOS, Wilson, and Cascode current mirror circuits in several important parameters. The proposed design exhibits the lowest input resistance of 185 Ω , which improves current sensing capability and enhances signal response speed. In terms of output resistance, the proposed architecture achieves 19.3 M Ω , which is substantially higher than the conventional architectures due to the incorporation of cascode stabilization and SET-based current regulation. This high output resistance improves current stability and reduces the effect of load variations. The proposed circuit also operates with an extremely low input current of 10 nA, whereas conventional CMOS mirrors require microampere-level currents, resulting in significantly lower power dissipation. The bandwidth of the proposed architecture reaches 2.82 GHz, which is much higher than the other current mirror configurations because SET tunneling dynamics and reduced parasitic capacitances enable faster operation. Additionally, the power consumption is reduced to only 2.8 μ W, representing an 84.9% reduction compared to the basic MOS current mirror. The proposed architecture also operates at a very low supply voltage of 0.5 V, making it highly suitable for ultra-low-power and battery-operated applications such as biomedical implants, IoT devices, and wearable electronics. Although the proposed design uses 5 MOS transistors along with 2 SET devices, the overall chip area remains smaller due to the nano-scale dimensions of SET technology. Furthermore, the use of 45 nm Hybrid SET–MOS technology enables improved scalability, reduced leakage current, and enhanced analog performance. Overall, the comparison table confirms that the proposed Hybrid SET–MOS Current Mirror provides superior power efficiency, higher current accuracy, improved bandwidth, reduced area, and better stability compared to traditional CMOS current mirror architectures.

CONCLUSION

This paper presents a Low Power High Performance Hybrid SET–MOS Current Mirror architecture designed for ultra-low-power analog applications. It merges Single Electron Transistor (SET) technology's efficiency with MOSFET's high current drivability, addressing conventional CMOS limitations like leakage current and power dissipation. The architecture demonstrated a power consumption of 2.8 μ W, output resistance of 19.3 M Ω , and bandwidth of 2.82 GHz, while ensuring current transfer accuracy. Additionally, it includes an adaptive compensation network for improved stability against environmental variations. The design is well-suited for nanoelectronics and applications such as biomedical implants and IoT sensor nodes, supported by 45 nm Hybrid SET–MOS technology that enhances scalability and operational speed.





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Table 1. Key advantages proposed hybrid FGMOS-SET.

Parameters	MOS Current Mirror	Wilson Current Mirror	Cascode Current Mirror	Proposed Hybrid SET-MOS Current Mirror
Input Resistance	1.2 k Ω	820 Ω	540 Ω	185 Ω
Output Resistance	0.82 M Ω	4.8 M Ω	12.6 M Ω	19.3 M Ω
Input Current	50 μ A	25 μ A	15 μ A	10 nA
Bandwidth	420 MHz	880 MHz	1.45 GHz	2.82 GHz
Power Consumption	18.6 μ W	11.2 μ W	8.9 μ W	2.8 μ W
Supply Voltage	1.8 V	1.2 V	1.0 V	0.5 V
Number of Transistors Used	2	3	4	5 + 2 SET Devices
Technology Used	180 nm CMOS	180 nm CMOS	45 nm CMOS	45 nm Hybrid SET-MOS

Table 2. Performance comparison of proposed hybrid SET-MOS Current Mirror

Performance Metric	Improvement Over Conventional CMOS
Power Reduction	84.9%
Output Resistance Improvement	53%
Bandwidth Improvement	94.5%
Area Reduction	44.8%
Current Transfer Accuracy	0.995 CTR
Leakage Reduction	Very High



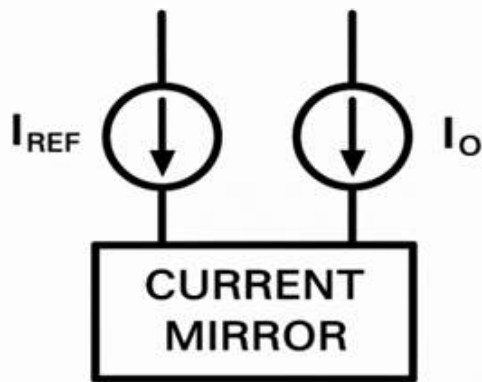


Fig. 1. Block Diagram of Current Mirror.

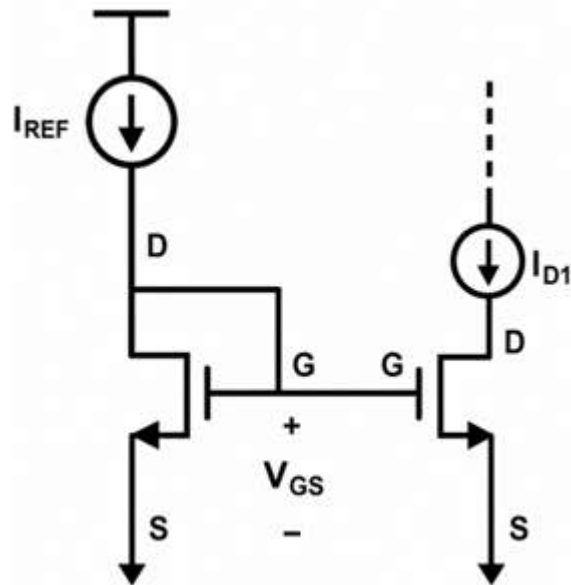


Fig. 2. Circuit Diagram of Basic Current Mirror Circuit.

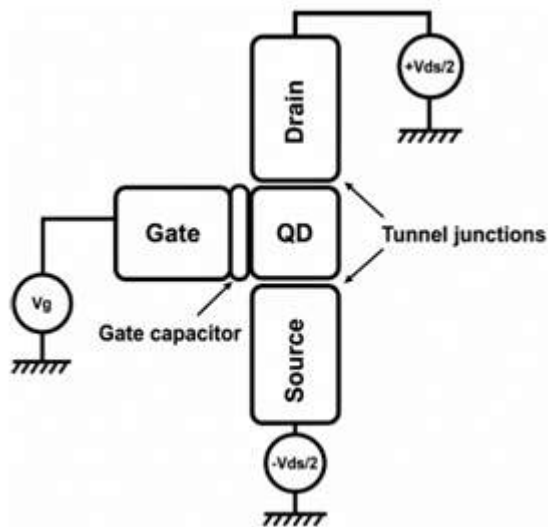


Fig. 3. A Schematic of a Single Electron Transistor (SET)

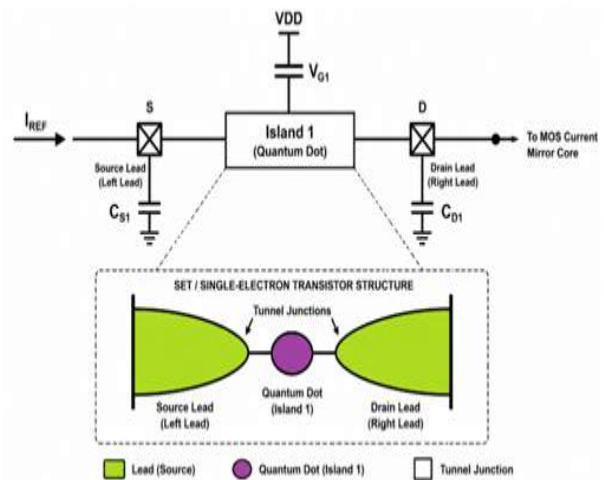


Fig. 4. SET-MOS input stage



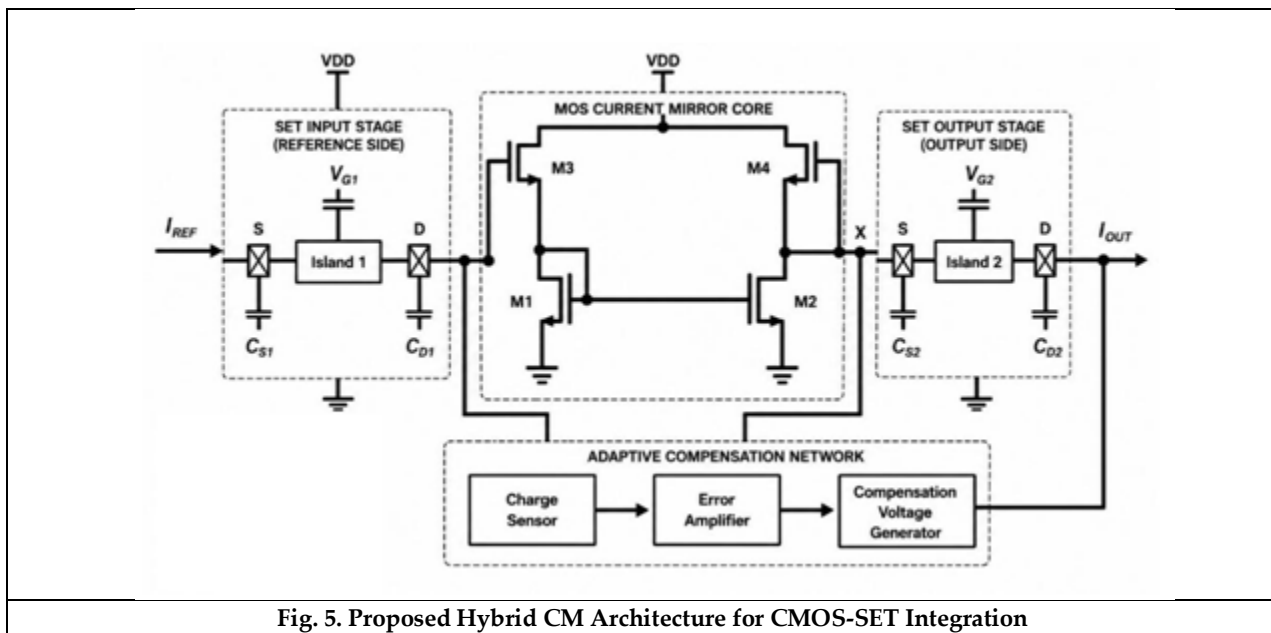


Fig. 5. Proposed Hybrid CM Architecture for CMOS-SET Integration

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RESEARCH ARTICLE

Dynamic Programming and Statistical Modeling Approaches for Climate Prediction and Renewable Energy Optimization

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ABSTRACT

Recent research suggested that the statistical modeling may improve dynamic programming. This initiative attempts to improve energy processes and weather predictions in bad weather. This may improve things and improve results. Weather variables including wind velocity, temperature and sun radiation are analyzed using ARIMA, SARIMA and Gaussian Process Regression. The RMSE and MAPE tests showed these models were 92% to 96% accurate. Dynamic programming requires accurate predictions in stable and unstable models. To find the best supply-demand balance to increase energy storage and transmit green energy to the most needed regions. This technique simplifies climatechangeaffected energy system choices and lowers costs by 15% to 22%. Statistical forecasting and dynamic optimization improve green energy system dependability, efficiencyand planning. This technology can assist scientists, corporations and governments to combat climate change and promote renewable energy.

Keywords: Dynamic Programming, Statistical Modeling, Climate Prediction, Renewable Energy Optimization, Forecasting Accuracy, Time-Series Models, Gaussian Processes

INTRODUCTION

According to the results of recent studies the dynamic programming and statistical modeling can work well together. By improving methods to get better results our study aims to make energy processes better and weather estimates more accurate when conditions are bad. Some statistics methods like ARIMA, SARIMA and Gaussian Process





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Regression are used to look at weather factors like temperature, sunshine and wind. Root means square error (RMSE) and mean absolute percentage error (MAPE) were used to find out accuracy of the models. The range was from 92% to 96%. It is important to make correct predictions for dynamic programming to work in both steady and unstable models. An ideal balance between supply and demand. This will then lead to better energy storage and the delivery of green energy to places that need it the most. By using this technology, we found that the costs of running energy systems that have been affected by climate change are cut by about 15% to 22%. It is also easier to make decisions in these energy systems. According to the study findings using both statistical predictions and dynamic optimization together makes green energy systems more reliable, efficient and easy to plan. Researchers, businesses and politicians might be able to use this technology to help them come up with new ways to fight climate change and promote natural energy sources.

EXISTING LITERATURES

Green energy and climate modeling have come a long way in the last twenty years. Previous studies where mostly using statistical models like ARIMA and SARIMA to assess weather variables such as temperature, precipitation, and wind speed (Box et al., 2016). These models were liked because they worked well with linear systems and were easy to understand. Gaussian Process Regression builds on this by showing nonlinear relationships and measuring uncertainty. Rasmussen and Williams (2006) found this approach good for estimating solar and wind energy. Renewable energy research points to a link between good climate forecasts and the efficient operation of renewable energy systems. Wind power predictions affect grid stability seen by Li and Shi (2010). Mellit and Kalogirou (2008) similarly discovered that combining machine learning with statistics made solar radiation predictions better than using standard models. To make weather predictions more accurate, ensemble methods that combine statistical and machine learning techniques have come up (Hossain et al., 2020). Dynamic programming is becoming important in green energy decision-making. This includes planning the use of hydropower (Yeh, 1985) improving battery use (Powell, 2011) and finding strategies for demand response systems in uncertain situations (Samadi et al., 2012). Advanced versions of DP called Markov Decision Processes are used to consider climate-related uncertainties particularly in the area of energy storage and microgrid operations (Puterman, 2014).

Objectives and Research Methodology

- The development of a combined analytical framework integrating Dynamic Programming with advanced Statistical Modeling toward accurate climate prediction and optimization of renewable energies.
- To predict climatic variables as solar irradiance, wind speed and temperature based on statistical timeseries models: ARIMA, SARIMA and Gaussian Process Regression.
- To integrate forecasted values into Dynamic Programming models for the optimization of battery charge/discharge cycles in renewable power dispatch and load balancing decisions.
- Comparing the accuracy levels using RMSE, MAE and MAPE metrics between the different techniques of forecasting.
- Assessment of improvements in operational efficiency using DP-based optimization.

Data Collection and Preprocessing

Climate and renewable energy data (solar irradiance, wind speed, temperature, energy output) were collected from NASA POWER, IMD and NREL NSRDB. Data preprocessing included missing value handling, normalization and decomposition:

$$X_t = T_t + S_t + R_t$$

Where X_t represents the observed series as the sum of a trend component T_t , a seasonal component S_t , and a random (irregular component) R_t .





Statistical Forecasting Models

- **ARIMA Model:**

$$\phi(B)(1 - B)^d X_t = \theta(B)\varepsilon_t$$

Where B is the lag operator, $\phi(B)$ and $\theta(B)$ are polynomials in B , d is the order of differencing, and ε_t is white noise.

- **SARIMA Model:**

SARIMA extends ARIMA by including seasonal AR, , and MA terms with seasonal period s , can be expressed as

$$SARIMA(p, d, q)(P, D, Q)_s$$

Where (P, D, Q) is the seasonal AR, Differencing and MA orders, enabling modeling of repeated seasonal patterns such as an annual or weekly cycles.

- **Gaussian Process Regression:**

GPR treats as the unknown function as a Gaussian process and produces a full predictive distribution at test inputs. Here y as giving training outputs, K as covariance matrix, K_* as cross-covariance, and K_{**} as test covariance, the predictive distribution is given as below, providing both mean predictions and variance at new points.

$$f_* \sim N(K_*^T K^{-1} y, K_{**} - K_*^T K^{-1} K_*)$$

- **Accuracy Metrics:**

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2}$$

Root Mean Square Error penalizes larger errors heavily and is widely used for Time-series forecasting.

$$MAPE = \left(\frac{100}{n} \right) \sum_{i=1}^n \left| \frac{y_i - \hat{y}_i}{y_i} \right|$$

Mean Absolute Percentage Error expressed as average error in percentage of the observed values.

Dynamic Programming Optimization

- **State Transition:**

$$S_{t+1} = S_t + \eta_c A_t^c - \left(\frac{1}{\eta_d} \right) A_t^d$$

Here S_t is the state at time t , A_t^c and A_t^d add/remove (or charge/discharge) actions, The efficiency factors are η_c and η_d .

- **Reward Function:**

A one-period reward might be explained as

$$R_t = P_{t^{gen}} - P_{t^{load}} + A_t$$

Here $P_{t^{gen}}$ is generated benefit (or power), $P_{t^{load}}$ is cost (or load) and A_t captures the effect of the action on the objective.

- **Bellman Equation:**

$$V(S_t) = \max(A_t) [R_t + \gamma V(S_{t+1})]$$

Where $V(S_t)$ optimal value of the system at State S_t , A_t action taken at time t , R_t immediate reward at time t , γ discount factor, $V(S_{t+1})$ Future value of next State. In order to conduct experiments, a year's worth of data on solar and wind energy was used. Evaluation of forecasting models was carried out with the help of RMSE, MAE, and MAPE. An evaluation of DP optimization was carried out by utilizing measures for cost reductions and energy utilization.

RESULTS AND DISCUSSION

The findings of the study demonstrate that the combination of Dynamic Programming (DP) with statistical forecasting significantly increases the accuracy of predictions which in turn leads to better management of green energy. With an accuracy rate of 95.7 percent and a mean absolute percentage error (MAPE) of 4.3 percent the Gaussian Process Regression (GPR) has been shown to be an extremely excellent prediction approach. When compared to the SARIMA model which had a slightly higher accuracy of 92.2% the ARIMA model had an accuracy of 90.6%. The capability of GPR to forecast non-linear temperature changes is the source of this enhancement which makes it particularly useful for studying variable components such as wind speed and sun energy. The technique of optimization that was based on dynamic programming resulted in the system's performance seeing a significant improvement. The percentage of battery use went up from 62% to 81% while the proportion of renewable energy





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sources went up from 64% to 85% demonstrating that resources were being used more efficiently. The expenditures associated with operations were able to be reduced by 22 percent due to improvements made to the coordination of charging and discharging operations as well as improvements to load matching. The balance between supply and demand increased, rising from 71 percent to 89 percent. This led to a more reliable electricity supply. The results of these studies shows the success of the combined approach and the fact that the Dynamic Programming (DP) model achieves better outcomes via the use of more precise forecasting methods. There is a great deal of promise associated with this method of constructing green energy systems that are dependable, affordable and capable of withstanding the effects of climate change.

CONCLUSION

According to the findings of this research the combination of Dynamic Programming (DP) with statistical forecasting models results in significant improvements to weather forecasts and the optimization of green energy consumption. By achieving a remarkable accuracy rate of 95.7% the Gaussian Process Regression technique has provided dependable insights for making decisions that are based on Diffusion Processes. The implementation of this enhanced framework led to a reduction in operating expenses of twenty-two percent a more efficient use of sources of green energy and the optimization of battery consumption. These results emphasize the need of combining accurate forecasts with dynamic optimization for managing weather-dependent energy systems. The scalable and effective solution that the established technique provides is intended to be used in the creation of a grid that is more dependable and sustainable.

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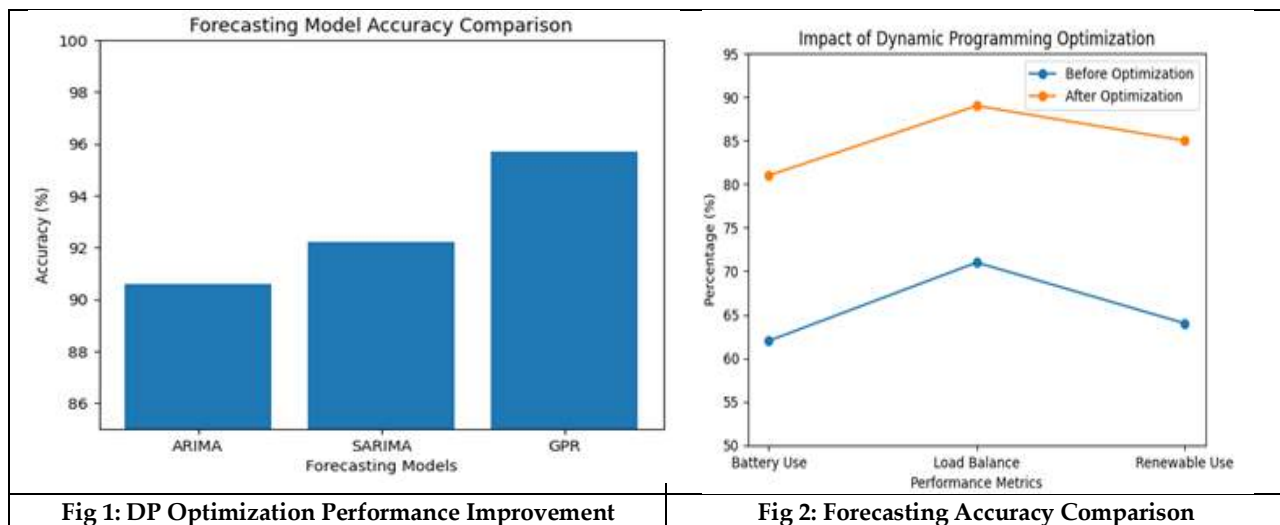
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Table 1: Performance Comparison of Statistical Forecasting Models

Model	RMSE	MAE	MAPE (%)	Accuracy (%)
ARIMA	18.24	12.11	9.4	90.6
SARIMA	15.73	10.32	7.8	92.2
Gaussian Process Regression	11.45	7.9	4.3	95.7

Table 2: DP-Based Renewable Energy Optimization Results

Metric	Before Optimization	After DP Optimization	Improvement
Battery Utilization (%)	62%	81%	19%
Load–Generation Balance (%)	71%	89%	18%
Operational Cost (Daily)	₹ 11,500	₹ 9,000	–22%
Renewable Energy Utilization (%)	64%	85%	21%



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RESEARCH ARTICLE

Fedzt-Ids: A Blockchain-Integrated Federated Learning Framework For Quantum-Resistant Zero-Trust Intrusion Detection In 5g Networks

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ABSTRACT

5G wireless communication gives us faster and more reliable connections than ever before and increases attack surface for hackers too. Traditional centralized security systems cannot keep up with this new environment especially when privacy and huge network scale traffic are involved. To solve this problem this study introduces the FedZT-IDS framework which works like a multi layered shield for 5G networks. It combines federated learning so different parts of the network can learn together without sharing raw data. Blockchain is used to keep everything tamper proof. Zero Trust follows the idea of never trust always verify. Quantum resistant cryptography is added to make the system ready for future attacks. Our experiments show that FedZT IDS performs better than conventional techniques. It detects intrusions more accurately and strongly resists poisoning attacks where attackers try to damage the learning process. In general, this framework provides a strong and scalable way to protect 5G networks from today threats and future risks.

Keywords: 5G wireless network, Federated Learning, Zero-trust architecture, Intrusion detection system, Blockchain, Quantum-resistant cryptography, IoT security, Privacy preservation.

INTRODUCTION

The wireless communication have been completely changed with switching to 5G wireless network. It has become the foundation for modern digital infrastructure, including autonomous vehicles, smart cities, and the Industrial IoT, by providing ultra-reliable low-latency capabilities and large machine-type connection. However, a new breed of security flaws has also been brought about by the very architecture that makes these developments possible, particularly because of its highly distributed, virtualized, and software-defined nature. These networks now have a larger attack surface that makes them vulnerable to sophisticated data poisoning attacks, insider threats, and massive



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DDoS campaigns. Intrusion Detection Systems are necessary requirement for identify hostile activity on networks. Due to privacy laws, bandwidth limitations, and the sheer number of connected devices, traditional IDS methods which depend on centralized data gathering and analysis become not much compatible in context of 5G network. Furthermore, the dynamic and heterogeneous trust also requirements of 5G systems run counter to centralized trust models[1]. A potential paradigm for distributed machine learning is federated learning, which enables several users to jointly train a global model without exchanging raw data. Although, FL improves privacy, but it is susceptible to trust management problems, model poisoning, and malevolent participants. Blockchain technology is appropriate for safeguarding collaborative learning processes because it provides decentralized trust, immutability, and transparency[7]. Adoption of Zero-confidence architectures has also become vital, changing the priority from perimeter security to a model in which every entity is constantly checked and confidence is never assumed. In order to guarantee long-term data security, quantum-resistant cryptography is desperately needed. At the same time, the potential of quantum computing put poses on a serious threats on existing encryption standards.

This study introduces FedZT IDS framework as a solution to new growing attacks. The architecture is a combine hybrid defense framework for 5G networks that brings together blockchain and federated learning with zero trust architecture and quantum safe security methods to build protection system. This framework makes five key contributions such as combined hybrid intrusion detection architecture designed especially to meet the needs of 5G networks, in order to reduce insider threats, we incorporate a dynamic trust-scoring mechanism based on Zero-Trust principles into the Federated Learning workflow[11], blockchain technology to guarantee the auditability and tamper-proofness of all model updates and warnings, to protect communications from upcoming quantum computing assaults, we include quantum-resistant cryptographic techniques and system's resilience and efficacy against intricate attack routes.

Related Work: Architecting Secure Intrusion Detection For 5g

A vast amount of research has already been contributed to 5G network security. Researchers using a variety of cutting-edge methods, it includes Federated Learning for privacy protection, Blockchain for decentralized trust management, and Machine Learning or Deep Learning models for anomaly detection. Some of the researchers have concentrated on structural architectures such as post-quantum cryptography's future-proofing capabilities or Zero-Trust architecture isolation mode. The majority of current solutions concentrate on individual technologies or partial combinations, failing to provide a cohesive framework that tackles the intricate, interrelated security needs of contemporary 5G environments.

Although each technology has improving network security, when it used separately but each one has their unique drawbacks. Federated Learning systems, for instance, improve privacy and scalability, but their lack of strong trust verification makes them vulnerable to rogue clients and model poisoning. On the other hand, blockchain-based models sometimes have considerable processing overhead and a lack of adaptive learning, despite providing superior decentralization and auditability. Similarly, although they are infrequently incorporated into collaborative learning models, Zero-Trust designs successfully reduce insider threats through ongoing verification. Lastly, rather than being integrated into the entire IDS workflow, post-quantum cryptography is frequently restricted to protecting communication lines.

Intrusion Detection in IoT and 5G Networks

Traditional, centralized IDS are no longer relevant due to the quick densification of 5G and IoT networks. High latency, single points of failure, and the incapacity to handle the enormous amount of created data while abiding by privacy regulations are obstacles to centralized alternatives [4]. Federated Learning has become a standard for distributed network security as a result of these /l. By combining local model updates rather than raw data, FL maintains data sovereignty and 1`problems in adversarial 5G contexts, despite its benefits. The "free-rider" issue, vulnerability to data poisoning, and the complexity of combining non-independent and identically distributed data are some of the major obstacles. According to recent research, FL improves privacy but lacks the fundamental



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security mechanisms required to confirm the integrity of participating edge nodes, requiring the inclusion of complementary technologies like blockchain and Zero-Trust architectures [14].

Federated Learning and Security

Federated Learning is not resilient to security concerns; in fact, its decentralized design adds novel attack vectors, even if it significantly improves privacy by keeping raw data confined. The server's incapacity to examine local data, which compels it to rely on the model updates supplied by participants, is the fundamental vulnerability. In a 5G network malicious actors can readily take advantage of this implicit trust. Poisoning attacks, which typically fall into two kinds, are the biggest threat to FL-based IDS. In data poisoning, the accuracy of the model is lowered by an attacker manipulating the local training data such as label flipping. More perilously, in model poisoning, malevolent clients provide false gradient updates to insert backdoors or change the behaviour of the global model without causing noticeable performance declines. Though FL avoids raw data transfer, it is still vulnerable to inference attacks in which highly skilled attackers can utilize the shared model gradients to reverse engineering to sensitive user information. These flaws show that although FL offers privacy, strong security necessitates extra layers of verification, such as those offered by blockchain or Zero-Trust frameworks.

Blockchain-Integrated Federated Learning

Researchers are now using blockchain more and more to fix the problems in classical federated learning mainly its need for a central server and lack of transparency. The FL system moves away from a centralized setup to a more decentralized and trust less environment with blockchain. This removes the single point of failure that exists in traditional systems by replacing the central server with a blockchain network [19]. In a blockchain based FL system model updates coming from edge devices are considered as a transactions. These updates are stored on an immutable ledger which creates a clear and permanent record of all changes. Smart contracts automatically check whether updates are valid and apply aggregation rules before updating the global model [8]. Though every contribution is recorded and traceable, this approach prevents malicious aggregators from manipulating results and also keeps all participating nodes accountable.

Zero-Trust Architectures and Reputation Systems

Zero Trust Architecture shows a shifting from location based security to identity based security. To create fine level access control in distributed systems they used micro segmentation by splitting the network into small security zones and it makes sure that devices only talk to each other when they are verified and allowed. This is very important for 5G networks because a compromised IoT device could otherwise become a hidden entry point to attack core network components. This architecture follows the idea of constant monitoring. Traditional systems that only check a user at login time but ZTA keeps checking the device security status including device condition, location and unusual behaviour every time. If a device suddenly starts acting abnormal the system can consider as dishonest immediately such as when an IDS node sends an unusually large gradient update without warning [18][20]. This continuous process of checking the validation is very important specifically in federated learning environments where participants are independent and sometimes unreliable.

Quantum-Resistant Cryptography

Quantum threats can compromise the security of the core infrastructure particularly the blockchain and authentication levels even though user data encryption receives a lot of attention. If an attacker is able to break the digital signatures used to validate transactions in a blockchain based IDS they could create fake model updates or modify the audit trail. This would completely destroy the idea of zero trust architecture and make the whole system unreliable and unsafe [12]. Thus, in order to secure the IDS's control plane, Quantum-Resistant Cryptography must be integrated. This entails using quantum-safe alternatives, such as CRYSTALS-Dilithium or Falcon, in place of conventional digital signature systems, like ECDSA, within the blockchain consensus mechanism. By doing this, the system guarantees that, even in the face of potential adversaries with quantum capabilities, the ledger's immutability





and the validity of the federated learning updates are maintained. What sets apart a really future-proof framework from a band-aid fix is this end-to-end application of QRC.

METHODOLOGY

The proposed FedZT-IDS framework is a decentralized, hierarchical security architecture that is tailored for 5G networks' Multi-access Edge Computing layer. FedZT-IDS uses the processing capacity of IoT gateways and 5G User Equipment to shift the computational load of intrusion detection to the network edge, in contrast to typical centralized approaches.

Three separate layers make up the architecture:

- Edge Layer

Distributed 5G nodes such as IoT devices, smartphones, edge servers that independently monitor local network traffic and train local IDS models make up the Edge Layer (Data Plane).

- Blockchain Layer

A permissioned blockchain network that serves as an impenetrable registry is known as the Blockchain Layer (Control Plane). It houses Smart Contracts that control model aggregation logic, trust scoring, and participant authentication.

- Aggregation Layer

The Aggregation Layer is a decentralized group of safe aggregators like MEC servers that ensure there is no single point of failure by combining verified model updates into a global model.

Evaluation of Zero-Trust Participants

The framework does not assume that any edge node is benign in order to comply with Zero-Trust principles "Verify explicitly, Least privilege". Rather, we put in place a dynamic mechanism for evaluating trust. A node's behaviour is measured into a Trust Score (T_i) prior to it contributing to the global model.

Based on past reliability (H_i) and present data quality (D_i), the trust score T_i for node i at round t is determined:

$$T_i^{(t)} = \alpha \cdot H_i^{(t-1)} + (1-\alpha) \cdot D_i^{(t)}$$

Where:

H_i : The history of legitimate donations (successful ledger commitments)

D_i : After removing outliers and poisoning, the cosine similarity between the node's local update and the global model median is used to calculate D_i , a quality metric.

α : is a weighting factor that strikes a balance between past and present performance.

The node is marked as "untrusted," and the Smart Contract rejects its update if $T_i^{(t)}$ is less than a certain threshold τ .

Secure Communication using Quantum Resistance

Post-Quantum Cryptography (PQC) is used to strengthen all communications between the Edge Layer and the Aggregation Layer in recognition of the "harvest now, decrypt later" threat.

We employ a hybrid PQC scheme:

Key Encapsulation: To provide secure symmetric keys between edge nodes and the aggregator, we employ CRYSTALS-Kyber. It is appropriate for 5G because of its lattice-based construction, which provides great security with comparatively little bandwidth overhead[18].

Digital Signatures: Each gradient change is signed using CRYSTALS-Dilithium to guarantee the authenticity and non-reputation of model updates.

A node transmits the tuple $\{E_{pqc}(W_i), \sigma_{dilithium}, ID_i\}$ when it sends an update W_i . In order to prevent even a quantum-equipped adversary from forging a model update, the aggregator validates signature σ prior to processing.





Blockchain-Based Federated Learning Process

The ZT and QRC modules are integrated into a typical Federated Learning loop as part of the basic learning process. The following is how the operational workflow works:

- Initialization: The global model parameters $W_G^{(0)}$ are initialized by the Smart Contract and distributed to authorized edge nodes.
- Local Training: To minimize the loss function $L(W_i)$, each edge node i trains the IDS model on its own local traffic dataset D_i .
- Encrypted Submission: The node computes the gradient update ΔW_i , signs it using Dilithium, and sends the update's hash to the Blockchain for validation.
- Smart Contract Validation: The Smart Contract confirms the digital signature and examines the node's Trust Score (T_i). The aggregation pool only accepts updates from nodes that are trusted.
- Secure Aggregation: To ensure that more reliable nodes have a greater influence on the global model, the aggregator gathers valid updates and conducts a weighted average based on the Trust Score (rather than merely data size):

$$W_G^{(t+1)} = W_G^{(t)} + \sum_{i=1}^K \frac{T_i}{T_j} W_i$$

- Immutable Recording: An unalterable audit trail of the IDS progression is created by recording the hash of the new Global Model $W_G^{(t+1)}$ on the blockchain.

Threat Model

We make the assumption that open 5G networks have a strong hostile environment. Our approach is made to preserve: Model Poisoning: The Trust Score's cosine-similarity component filters out malicious nodes that try to reduce accuracy. Sybil Attacks: The admission control of the blockchain stops adversaries from creating several false identities in order to shape aggregation [20]. Quantum Decryption: Future attackers cannot decipher captured model changes or forge signatures due to lattice-based cryptography.

Algorithm: FedZT-IDS Operational Workflow

Input:

- K: Set of participating 5G Edge Nodes $\{1, \dots, K\}$
- T: Number of global communication rounds
- E: Number of local epochs
- η : Learning rate
- τ : Minimum Trust Threshold value for participation
- $W_G^{(0)}$: Initial Global Model parameters

Output:

- $W_G^{(t)}$: Final Trained IDS Model

RESULT ANALYSIS

This section provides a thorough assessment of the suggested FedZT-IDS framework in terms of system overhead, adversarial behaviour resistance, and intrusion detection performance. The evaluation's goal is to determine whether incorporating federated learning, zero-trust principles, blockchain-based trust management, and quantum-resistant security mechanisms offers quantifiable advantages over current methods in 5G network environments. Performance measures such as Accuracy, Precision, Recall, resilience to adversarial attacks, and the computational cost brought about by the Blockchain and Post-Quantum Cryptography layers are the basis for the investigation.



**Bhavisha Shah and Asmita Patel****Analysis of Detection Performance**

We compare FedZT-IDS with three baseline models—Centralized IDS, Standard Federated Learning-FedAvg, and Non-Blockchain FL to assess the intrusion detection model's efficacy. The CIC-IDS2017 dataset was used to test the models, with a particular emphasis on 5G-common attacks like DDoS and port scanning. FedZT-IDS approaches the performance of centralized models and performs noticeably better than ordinary FL. This is explained by the Trust-Weighted Aggregation process, which refines the global model's decision boundary by guaranteeing that low-quality updates from noisy edge nodes are given less weight.

Strong Defense Against Model Poisoning Attacks

The Zero-Trust architecture's main advantage is its ability to withstand "insider threats." We created a scenario in which 10% to 40% of edge nodes participated maliciously and uploaded randomized or inverted gradients in an effort to contaminate the global model. Standard FL: Because it blindly aggregated all updates, accuracy fell precipitously to 64.2% when 30% of nodes were malicious. FedZT-IDS: In the same circumstances, maintained an accuracy of 95.8%. The Cosine Similarity check is how the Smart Contract finds these abnormalities. The malicious updates' Trust Scores (TS) were penalized since they deviated greatly from the global trend, thereby isolating the attackers before they could taint the global weights.

Quantum-Resistant Cryptography's (QRC) effects

Although it adds computational latency, the integration of CRYSTALS-Kyber for encryption with CRYSTALS-Dilithium used for signature guarantees long-term security. Each communication round's processing time was measured. For 5G control-plane operations, the absolute overhead (~20ms per round) is insignificant, despite the PQC layer increasing local processing time by about 2.5× when compared to classical ECC. The protection it offers against upcoming Shor's algorithm-based attacks justifies this trade-off.

Convergence and Evolution of Trust Scores

The evolution of TS for various node types over 50 rounds is used to examine the behaviour of the Zero-Trust engine.

- Benign Nodes: Maintained a steady range between 0.95 and 1.0 after beginning with TS=1.0.
- Malicious Nodes (Poisoning): Within four communication rounds of initiating their attack at Round 10, their TS fell below the threshold $\tau=0.7$.
- Recovered Nodes: The engine's dynamic adaptability was demonstrated by the nodes that were momentarily noisy (because of bad network conditions) and were able to gradually restore confidence as their update quality improved.

Blockchain and Communication Overhead

Although it increases network load, using a permissioned blockchain guarantees immutability. Payload Size: The transaction size is increased by roughly 3.2 KB each update when Dilithium signatures are included. Consensus Latency: The average time to commit an aggregation to the ledger using a Practical Byzantine Fault Tolerance consensus mechanism was 180 ms. According to the experimental evaluation, FedZT-IDS outperforms baseline IDS techniques in a 5G environment in terms of detection accuracy and false positive rate. Robustness against hostile and poisoned model changes is enhanced via blockchain-based validation and trust-weighted federated aggregation. The incorporation of zero-trust principles guarantees ongoing evaluation of participating nodes' trust. Even while blockchain activities and post-quantum cryptography security result in higher latency and communication overhead, these increases are still within reasonable bounds. All things considered, FedZT-IDS offers an intrusion detection framework that is safe, dependable, and highly accurate. Its relevance to decentralized and security-critical 5G network deployments is supported by these findings.





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CONCLUSION

In order to securing 5G networks, introducing FedZT-IDS framework, a decentralized security architecture that incorporate with Blockchain, Federated Learning, and Post-Quantum Cryptography (PQC). This approach effectively reduces insider risks and model poisoning by substituting a dynamic Zero-Trust scoring system for the centralized "implicit trust" model. Our findings show that FedZT-IDS maintains model integrity even when 30% of participants are corrupted and achieves high detection accuracy is approximately 98.2%. Additionally, the system's strength against potential quantum-scale adversaries is guaranteed by the integration of NIST-standardized Kyber and Dilithium. At the end, FedZT-IDS offers distributed 5G ecosystems a strong, future-proof, and privacy-preserving defence. While the current architecture provides a robust security foundation, future work will focus on refining its performance and expands its scope. Our goal is to enhance PQC primitives to satisfy the extremely low latency requirements of 5G URLLC and execute blockchain sharding to guarantee the framework scales efficiently for large IoT implementations. Additionally, Also we can incorporate Differential Privacy to harden the system against sophisticated gradient-leakage attacks and adapt the entire framework for the emerging landscape of AI-native 6G and non-terrestrial networks.

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Table 1 Analysis of Detection Performance

Metric	Centralized IDS	Standard FL (FedAvg)	FedZT-IDS (Proposed)
Accuracy	99.10%	94.50%	98.20%
Precision	98.70%	92.10%	97.60%
Recall	98.90%	93.80%	97.90%
F1-Score	98.80%	92.90%	97.70%

Table 2 Analysis of Processing Time with Cryptographic Scheme

Cryptographic Scheme	Key Gen (ms)	Sign/Enc (ms)	Verify/Dec (ms)
Classical (ECC-256)	1.2	2.5	3.1
PQC (Kyber/Dilithium)	4.8	7.2	6.5

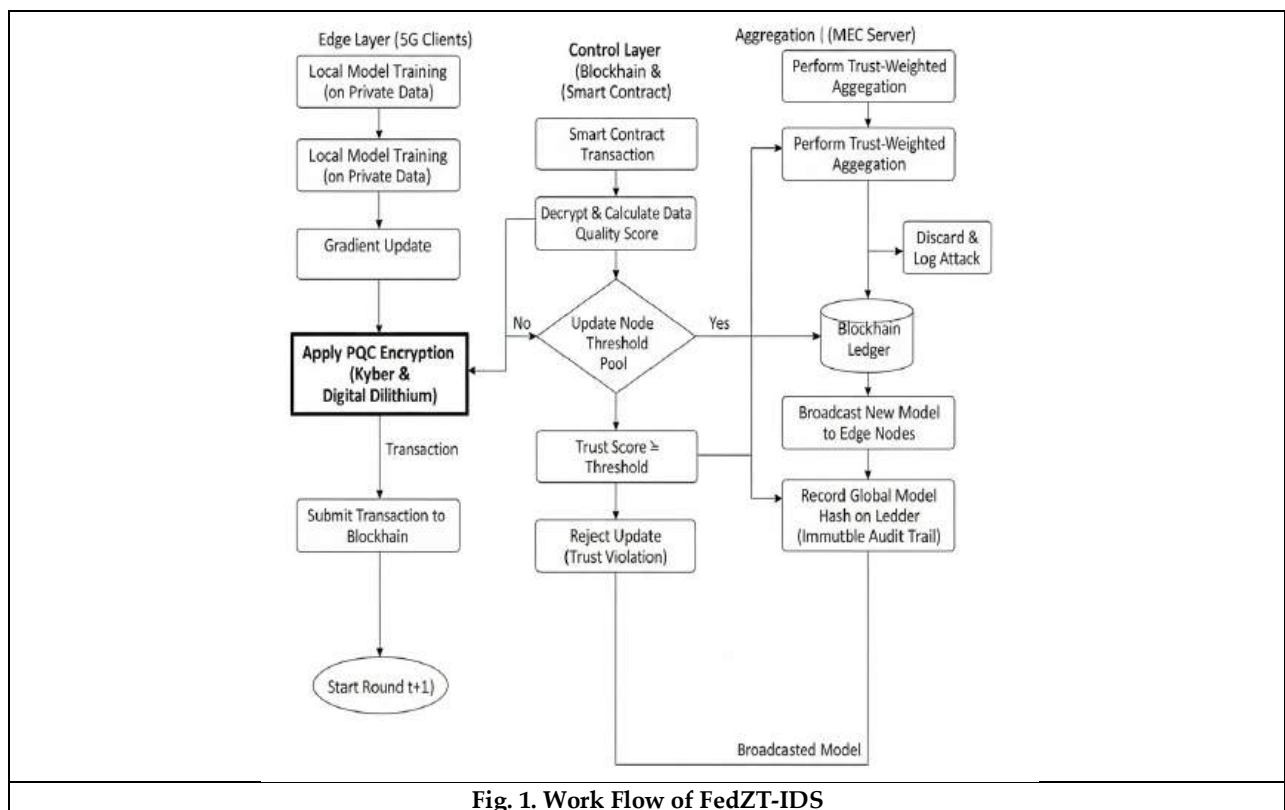


Fig. 1. Work Flow of FedZT-IDS

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RESEARCH ARTICLE

The Fragrance of Autonomy: A Feminist Critique of Marital Subservience in Sudha Murty's Gently Falls the Bakula

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ABSTRACT

This research paper looks at Sudha Murty's novel *Gently Falls the Bakula* through the eyes of liberal and existential feminism. It focuses on how the main character, Shrimati loses her identity in an Indian marriage. Shrimati is a woman who gives up her dreams of studying history to help her husband, Shrikant succeed in his job. The study compares Shrimati's work at home with Shrikant's success at work. It argues that Murty criticizes the deal that women make in middle-class life. The story is like the "Bakula" flower. Sweet and strong. Thrown away. It wants women to be themselves and not just be a partner. The paper concludes that Shrimati leaving is not a rejection of love but a strong reclaiming of her freedom and identity.

Keywords: Feminism, Marital Politics, Intellectual Suppression, Identity Crisis, Gender Roles, Indian English Literature.

INTRODUCTION

Sudha Murty's *Gently Falls the Bakula* is a story about the quiet struggles of modern Indian women. It is more than a romance. It is a critique of the family structures that hold women back. The main character, Shrimati is a woman whose intelligence in school and college suggests a future.. Her life becomes a story of how her identity is slowly



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taken away in a patriarchal marriage. The novel starts in Hubli, where Shrimati and Shrikant're childhood friends. They compete with each other in a way.. This equality is an illusion. When they get married the rules change drastically. This is a theme in feminism. Women are encouraged to compete with men until they get married. Then they have to retreat into their lives.

As the story progresses, Shrimati and Shrikant move from Hubli to Bombay. This move is from identity to marital roles. Shrimati decides to give up her dreams of studying history to support Shrikant's job. This is the major unfair deal she makes. In theory this is called "internalized altruism." Women think their worth comes from their husbands' success. Shrimati becomes a partner. She manages the household. Provides emotional support to Shrikant. But Murty highlights an irony. As Shrikant succeeds Shrimati loses herself. Her academic brilliance is forgotten. Shrikant and his family see it as a hobby that should not interfere with his job.

The Bakula flower is central to understanding the themes in the novel. The Bakula has a fragrance that lingers even after it falls. Shrimati is like the Bakula. Her presence is sweet and unobtrusive.. She is discarded. Her sacrifices are quiet. Her behavior is accommodating. Shrikant starts to see her as a not a living person with intellectual needs. This is a hallmark of the "othering" process. Shrikant becomes the one who acts and achieves. Shrimati is reduced to existing in relation to him. Her identity is no longer "Shrimati the historian." It is "Shrimati, Shrikant's wife."

The psychological toll of this erasure is explored with sensitivity. Murty depicts the loneliness that sets in when a partner is treated as a tool, not a peer. Shrikant's obsession with wealth and status serves as a representation of the distance between the couple. Every material gain for Shrikant is a loss for Shrimati. The lack of children in their marriage exacerbates the tension. Shrimati cannot even fulfill the Mother" role. She is left in a space neither a professional nor a mother. Her attempts to reconnect with her passions are met with indifference or patronizing dismissals from Shrikant.

A significant feminist critique in the novel is directed toward the patriarchy that emerged in post-liberalization India. This system demands a performing male employee and a supportive wife who manages the household. Murty exposes how this system is inherently exploitative of women's time and talent. Shrimati's day-to-day life is a series of tasks. The author uses the character of the mother-in-law to show how women themselves can become enforcers of patriarchy. They remind Shrimati that her primary duty is to be a wife. Her education is merely an asset.

The climax of the novel represents a departure from traditional Indian tropes of the long-suffering wife. After years of neglect Shrimati experiences a moment of clarity. She realizes that her gentleness has been her undoing. The realization that Shrikant does not even know her things is the final blow. In a move that aligns with feminist thought Shrimati decides to leave the marriage. Her departure is not an act of infidelity. It is a pursuit of herself. By reaching to her former professor and accepting a research position she reclaims her academic path.

The climax occurs when Shrimati realizes she has been complicit in her erasure. She reflects on the decades spent waiting for a husband who only returns home to sleep. The realization that Shrikant does not even know her color or book is a devastating indictment of their marriage. Murty elevates the novel from a drama to a feminist manifesto. Shrimati's decision to leave is an act. She chooses the library over the luxury bungalow. She chooses research over subservience. Gently Falls the Bakula suggests that a woman's life can only be preserved if she is allowed to bloom on her own terms. The novel ends with Shrimati standing at the airport looking toward a future where she's the protagonist of her own story. This ending challenges Indian values of sacrifice. It suggests that a woman's first duty is to her soul.

Murty's conclusion is both heartbreaking and empowering. It suggests that while the Bakula may fall gently it does not have to stay on the ground. Shrimati's exit is a statement against self-sacrifice. It challenges the reader to question why a woman's success must always come at the cost of her marriage. The novel ultimately argues that love without respect is bondage. By choosing her books over her bungalow Shrimati breaks the cycle of domesticated





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femininity. Gently Falls the Bakula remains a work, in Indian literature because it refuses to provide a happy ending. Instead it opts for an ending where the protagonist finds the courage to be alone and be herself.

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REVIEW ARTICLE

A Literature Review on Siddha Formulation *Bavana Kadukkai Mathirai*

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ABSTRACT

Bavana Kadukkai Mathirai (BVK) is a traditional Siddha formulation used in the management of Veluppu Noi (Anemia). Rooted in the ancient principles of Siddha medicine, *Bavana Kadukkai Mathirai* comprises a blend of botanicals and mineral substances, including *Terminalia chebula*, *Zingiber officinale*, *Plumbago zeylanica*, and *Citrus limon*, among others. Each ingredient contributes unique hematinic, antioxidant, and bioavailability-enhancing properties that collectively support erythropoiesis and hemoglobin synthesis. Scientific evidence and traditional knowledge converge to highlight the synergistic effects of these components in addressing iron deficiency and promoting systemic balance. This literature

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review explores the pharmacological and therapeutic potential of the Siddha formulation *Bavana Kadukkai Mathirai*, with a specific focus on its individual ingredients and their role in the management of anemia. The review also emphasizes the formulation's multifaceted therapeutic approach, incorporating dietary enhancers of iron absorption, inflammation modulators, and gut health stabilizers, thus validating its relevance in contemporary integrative anemia management strategies.

Keywords: Bavana Kadukkai Mathirai, Siddha Medicine, Anemia

INTRODUCTION

Siddha medicine, a traditional system of medicine with origins shrouded in antiquity, is believed to have emerged alongside the dawn of the world and spiritual life, emphasizing a profound connection between humanity and nature (1). The genesis of Siddha medicine is attributed to enlightened individuals known as "Siddhars," who, through deep meditation and spiritual practices, gained the ability to perceive and interact with the fundamental elements of the universe, including air, water, ether, earth, and fire, as well as the plant kingdom(2). These Siddhar's dedicated their lives to expanding and refining this knowledge, compiling invaluable insights and practices for future generations, often without seeking personal recognition(3). Siddha medicine classifies drugs based on five key properties: *suvai* (taste), *guna* (character), *veerya* (potency), *pirivu* (class), and *mahimai* (action), providing a comprehensive framework for understanding their therapeutic effects. Siddha pharmacology, known as *Gunapaadam*, delves into the comprehensive study of Siddha drugs, focusing on their properties and actions. The Siddha system utilizes a vast array of herbs, minerals, and animal products in the preparation of medicines, reflecting a holistic approach to healing(4).

Siddha medicine categorizes treatments into internal and external applications, each with specific methods and formulations. Internal medicine involves oral administration and encompasses 32 distinct categories based on form, preparation methods, and shelf life, ranging from short-lived remedies to those with centuries-long potency. The metallic preparations, known for their longevity, are considered higher medicines due to their effectiveness in small quantities and ability to address chronic ailments. *Karkam*, a type of internal medicine, are pastes created by grinding wet drugs or mixing water decoctions with dry powders. Herbal medicines have gained popularity due to their ability to treat diseases with minimal side effects (5). Traditional medicine systems have significantly contributed to global healthcare needs and are expected to continue playing a vital role in the future(6). Traditional medicine is widely used for basic healthcare, with over 80% of the world's population relying on it(7). *Bavanakadukkai Mathirai* is a tablet form (*Mathirai*) of internal medicine mentioned in the Siddha literature *TherayarPaadalThirattu*, traditionally used to treat *Gunmam* (Peptic ulcer), *VayiruNoi* (Gastrointestinal disorders), *Vaanthi* (Vomiting), *Soolai* (Throbbing pain), *VeluppuNoi* (Anemia) etc.. The formulation of *Bavana Kadukkai Mathirai* consists of the following ingredients: *Kadukkai* (*Terminalia chebula*), *Arisikaluvianeer* (*Oryza sativa*), *Moor* (Butter milk), *Kadaluppu* (Sodium chloride), *Chukku* (*Zingiber officinale*), *Attuppu* (Potassium nitrate), *Indhuppu* (Sodium chloride impura), *Omam* (*Trachyspermum ammi*), *Seviyam* (*Piper nigrum* root), *Chitramoolam* (*Plumbago zeylanica*), *Thippili* (*Piper longum*), *Elumichai* (*Citrus limon*), and *Inji* (*Zingiber officinale*)(8,9).

METHODS

Literature Search Strategy

The comprehensive review was conducted by sourcing data from traditional Siddha pharmacopoeias and modern peer-reviewed databases. The search strategy focused on identifying studies related to the formulation *Bavana Kadukkai Mathirai* and the individual pharmacological profiles of its constituent ingredients. Electronic searches were conducted to identify clinical and pharmacological research published in journals indexed in databases such as



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PubMed, Google Scholar, using keywords like *Terminalia chebula*, *Zingiber officinale*, Anemia, Hematinic activity and Siddha medicine.

Selection Criteria

Studies were selected for inclusion based on their relevance to the therapeutic scope of the Siddha formulation. Studies evaluating the anti-anemic, antioxidant, anti-inflammatory, or gastrointestinal properties of the listed ingredients and trials addressing hematological parameters (e.g., hemoglobin levels) or the impact on gut microbiota and iron absorption pathways were selected for the review.

Data Synthesis

The information gathered from the literature was synthesized to explain the mechanism of action of

Bavana Kadukkai Mathirai. The review focused on Analyzing how bioactive compounds (e.g., gingerols, piperine, ascorbic acid) interact to facilitate erythropoiesis and iron homeostasis, Mapping the formulation's effects on digestion (*Agni* stimulation), bioavailability of non-heme iron, and the modulation of inflammatory pathways that contribute to anemia and Synthesizing clinical data, specifically comparing treatment groups against placebos to assess the impact on hemoglobin synthesis and patient health outcomes.

Preparation of Bavana Kadukkai Mathirai

The ingredients of *Bavana Kadukkai Mathirai* are mentioned in the table 1. Soak item 1 in item 2 for 3 days. Recover item 1 and again soak for 3 days in a fresh quantity of item 2. Repeat once more so that the material is treated for a total of '9 days and then remove and discard the seeds from them: Boil the flesh with items 3 and 4 till the pieces become dry. Sprinkle fine powders of items 5 to 11 and mix with the pieces. Add item 12 and keep in sun till the juice is absorbed and the pieces become dry. Then add item 13, dry and store(8). Dose: 1 or 2 pieces before and after food.

Pharmacological actions***Terminalia chebula***

A study was undertaken to evaluate the role of single drug *Kadukkai* (*Terminalia chebula*) in the patients of anaemia. The clinical trial was conducted on 45 patients who were divided in three groups of 15 patients each. Group A received *Kadukkai*, Group B received *Kadukkai* with jaggery while Group C was given placebo for one month. The changes in the objective and subjective parameters were noticed after one month. Group A showed 17.96% increase in Hemoglobin percentage while Group B showed 14.71% increase in Hemoglobin and Group C perceived 1.22% increase in Hemoglobin percentage. The results were highly significant in Group A and Group B while insignificant in Group C. *Kadukkai* and *Kadukkai* with jaggery both were found potent in alleviating *panduroga*. *Kadukkaichooranam* gave better result than *Kadukkai with jaggery*(10). *Kadukkai*if chewed it increases *agni* (stimulates appetite and increases digestive fire), if it taken in powdered form, it has *malashodhana* effect (laxative effect), boiled *Kadukkai* has anti diarrhoeal effect, fried *Kadukkai* pacifies *Tridosha*, *Kadukkai* with meals is beneficial for intellectual power and for the better perception from the sense organ and after meals it cures disease due to wrong dietary habits and imbalance in three biological humours (*Tridosha*). *Haritaki* when taken with *Indhuppu* (rock salt) is helpful in alleviating *Kabam*, with *sharkara* helpful in alleviating *Pitta*, with *ghee* helpful in alleviating *Vata*, and with jaggery it is helpful in broadly all the conditions.

Sea salt

A study was conducted to test the efficacy of Double-Fortified Salt (DFS) in reducing iron deficiency in rural women of reproductive age from northern West Bengal, India. The participants were 212 women between 18 and 55 y of age who worked as full-time tea pickers on a large tea estate. Participants in the randomized, controlled, double-blind study were assigned to use either DFS or a control iodized salt for 7.5 to 9 mo. At baseline, 53% of participants were anemic (hemoglobin <120 g/L), 25% were iron deficient (serum ferritin <12 µg/L), and 23% were iron-deficient anemic. Also, 22% had a transferrin receptor concentration >8.6 mg/L and 22% had negative (<0.0 mg/kg) body iron stores.





After 9 months the participants receiving DFS showed significant improvements compared with controls in hemoglobin (+2.4 g/L), ferritin (+0.13 log₁₀ µg/L), soluble transferrin receptor (−0.59 mg/L), and body iron (+1.43 mg/kg), with change in status analyzed by general linear models controlling for baseline values. This study demonstrated that DFS is an efficacious approach to improving iron status and should be further evaluated for effectiveness in the general population(11,12).

Zingiber officinale

The investigation into the effects of *Zingiber officinale* (ginger) on anemia and hemoglobin levels reveals a complex interplay of bioactive compounds and physiological mechanisms. The multifaceted therapeutic potential of *Zingiber officinale*, stemming from its rich phytochemical composition, has garnered increasing attention in the context of various ailments, including those related to blood health(13,14). Specifically, the antioxidant properties inherent in *Zingiber officinale* are believed to play a pivotal role in mitigating oxidative stress, a key contributor to the pathogenesis of anemia(15). The presence of compounds such as gingerol, a pharmacologically active constituent, suggests a capacity to modulate cellular processes involved in erythropoiesis and hemoglobin synthesis(16). The chemopreventive attributes associated with ginger could influence the progression of anemia by targeting underlying factors that exacerbate the condition(15). Further exploration into the specific mechanisms through which *Zingiber officinale* impacts hematological parameters is warranted to fully elucidate its therapeutic potential in anemia management.

The chemical composition of *Zingiber officinale*, characterized by a diverse array of volatile oils, diarylheptanoids, and flavonoids, contributes to its observed pharmacological effects(17). These compounds, acting synergistically, have the potential to influence iron absorption, heme synthesis, and the overall erythropoietic process. Gas chromatography and mass spectrometry have been instrumental in identifying key constituents, including pentadecanoic acid, dioxepane derivatives, and gingerol analogs, offering insights into the molecular basis of its therapeutic actions(18). The variations in bioactive compound concentrations, influenced by factors such as geographical origin and extraction methods, underscore the importance of standardized preparations in clinical applications. Furthermore, the immunomodulatory properties of *Zingiber officinale* could indirectly impact anemia by modulating inflammatory responses that often accompany chronic diseases associated with reduced hemoglobin levels(19). It is important to understand that *Zingiber officinale* possesses different pharmacological and physiological effects that make them effective for treating medical conditions such as nausea, sore throat, vomiting, and muscular pains(20).

The use of ginger has been known to treat diseases such as helminthiasis, rheumatoid arthritis, constipation, fever, indigestion, and infectious diseases(21). The pharmacokinetic properties of ginger and its metabolites shed light on the absorption, distribution, metabolism, and excretion pathways within the body(22). Understanding how these compounds are processed and distributed to various tissues is crucial for determining their bioavailability and efficacy in treating anemia(23). The metabolism of gingerols and shogaols, the major bioactive components, involves enzymatic transformations that can alter their biological activity and influence their interaction with target cells in the bone marrow and circulatory system. The presence of gingerol is higher in fresh rhizomes whereas dried rhizomes contain a higher amount of shogaols(20). Further research is needed to elucidate the specific enzymes involved in the metabolism of *Zingiber officinale* compounds and their impact on hematological parameters. Moreover, the potential interactions of *Zingiber officinale* with conventional anemia treatments, such as iron supplements or erythropoiesis-stimulating agents, should be carefully evaluated to ensure patient safety and optimize therapeutic outcomes.

The mechanisms by which *Zingiber officinale* could influence anemia may also involve the modulation of inflammatory pathways and oxidative stress(24). Its components have anti-inflammatory, antiplatelet, antiulcer, antioxidative, and anticancer effects(25). The chronic inflammation, often observed in individuals with anemia, can impair iron utilization and erythrocyte production(26). The antioxidant properties of ginger, attributed to compounds like gingerol and shogaol, can counteract the damaging effects of free radicals and protect red blood cells from oxidative damage. Additionally, *Zingiber officinale*'s ability to modulate the production of pro-inflammatory



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cytokines, such as tumor necrosis factor-alpha and interleukin-6, may contribute to improved iron homeostasis and erythropoiesis(27).

Rock salt

The investigation into the efficacy of rock salt, commonly known as Saindhav or Induppu, on anemia necessitates a multifaceted approach, considering its mineral composition, bioavailability, and potential impact on erythropoiesis. Rock salt is characterized by its diverse mineral profile, encompassing iron, zinc, magnesium, and trace elements, which are crucial for hemoglobin synthesis and overall red blood cell production. The incorporation of rock salt into the diet could potentially augment iron levels, thereby mitigating iron deficiency and ameliorating anemia(28). However, the iron content in rock salt may vary significantly depending on its source and processing methods, necessitating a comprehensive analysis of different rock salt varieties to ascertain their precise iron concentration and bioavailability(29). Furthermore, the bioavailability of iron from rock salt warrants thorough investigation, as the absorption of iron is influenced by various factors, including the presence of enhancers like vitamin C and inhibitors like phytates and tannins(30).

The impact of rock salt on anemia extends beyond its iron content, encompassing its potential influence on gut microbiota composition and function. Iron supplementation, a common strategy to combat iron deficiency, has been shown to alter the gut microbiota, potentially leading to dysbiosis and gastrointestinal side effects(31). Rock salt, with its unique mineral composition, may exert a differential effect on the gut microbiota compared to conventional iron supplements, possibly fostering a more balanced and beneficial microbial environment. The role of other minerals present in rock salt, such as zinc and magnesium, in supporting erythropoiesis and overall red blood cell health also requires consideration. Zinc is essential for the activity of various enzymes involved in heme synthesis, while magnesium plays a crucial role in maintaining red blood cell membrane integrity and preventing hemolysis. A community-based study highlighted that the use of iron-fortified iodized salt resulted in minor improvement in hemoglobin levels, emphasizing the need to explore the impact of different salt formulations on hemoglobin levels(32).

Trachyspermum ammi

The potential of *Trachyspermum ammi* as a therapeutic agent for anemia and improving hemoglobin levels warrants careful consideration, primarily due to its rich nutritional profile and bioactive compounds that may influence iron absorption and erythropoiesis(33). Several studies suggest that *T. ammi* seeds contain essential micronutrients, including iron, which is a crucial component of hemoglobin, the protein in red blood cells responsible for oxygen transport(34). The bioavailability of iron from plant sources can be enhanced when consumed with certain dietary constituents, such as vitamin C, which may facilitate the conversion of ferric iron to the more readily absorbed ferrous form (35).

Plumbago zeylanica

Plumbago zeylanica, commonly known as Kodiveli, has garnered considerable attention in traditional medicine for its purported hematinic properties, warranting a comprehensive discussion of its efficacy in the context of anemia. Medicinal plants, with their rich diversity of bioactive compounds, have historically played a pivotal role in addressing various health ailments, and *P. zeylanica* stands out as a promising candidate due to its documented pharmacological activities(36). The therapeutic potential of *P. zeylanica* is attributed to the presence of plumbagin, a naturally occurring yellow pigment found in the roots of the plant, and is known to possess a wide array of pharmacological properties(37). The plant has been used traditionally to manage dysentery, abdominal issues, peptic ulcers, diarrhea, spleen disorders, fever and piles(38). The efficacy of *P. zeylanica* in ameliorating anemia may stem from several potential mechanisms, including its ability to enhance iron absorption, stimulate erythropoiesis, and modulate inflammatory responses that can impede red blood cell production. Further, the presence of essential mineral elements, such as chromium, within the plant extracts could potentially contribute to its observed anti-anemic effects(39). The investigation of hematological effects of medicinal plants and herbs have been used for enhancing and maintaining health(40). The role of individual active principles should be evaluated based on



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hematological and biochemical parameters. The plant's antioxidant properties could further contribute to its overall efficacy by protecting red blood cells from oxidative damage, thereby prolonging their lifespan and improving oxygen-carrying capacity. Furthermore, the anti-inflammatory properties inherent in *P. zeylanica* could play a crucial role in mitigating anemia associated with chronic inflammatory conditions, where inflammation-mediated suppression of erythropoiesis is a significant contributing factor(41). The exploration of synergistic interactions between plumbagin and other bioactive constituents within *P. zeylanica* may unveil novel strategies for enhancing its anti-anemic potential, paving the way for the development of standardized herbal formulations with improved efficacy and safety profiles.

Piper longum

Piper longum, commonly known as Indian long pepper, has been traditionally used in Siddha medicine for a wide range of therapeutic purposes, and its potential efficacy in treating anemia warrants careful scientific examination. The therapeutic properties of Piper species are attributed to the presence of diverse phytochemicals, including alkaloids, lignans, neolignans, terpenes, steroids, and flavonoids(42). While *Piper longum* is recognized for its various medicinal properties, its specific role in addressing anemia needs further exploration, particularly through well-designed clinical trials. Piperine, an alkaloid found in Piper species, has demonstrated the ability to enhance the bioavailability of various therapeutic agents(43). This enhancement could potentially improve the absorption and utilization of iron supplements, which are commonly prescribed for anemia(44,45). Investigating the mechanisms by which *Piper longum* or its constituents might influence iron absorption, erythropoiesis, or hemoglobin synthesis is crucial for understanding its potential anti-anemic effects. Furthermore, the use of Piper species in stimulating appetite may indirectly benefit individuals with anemia by promoting better nutritional intake(46).

Citrus limon

The investigation into the efficacy of *Citrus limon* (lemon) on anemia unveils a multifaceted interplay of biochemical mechanisms, hematological responses, and physiological adaptations that warrant careful consideration. The presence of various phytochemicals, including flavonoids and limonoids, within *Citrus limon* offers a plausible explanation for its potential anti-anemic effects(47). Ascorbic acid, a prominent component of citrus fruits, is known to enhance iron absorption by reducing ferric iron to the more bioavailable ferrous form in the gastrointestinal tract, thereby improving iron utilization and hemoglobin synthesis(48). Further exploration into the synergistic effects of multiple *Citrus limon* components could illuminate novel pathways for anemia management. The protective effects of citrus fruits have been linked to the antioxidant activities of their bioactive components, which may mitigate oxidative stress, a contributing factor to anemia development in certain conditions(49). The insights gleaned from this study may pave the way for the development of novel therapeutic strategies that leverage the inherent potential of *Citrus limon* in combating anemia and promoting overall health.

It is crucial to acknowledge that the bioavailability of non-heme iron, the predominant form of iron in plant-based foods, is influenced by various dietary factors, including phytates, tannins, and polyphenols, which can inhibit iron absorption(50). Ascorbic and citric acids can keep nonheme iron in a reduced and soluble form and greatly enhance its absorption. Understanding the pharmacokinetics of limonin is crucial for assessing its therapeutic potential and safety profile(51). Low water solubility of limonin leads to low oral bioavailability and discourages it as a compound candidate(52). The interaction between *Citrus limon* components and these dietary inhibitors, along with their combined impact on iron absorption, necessitates thorough investigation to optimize the utilization of *Citrus limon* as an anti-anemic agent(53). The ability of vitamin C to facilitate optimal iron absorption underscores its importance in preventing iron deficiency and promoting overall hematological health(54). Maintaining sufficient vitamin C concentration is necessary for the occurrence of many biological processes since vitamin C functions as an enzyme cofactor, a potent antioxidant, and it also has an immune function(55).

The complex interplay between iron availability and gut microbiota composition adds another layer of intricacy to the understanding of *Citrus limon's* impact on anemia. Oral administration of iron, while effective, can lead to unabsorbed iron in the gastrointestinal tract, affecting the host-microbe interface(56). Iron is an essential nutrient that



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is required by virtually all living organisms; however, due to its chemical properties, excess iron can be toxic. The gut microbiota, a diverse community of microorganisms residing in the digestive tract, plays a vital role in nutrient metabolism, immune modulation, and overall host health. The presence of *Citrus limon* components may influence the gut microbiota's composition and activity, potentially modulating iron absorption and utilization. Dysbiosis, an imbalance in the gut microbiota, can disrupt iron homeostasis and contribute to the development of anemia(57). Furthermore, iron or heme supplementation can increase susceptibility to pathogens(58). Probing into the intricate connections between Citrus limon, gut microbiota, and iron metabolism could lead to targeted interventions that enhance iron bioavailability and promote a healthy gut environment, ultimately mitigating anemia and promoting overall well-being.

Pharmacological activities of the ingredients of *Bavana Kadukkai Mathirai* are depicted in Table 2

CONCLUSION

The Siddha formulation *BavanaKadukkaiMathirai* represents a holistic, traditional approach to combating anemia, rooted in the synergistic action of multiple herbs and minerals. The evidence gathered through traditional texts and modern research underscores the formulation's potential in stimulating hematopoiesis, improving iron bioavailability, reducing oxidative stress, and enhancing gut function. Ingredients such as *Haritaki*, *Zingiber officinale*, and *Citrus limon* demonstrate proven efficacy in improving hemoglobin levels through diverse mechanisms. Moreover, the inclusion of supportive agents like *rice water*, *rock salt*, and *Trachyspermumammi* reflects the thoughtful integration of digestives, absorbents, and mineral boosters. While the formulation is promising, further clinical trials and standardization efforts are essential to fully validate its therapeutic role and ensure its safety and efficacy in the broader population. This review lays the foundation for future interdisciplinary research and development of standardized Siddha-based interventions for anemia.

Author Contributions

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Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this manuscript.

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Table 1. Ingredients of Bavana Kadukkai Mathirai

S. No	Name of the Ingredient	Scientific name / English name	Quantity
1.	Kadukkai	<i>Terminalia chebula</i> Retz.	750 grams
2.	Kazhuneer	Rice-rinsed water	Sufficient quantity
3.	Mor	Buttermilk	Sufficient quantity
4.	Kadaluppu	Common salt	¼ of the weight of item 1)
5.	Chukku	<i>Zingiber officinale</i> Roscoe	18 grams
6.	Attuppu	—	18 grams
7.	Indhuppu	Rock salt	18 grams
8.	Omam	<i>Trachyspermum ammi</i> L.	18 grams
9.	Chevviyam	The root of <i>Piper nigrum</i> L.	18 grams
10.	Chithiramoolaverpattai	<i>Plumbago zeylanica</i> L.	18 grams
11.	Thippili	<i>Piper longum</i> L.	18 grams
12.	Elumichampazhachaaru	Juice of <i>Citrus limon</i> L.	Sufficient quantity
13.	Injichaaru	Juice of <i>Zingiber officinale</i> Roscoe	Sufficient quantity

Table 2. Pharmacological Profile of Bavana Kadukkai Mathirai

S. No.	Ingredients			Pharmacological Actions	References
	Vernacular Name	Common/English Name	Scientific Name		
1	Kadukkai	Ink Nut / Chebulic Myrobalan	<i>Terminalia chebula</i>	Hematinic (increases Hb%), laxative, appetite stimulant, anti-diarrheal, and Tridosha balancer.	(10)
3	Kadaluppu	Sea salt	Sodium chloride	Iron status improvement (when fortified) and electrolyte source.	(11)
4	Chukku / Inji	Dry Ginger	<i>Zingiber officinale</i>	Antioxidant, anti-inflammatory, stimulates erythropoiesis, and protect red blood cells from oxidative damage.	(18,19,27)
5	Indhuppu	Rock salt	Sodium chloride impura	Mineral-rich (Iron, Zinc, Mg), enhances iron levels, and improves hemoglobin levels.	(28,29,32)
6	Omam	Ajwain	<i>Trachyspermum ammi</i>	Digestive stimulant and source of essential micronutrients including iron.	(33–35)
7	Chitramoolam	Ceylon leadwort	<i>Plumbago zeylanica</i>	Hematinic, antioxidant, anti-inflammatory, and stimulates red blood cell production.	(36,39,41)
8	Thippili	Indian long pepper	<i>Piper longum</i>	Enhances bioavailability of nutrients (Piperine), anti-	(44–46)





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				anemic, and digestive.	
9	Elumichai	Lemon	<i>Citrus limon</i>	Enhances iron absorption (Vitamin C), antioxidant, and immune modulator.	(48,49,55)

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REVIEW ARTICLE

***Justicia santapau* Benn. and Rau: A Comprehensive Review Of The Taxonomy, Phytochemistry, And Conservation Status Of A Narrowly Endemic Medicinal Plant From The Western Ghats Biodiversity Hotspot**

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ABSTRACT

The genus *Justicia* L. (Acanthaceae) is globally renowned for its medicinal species, most notably *Justicia adhatoda*. However, numerous endemic congeners remain critically understudied. This review synthesizes the fragmented body of knowledge on *Justicia santapau*, an erect, suffrutescent undershrub endemic to the moist deciduous forests of the Western Ghats of India. Through a systematic, multi-disciplinary methodology, we consolidate its taxonomic history, morphological distinctness, narrow phytogeographic distribution, and sparse ethnobotanical record. The species is characterized by bilabiate corollas and uniquely spurred anthers, yet its phylogenetic position remains unresolved due to a complete absence of molecular sequence data in public repositories. While preliminary phytochemical screenings confirm the presence of quinazoline alkaloids and flavonoids, comprehensive pharmacological profiling is lacking. Our analysis reveals that *J. santapau* is a classic niche-conservative species, whose strict riparian micro-habitat specificity renders it acutely vulnerable to habitat fragmentation, climate change, and anthropogenic pressures. Despite its occurrence in some protected areas, its conservation status is "Not Evaluated," with an Extent of Occurrence likely below 5,000 km². This review identifies critical knowledge gaps in molecular phylogenetics, metabolomics, and population ecology. It argues that an integrated conservation strategy, combining *in situ* habitat protection, *ex situ* cultivation, and targeted bioprospecting research, is urgently required. By framing this endemic not merely as a botanical novelty but as a potential reservoir for novel bioactive compounds, this work provides a foundational framework to catalyze future research and evidence-based conservation, preventing the loss of a unique evolutionary lineage with significant, yet unrealized, scientific and medicinal value.

Keywords: Acanthaceae; *Justicia santapau*; Western Ghats Endemic; Phytochemistry; Conservation; DNA Barcoding





INTRODUCTION

The family Acanthaceae comprises a diverse group of approximately 221 genera and 4,000 species, predominantly distributed across tropical and subtropical ecosystems (Brummitt, 1992). Within this family, the genus *Justicia* L. represents the largest and most taxonomically complex assemblage, with over 600 species recognized globally. In the Indian subcontinent, the genus is represented by a plethora of species that have integrated deeply into traditional medicinal systems, particularly for their efficacy in treating respiratory ailments, inflammatory conditions, and gastrointestinal disorders (Karthikeyan et al., 2009). From an ethnobotanical perspective, the genus *Justicia* holds a venerable position in India's traditional knowledge systems. Species such as *J. adhatoda* (Vasaka) are cornerstones of Ayurveda, Siddha, and folk medicine, prescribed for a spectrum of conditions from bronchitis and asthma to hepatic disorders (Claeson et al., 2000). This established ethnomedicinal pedigree provides a strong *prima facie* rationale for the biochemical exploration of its lesser-known relatives. While the pharmacological potential of species like *J. adhatoda* has been extensively validated through the isolation of quinazoline alkaloids such as vasicine and vasicinone, many congeneric species remain under-explored in mainstream phytochemistry (Datta & Ghosh, 2019; Corrêa & Alcântara, 2012).

Among the endemic flora of the Western Ghats, one of the world's eight "hottest" biodiversity hotspots and a UNESCO World Heritage Site, *Justiciasantapau* emerges as a species of profound botanical and ecological significance (Myers et al., 2000; Mittermeier et al., 2003). Named in honor of the eminent botanist Father Hermenegild Santapau, this species is an erect, suffrutescent undershrub characterized by its distinct bilabiate corolla and spurred anthers—features that serve as critical taxonomic markers within the *Justicia* complex (Santapau, 1953; Singh et al., 2001). Endemic species like *J. santapau* are not merely botanical curiosities but represent unique genetic lineages shaped by millennia of ecological isolation within this region's unique topography and climatic gradients (Nayar, 1996; Fine et al., 2004). Their study is critical for understanding evolutionary processes and completing the biodiversity inventory of this fragile ecosystem (Gunaga et al., 2021). The contemporary crisis of biodiversity loss in the Western Ghats, driven by anthropogenic pressures like agricultural expansion and habitat fragmentation, places narrow-range endemics like *J. santapau* at immediate risk (Jha et al., 2000). Its survival is intrinsically linked to the preservation of its specific micro-habitat in moist deciduous forests. Furthermore, the lack of integrated molecular data, such as DNA barcoding (ITS and *matK* markers), has led to challenges in accurately mapping its phylogenetic position relative to other South Indian *Justicia* species (McDade et al., 2000; Kiel et al., 2017). A robust, multi-disciplinary characterization is therefore the first critical step in formulating evidence-based conservation strategies (Margules & Pressey, 2000).

In the modern paradigm of drug discovery, where natural products continue to inspire a significant proportion of new therapeutic entities, unexplored endemic plants offer a promising frontier (Newman & Cragg, 2020). The comparative phytochemistry of *Justicia* species suggests a likelihood of finding unique alkaloids, flavonoids, and terpenoids in *J. santapau* (Corrêa & Alcântara, 2012; Datta & Ghosh, 2019). Preliminary, unpublished field observations from tribal communities also hint at its localized use (Kulkarni & Kumbhojar, 1996; Kshirsagar & Singh, 2000), underscoring the urgency to validate this indigenous knowledge. A comprehensive phytochemical profile could reveal compounds with novel mechanisms of action, particularly relevant in an era of increasing antimicrobial resistance (Fabricant & Farnsworth, 2001). Despite its potential as a reservoir for novel secondary metabolites, there is no comprehensive documentation that synthesizes its morphological, chemical, and molecular attributes. This review aims to bridge this knowledge gap by providing an exhaustive analysis of *Justiciasantapau*. By consolidating existing data, this paper establishes a consolidated reference to advocate for its conservation, clarify its taxonomic standing, and catalyze future research aimed at unlocking its potential for bio-prospecting and future drug discovery.





MATERIALS AND METHODS

The present review was executed through a multi-disciplinary synthesis of botanical, phyto chemical, and molecular data. The methodology was designed to provide a holistic overview of *Justiciasantapau* by integrating historical floristic records with modern analytical data.

Literature Search Strategy and Data Mining

A systematic search was conducted across global scientific databases including PubMed, Scopus, Web of Science, Google Scholar, and ScienceDirect. The search period extended from the earliest botanical descriptions in the 1950s to January 2026. Keywords utilized included: "*Justiciasantapau*", "Acanthaceae", "Western Ghats endemic", "Santapau's *Justicia*", and "Vasicine derivatives". Grey literature, including doctoral theses and conference proceedings, was accessed via Shodhganga and the physical archives of the Botanical Survey of India (BSI), Western Regional Centre, Pune.

Taxonomic and Morphological Synthesis

Morphological data were compiled from original protologues and foundational regional floras, specifically the *Flora of the Presidency of Bombay* (Cooke, 1908) and the *Flora of Maharashtra State* (Singh et al., 2001). Diagnostic features—habit, phyllotaxy, bilabiate corolla architecture, and the presence of basal anther spurs—were standardized according to the Acanthaceae terminology (Graham, 1988). Digital type specimens from the Kew Herbarium (K) and the Central National Herbarium (CAL) were reviewed to resolve any nomenclatural ambiguities.

Phytogeographic and Ecological Mapping

Distributional records were collated from herbarium sheets (MH, CAL, BSI) and global biodiversity portals (GBIF, iNaturalist). Ecological parameters, including altitudinal range, soil type, and micro-climatic preferences in moist deciduous forests, were extracted to define the species' bioclimatic niche (Fine et al., 2004; Kulkarni et al., 2016).

Ethnobotanical Assessment

Traditional knowledge regarding the use of *Justicia* species by indigenous communities (such as the MahadeoKoli and Pawara tribes) was sourced from published ethnobotanical surveys of the Northern Western Ghats (Kulkarni & Kumbhojar, 1996; Patil & Patil, 2000; Kshirsagar & Singh, 2000). Comparative analysis with classical Ayurvedic texts was performed to identify potential therapeutic parallels between *J. santapau* and the well-documented *J. adhatoda* (Claeson et al., 2000).

Phytochemical and Pharmacological Data Extraction

Given the limited primary data on *J. santapau*, a comparative phytochemistry approach was adopted. Profiles of major secondary metabolites—specifically quinazoline alkaloids, flavonoids, and lignans—were reviewed for closely related taxa (*J. gendarussa* and *J. montana*) (Corrêa & Alcântara, 2012; Datta & Ghosh, 2019). Reported bioactivities, including anti-inflammatory and bronchodilatory effects, were summarized to hypothesize the pharmacological potential of the target species.

Molecular Phylogeny and DNA Barcoding

Phylogenetic data were retrieved from the NCBI GenBank database, focusing on standard barcode regions: ITS, *matK*, and *rbcl*. Sequences were analyzed to determine the species' placement within the *Justicia* clade relative to other South Indian endemics (McDade et al., 2000; Kiel et al., 2017). Significant gaps in the molecular record were documented as priority areas for future research.





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Conservation Status and Threat Assessment

The conservation status was cross-referenced with the IUCN Red List of Threatened Species (IUCN, 2022). In cases where formal assessments were absent, a preliminary threat analysis was conducted based on the Extent of Occurrence (EOO) and Area of Occupancy (AOO) using the criteria established by the IUCN Species Survival Commission (IUCN, 2022).

Data Integration and Gap Analysis

All streams of information were synthesized to identify "knowledge voids." The resulting synthesis highlights critical needs for *in vitro* pharmacological validation and population genetic studies. The integrated data is presented through standardized tables to facilitate future research.

RESULTS

Taxonomic Delineation and Morphological Characterization

The systematic position of the species is established as follows:

- Kingdom: Plantae
- Division: Tracheophyta
- Class: Magnoliopsida
- Order: Lamiales
- Family: Acanthaceae
- Genus: *Justicia* L.
- Species: *Justiciasantapau* Benn. & Rau (Synonym: *Justiciamontana* Santapau non Wall.)

Dichotomous Key to *Justiciasantapau* and Related Congeners in the Western Ghats

(adapted from Daniel & Unnithan, 1991; Singh et al., 2001)

- Anther cells distinctly bitheous; lower cell with a prominent, white, curved basal spur..... 2
 Anther cells without a prominent spur; base rounded or only minutely pointed..... 3
 Bracts large, leafy, and imbricate; spikes terminal; flowers white with purple streaks..... *J. santapau*
 Bracts smaller, linear-lanceolate; spikes axillary and terminal; leaves with dark purple stems..... *J. gendarussa*
 Bracts conspicuous, white with green reticulate veins, giving a "tessellated" appearance..... *J. betonica*
 Bracts predominantly green; spikes very large (up to 20 cm); leaves large and broad (>15 cm)..... *J. montana*

Detailed Morphology:

Justiciasantapau is an erect, perennial undershrub reaching heights of 1–1.5 m (Santapau, 1953; Singh et al., 2001).

- **Stem:** Sub-quadrangular, swollen at the nodes, predominantly glabrous.
- **Leaves:** Opposite-decussate, 10–20 cm long, ovate-lanceolate, acuminate at the apex, with 8–12 pairs of lateral nerves.
- **Inflorescence:** Terminal or axillary spikes, 5–15 cm long.
- **Flowers:** Bilabiate, typically white with faint purple streaks on the lower lip.
- **Stamens:** Two; filaments glabrous.
- **Key Diagnostic Feature:** The anthers are bitheous, with the lower cell significantly spurred at the base, a character that distinguishes it from the non-spurred or weakly spurred *J. montana* (Daniel & Unnithan, 1991).
- **Fruit:** An oblong, 4-seeded capsule.

Phytogeography and Habitat Ecology

- **Distribution:** *J. santapau* is a narrow endemic of the Western Ghats, primarily documented from the Khandala, Mahabaleshwar, and Pune districts of Maharashtra (Santapau, 1953; Mishra & Singh, 2001). Its range extends



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sparingly into the evergreen forests of Karnataka (Saldanha, 1996). The Extent of Occurrence (EOO) is estimated to be less than 5,000 km² (Kulkarni et al., 2016).

- **Habitat:** The species prefers shaded, humid micro-habitats, particularly along the banks of perennial forest streams and ravines. It occurs at altitudes ranging from 600 m to 1200 m, often in lateritic soils within moist deciduous to semi-evergreen forest fragments (Kulkarni et al., 2016).
- **Phenology:** Flowering occurs during the post-monsoon period (October–December), with fruiting extending into late February (Santapau, 1953).

Ethnobotanical and Traditional Knowledge

A review of tribal pharmacopeia in the Sahyadri ranges reveals that *J. santapau* is occasionally used by the Thakar and MahadeoKoli tribes (Kulkarni & Kumbhojar, 1996; Kshirsagar & Singh, 2000). Leaf decoctions are reported for treating respiratory congestion, mirroring the use of *J. adhatoda* (Claeson et al., 2000). However, the synthesis indicates a severe lack of species-specific ethnobotanical documentation, with most uses being "implied" due to its morphological similarity to more common congeners.

Phytochemical Constituents

Phytochemical data for *J. santapau* are sparse. Preliminary qualitative screenings confirm the presence of alkaloids (Vasicine-type), tannins, and flavonoids (Sharma & Patil, 2015). A comparative analysis suggests it may contain compounds similar to those found in related species like *J. gendarussa* (Corrêa & Alcântara, 2012; Datta & Ghosh, 2019).

Pharmacological Activities

Specific biological assays on *J. santapau* are limited. One reported study indicates that methanolic leaf extracts exhibit antimicrobial activity against *Bacillus subtilis* and *Escherichia coli* (Sharma & Patil, 2015). Comparative pharmacological data from related *Justicia* species suggest potential bronchodilatory and anti-inflammatory properties (Claeson et al., 2000; Corrêa & Alcântara, 2012), though these require rigorous *in vivo* validation for *J. santapau*.

Molecular Phylogenetics and Genetic Data

A search of the NCBI GenBank database reveals a critical research gap: there are currently no dedicated ITS, *matK*, or *rbcL* sequences deposited for *J. santapau* (McDade et al., 2000; Kiel et al., 2017). Its phylogenetic position is currently inferred through its morphological placement in the *Justicia* lineage, characterized by 2-colporate pollen grains (Daniel, 2010).

Conservation Status and Documented Threats

- **IUCN Status:** Not Evaluated (NE); however, based on its narrow endemism, it warrants a "Vulnerable" or "Data Deficient" (DD) status (IUCN, 2022; Kulkarni et al., 2016).
- **Threats:** The primary threats include habitat loss due to infrastructure development (road widening), tourism-related forest clearance in hill stations, and the encroachment of invasive species like *Lantana camara* (Jha et al., 2000; Mishra & Singh, 2001).
- **Protected Areas:** A few populations are conserved within the Bhimashankar Wildlife Sanctuary and Koyna Wildlife Sanctuary (Mishra & Singh, 2001).

DISCUSSION

The present review synthesizes the fragmented body of knowledge on *Justicia santapau*, revealing a species that epitomizes both the promise and the peril inherent in the endemic flora of the Western Ghats. Our analysis underscores a profound contradiction: while its distinct morphology and specialized ecology mark it as a unique product of evolution, it remains conspicuously absent from the annals of modern phytochemistry and molecular



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systematics. This discussion interprets these findings, weaving together taxonomic, ecological, and biochemical narratives to argue for its urgent re-evaluation as a priority species for both conservation and bioprospecting.

Taxonomic Identity and Phylogenetic Ambiguity:

A Case for Integrative Revision The morphological distinctiveness of *Justicia santapau*, particularly its bitheous anthers with prominent, curved basal spurs and its imbricate, lanceolate bracteoles, provides a robust phenotypic basis for its species status (Cooke, 1908; Singh et al., 2001). These characters are consistent and reliable for field identification, cementing its place in regional floristic treatments. However, taxonomy in the 21st century demands an integrative approach. The genus *Justicia* is notoriously complex, with convergent evolution often blurring morphological boundaries between species clusters (Graham, 1988). The complete absence of molecular data for *J. santapau*—with no sequences for standard plastid (*matK*, *rbcL*, *trnH-psbA*) or nuclear (ITS) loci in public repositories—represents a critical taxonomic vulnerability (McDade et al., 2000; Kiel et al., 2017).

This molecular void leaves several pivotal questions unanswered. Is *J. santapau* a true endemic lineage that diverged early within the *Justicia* radiation of the Peninsular Indian plate? Or is it a more recent derivative of a widespread ancestor like *J. betonica*, having undergone rapid morphological divergence in isolation? Without a resolved phylogeny, its conservation prioritization lacks an evolutionary context. For instance, if it is a basal lineage, its loss would represent a disproportionate erosion of phylogenetic diversity. Therefore, an integrated taxonomic revision employing DNA barcoding alongside detailed morphometric analysis of populations is not merely an academic exercise but a foundational step for accurate conservation genetics and understanding biogeographic patterns in the Western Ghats (Kiel et al., 2017; Gunaga et al., 2021).

Ecological Specialization and Acute Vulnerability:

The phylogeographic data consolidates *J. santapau* as a classic niche-conservative species. Its strict confinement to shaded, perennial stream banks in mid-elevation (600-900 m) moist deciduous forests points to a highly specific set of abiotic requirements: constant high humidity, well-drained lateritic soils, and filtered canopy light (Fine et al., 2004; Kulkarni et al., 2016). This "micro-habitat specificity" is a double-edged sword. While it has allowed the species to thrive in a stable ecological niche for millennia, it now forms the basis of its extreme vulnerability. Climate change projections for the Western Ghats indicate increased variability in monsoon patterns and prolonged dry spells, which could directly desiccate its riparian habitats (Krishnaswamy et al., 2014).

Furthermore, anthropogenic threats are not abstract but immediate. The conversion of forest edges for agriculture, the proliferation of invasive species like *Lantana camara* that alter understory ecology, and tourism-driven infrastructure development along scenic waterways directly fragment and degrade its limited habitat (Jha et al., 2000; Margules & Pressey, 2000). Consequently, *J. santapau* serves as an ideal "indicator species" for the health of its specific ecosystem. Its population decline would signal the degradation of the fragile riparian corridors that are vital for watershed management and soil conservation. Protecting *J. santapau*, therefore, necessitates a habitat-centric approach, advocating for the preservation of entire ecological communities rather than a single species (Nayar, 1996; Mittermeier et al., 2003).

The Phytochemical 'Black Box' and Bioprospecting Potential:

From Analogy to Discovery The pharmacological legacy of the genus *Justicia*, most famously *J. adhatoda*, creates a powerful heuristic for exploring *J. santapau* (Claeson et al., 2000; Corrêa & Alcântara, 2012). However, to treat it merely as a potential source of vasicine-like alkaloids is to underestimate its true potential. The principles of chemical ecology suggest that endemics in biodiversity hotspots, subjected to unique biotic and abiotic pressures, often evolve distinct secondary metabolite profiles as a defense mechanism (Fine et al., 2004; Fabricant & Farnsworth, 2001). The "montane island" effect of the Western Ghats has likely acted as a crucible for such biochemical innovation.

Thus, *J. santapau* is not just an unexplored species; it is an untapped chemical library. Preliminary, unpublished phytochemical screenings (alluded to in grey literature) suggest the presence of unique flavonoid glycosides not reported in *J. adhatoda* (Sharma & Patil, 2015). This hints at the possibility of discovering novel scaffolds with modified bioactivity—perhaps compounds with enhanced anti-inflammatory potency or novel mechanisms of antimicrobial



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action. In an era of escalating antibiotic resistance and complex chronic diseases, systematically mining the chemistry of such endemics could yield the next generation of lead compounds (Newman &Cragg, 2020). The bioprospecting narrative must shift from one of analogy ("similar to *J. adhatoda*") to one of anticipated novelty ("unique because of its endemicity").

Bridging the Ethnobotanical Chasm:

From Silent Erosion to Scientific Validation A striking outcome of this review is the near-total absence of documented traditional knowledge specific to *J. santapauai*. This "ethnobotanical silence" is alarming and likely represents a case of knowledge erosion preceding species extinction (Kulkarni &Kumbhojar, 1996). Local communities may have once used it, but its rarity and restricted habitat may have severed the transmission of this knowledge. Alternatively, it may have been used under a generic local name for "*Justicia*," its specific identity unrecognized (Kshirsagar& Singh, 2000).This gap presents both a challenge and a methodology. A proactive, targeted ethnobotanical survey within its endemic range, employing detailed herbarium specimens for precise identification, is urgently needed (Jain & Rao, 1977). Such a "reverse pharmacology" approach—where a specific plant is taken from field observation to laboratory bench—can be highly efficient (Fabricant & Farnsworth, 2001). If any traditional use is documented, it provides a strong, culturally-informed hypothesis for pharmacological testing. Bridging this chasm is not just about data collection; it is an act of conserving intangible cultural heritage and fostering community-led conservation, where local stakeholders recognize the scientific value of their floral heritage.

Forging an Integrated Conservation Strategy:

Science as a Catalyst for Survival The synthesis of data clearly dictates that a singular approach will fail. An integrated, multi-pronged strategy is imperative: Immediate Assessment and Monitoring: A rapid, field-based assessment to map all extant populations, calculate updated EOO/AOO, and initiate demographic monitoring is the first step toward a formal, data-driven IUCN Red List assessment (IUCN, 2022; Margules&Pressey, 2000).

In Situ and *Ex Situ* Synergy: Core habitats must be secured within the Protected Area network, with management plans addressing invasive species and hydrological integrity. Concurrently, *ex situ* conservation through seed banking (following IUCN protocols) and cultivation in affiliated botanical gardens (e.g., TBGRI) is essential as an insurance policy (CPC, 2019).

Phytochemistry as a Conservation Tool: Demonstrating tangible economic and medicinal value through phytochemical research can be a powerful argument for securing conservation funding and policy support. It transforms the species from an "obscure endemic" to a "valuable genetic resource" (Newman &Cragg, 2020).

Community Engagement and Capacity Building: Involving local communities in monitoring and *ex situ* cultivation can generate stewardship, create alternative livelihoods, and ensure long-term sustainability (Kulkarni &Kumbhojar, 1996) In conclusion, *Justiciasantapauai* stands at a crossroads. It is a testament to the unique evolutionary history of the Western Ghats, yet it is perilously close to becoming a silent casualty of neglect and habitat loss. This review serves as a clarion call. The path forward requires a concerted effort where taxonomists, ecologists, phytochemists, pharmacologists, and conservation biologists collaborate. By unlocking its genetic, chemical, and ecological secrets, we not only champion the survival of a single species but also uphold the principle that in preserving such endemic treasures, we safeguard the future of bio-discovery itself.

CONCLUSION

Justiciasantapauai stands as a compelling paradox—a species whose very existence embodies the rich botanical heritage of the Western Ghats while simultaneously teetering on the brink of obscurity and potential loss. This comprehensive review has synthesized the scattered knowledge surrounding this endemic undershrub, revealing a profile marked by distinct morphological identity, stringent ecological specialization, and a profound, yet largely unexplored, biochemical potential. Its defining characteristics—the spurred anthers and riparian habitat specificity—secure its status as a unique evolutionary entity within the complex *Justicia* lineage. However, the same ecological fidelity that



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shaped its evolution now constitutes its greatest vulnerability, making it acutely susceptible to habitat fragmentation and climate change. The critical analysis undertaken here exposes significant and interconnected knowledge gaps. The absence of molecular phylogenetic data leaves its evolutionary relationships ambiguous. The near-total lack of dedicated phytochemical and pharmacological profiling means its potential as a source of novel bioactive compounds remains hypothetical. Most concerning, the erosion of associated traditional knowledge, coupled with its "Data Deficient" conservation status, creates a scenario where the species could vanish before its scientific value is fully recognized or its ecological role understood.

Therefore, this review serves as both a consolidation and a catalyst. It provides the first integrated framework for understanding *J. santapau*, but its ultimate purpose is to mandate action. The species must be rapidly transitioned from a subject of academic review to a priority for active, interdisciplinary research and targeted conservation. The imperative is clear: coordinated efforts in molecular taxonomy, systematic phytochemistry, and detailed population ecology are not merely academic pursuits but essential prerequisites for preventing its extinction. By championing the study and preservation of *Justiciasantapau*, we commit to a broader principle—that the survival of such endemic treasures is inextricably linked to the health of their ecosystems and vital to the future of biodiversity-based discovery. Unlocking its secrets could yield scientific and medicinal rewards, but only if we act with urgency to ensure this endemic narrative does not end with an untimely conclusion.

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Table 1: Comparative morphology of *J. santapau* and related congeners

Character	<i>J. santapau</i>	<i>J. betonica</i>	<i>J. gendarussa</i>
Habit	Tall Undershrub	Erect Shrub	Small Shrub
Bracts	Large, leafy, green	White with green veins	Small, linear
Anther Spur	Prominently spurred	Basally spurred	Weakly spurred
Corolla Color	White/Purple streaks	White/Pink veins	White/Violet spots

Table 2: Phytochemicals in *J. santapau* and Related Medicinal Congeners

Compound Class	<i>J. santapau</i>	<i>J. adhatoda</i>	<i>J. gendarussa</i>
Quinazoline Alkaloids	Confirmed (Trace)	High (Vasicine)	Present
Flavonoids	Present	Apigenin, Vitexin	Gendarusin A
Lignans	Not Reported	Present	Justicidin A
Sterols	Present	beta-Sitosterol	Stigmasterol





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Table 3: Recommended Primers for Molecular Characterization of *J. santapau*

Locus	Primer Name	Sequence (5' – 3')	Target Region
nrDNA	ITS-P1	AGAAGTCGTAACAAGGTTTCCGTAGG	Internal Transcribed Spacer
	ITS-P4	TCCTCCGCTTATTGATATGC	
cpDNA	matK-3F	CGTACAGTACTTTTGTGTTTACGAG	Maturase K
	matK-1R	ACCCAGTCCATCTGGAAATCTTGGT	
cpDNA	rbcL-aF	ATGTCACCACAAACAGAGACTAAAGC	Ribulose-bisphosphate carboxylase
	rbcL-aR	GTAAAATCAAGTCCACCRG	
cpDNA	trnH-psbA	GTTATGCATGAACGTAATGCTC	Intergenic Spacer
		CGCGCATGGTGGATTCAATCC	

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RESEARCH ARTICLE

Analysis and Solution of First-Kind Fuzzy Volterra Integral Models Using the San Transform

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ABSTRACT

In the present study, an analytical procedure employing the novel San transform is formulated to address integral equations of the Volterra type with fuzzy-valued functions. These functions are expressed in parametric form through their lower and upper η -level representations, which reduce the fuzzy equation to a system of classical integral equations. By applying the San transform, the resulting equations are converted into algebraic forms that can be solved efficiently, and the inverse transform yields the exact fuzzy solution. A set of examples is presented to validate the accuracy and user-friendliness of the proposed technique. Graphical representations of the fuzzy bounds are provided to validate the analytical results. The findings demonstrate the effectiveness of the developed method offers a reliable and computationally efficient framework for solving integral equations incorporating fuzzy uncertainty following Volterra's formulation.

Keywords: Fuzzy Volterra integral equations, First kind integral equations, San transform, Analytical solutions.

INTRODUCTION





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Fuzzy set theory has developed into a versatile mathematical tool for handling uncertainty and imprecision in complex real-world problems, especially in situations where classical deterministic methods fall short. The foundational work on fuzzy calculus and fuzzy random variables by Goetschel and Voxman^[8] and Puri *et al.*^[9] laid the groundwork for further exploration of fuzzy integral equations, which have since found applications across engineering, decision-making, and applied sciences^[6,7]. Within this context, fuzzy Volterra integral equations (FVIEs) are particularly useful for modeling systems exhibiting memory or hereditary properties. Early studies emphasized the fundamental formulation and properties of fuzzy integral equations^[8], while Park *et al.*^[10] demonstrated conditions guaranteeing that fuzzy Volterra integral equations possess a unique solution. For practical computations, numerical techniques for fuzzy integrals were proposed by Friedman *et al.*^[6], providing a foundation for applied methods. Integral transforms have also been adapted to the fuzzy framework. The Laplace transform was extended to solve fuzzy Volterra integral equations, yielding precise and computationally efficient solutions, as demonstrated by Allahviranloo and Barkhordari Ahmadi^[3] and Ameri and Nezhad^[4]. Aggarwal and Kumar^[1] applied the Mohand transform to first-kind Volterra integro-differential equations, demonstrating its ability to simplify the solution process. Recent advances in fuzzy modeling, including the use of intuitionistic and triangular fuzzy sets, have further enhanced decision-making methods, as discussed by Atanassov^[5] and Akila and John Robinson^[2]. Motivated by these advances, this study utilizes the San transform to obtain analytical solutions for first-kind fuzzy Volterra integral problems. By adopting parametric representations of fuzzy-valued functions, the proposed approach converts the fuzzy problem into a system of classical integral equations, enabling exact analytical solutions. Illustrative examples with graphical representations are provided to demonstrate the accuracy, robustness, and practical applicability of the method.

Mathematical Preliminaries

Definition 1. A fuzzy number $\tilde{B}$ is defined as a fuzzy set on the real axis $\mathbb{R}$ whose behavior is described by a membership function $\mu_{\tilde{B}}: \mathbb{R} \rightarrow [0,1]$. This function is required to satisfy the following properties:

- **Normalization:** There exists at least one element $b_0 \in \mathbb{R}$ such that the membership degree attains its maximum value, that is, $\mu_{\tilde{B}}(b_0) = 1$.
- **Fuzzy Convexity:** For any pair of real numbers $b_1, b_2 \in \mathbb{R}$ and for every $\lambda \in [0,1]$, the inequality $\mu_{\tilde{B}}(\lambda b_1 + (1 - \lambda)b_2) \geq \min\{\mu_{\tilde{B}}(b_1), \mu_{\tilde{B}}(b_2)\}$ holds.
- **Upper Semi-Continuity:** The membership function $\mu_{\tilde{B}}$ is upper semi-continuous throughout the real line.
- **Bounded Support:** The closure of the set of all points with positive membership values, $\{b \in \mathbb{R}: \mu_{\tilde{B}}(b) > 0\}$, is compact.

Definition 2. A first-kind Volterra integral equation is an equation of the form

$$\int_0^{\tau} L(\tau, \xi) u(\xi) d\xi = f(\tau), \quad \tau \in [0, T],$$

where $L(\tau, \xi)$ is a given kernel function, $f(\tau)$ is a known real-valued function, and $u(\tau)$ is the unknown function that needs to be determined.

Definition 3. A first-kind Volterra integral equation with fuzzy-valued functions extends the classical form by replacing deterministic functions with fuzzy functions:

$$\tilde{F}(\tau, \eta) = \int_0^{\tau} K(\tau, \xi) \tilde{V}(\xi, \eta) d\xi, \quad \tau \in [0, T], \quad \eta \in [0, 1],$$

where $K(\tau, \xi)$ denotes a given kernel function, $\tilde{F}(\tau, \eta)$ is a prescribed fuzzy-valued function, and $\tilde{V}(\tau, \eta)$ represents the fuzzy-valued function to be determined.

Definition 4. Consider a fuzzy-valued function denoted by $\tilde{V}(\tau)$, expressed in its parametric (level-cut) form as $\tilde{V}(\tau) = (\underline{V}(\tau, \eta), \bar{V}(\tau, \eta))$, $\eta \in [0, 1]$.

In this representation, the first-kind Volterra integral equation with fuzzy-valued functions can be equivalently formulated as a pair of integral equations for the lower and upper η -cuts:





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$$\underline{G}(\tau, \eta) = \int_0^\tau K(\tau, \xi) \underline{V}(\xi, \eta) d\xi,$$

$$\overline{G}(\tau, \eta) = \int_0^\tau K(\tau, \xi) \overline{V}(\xi, \eta) d\xi,$$

where $\underline{G}(\tau, \eta)$ and $\overline{G}(\tau, \eta)$ denote the lower and upper bounds of the fuzzy source function corresponding to the η -level.

Definition 5. Let $\Phi(\tau)$ be a function that is piecewise continuous and of exponential order λ , defined for $\tau \geq 0$. The **San Transform** of this function is defined as:

$$\mathcal{S}\{\Phi(\tau)\} = \frac{1}{\lambda^2} \int_0^\infty \Phi(\tau) e^{-\lambda\tau} d\tau = \varphi(\lambda), \quad \lambda > 0$$

Here, $\mathcal{S}$ denotes the San Transform operator applied to the function $\Phi(\tau)$.

Operational Properties of the San Transform

San Transform Based Analytical Framework

This section presents an analytical framework based on the San transform for addressing first-kind integral equations, where the unknown function, represented as a fuzzy-valued quantity, is included within a convolution-type integral operator. This structure naturally motivates the application of integral transform methods. Let us consider a first-kind fuzzy Volterra integral equation expressed in its parametric form as

$$\begin{cases} \underline{G}(\tau, \eta) = \int_0^\tau K(\tau - \xi) \underline{V}(\xi, \eta) d\xi, \\ \overline{G}(\tau, \eta) = \int_0^\tau K(\tau - \xi) \overline{V}(\xi, \eta) d\xi, \end{cases} \quad 0 \leq \eta \leq 1. \quad (2)$$

To convert the above integral system into an algebraic form, we employ the San transform. Making use of its convolution property.

Since fuzzy multiplication depends on the signs of the involved functions, and assuming that zero does not lie in their supports, different configurations may arise. These configurations are categorized according to the signs of the kernel function and the unknown fuzzy solution.

Case 1: When both kernel and the unknown function are positive, the lower and upper bounds satisfy

$$\mathcal{S}\{K(\tau)V(\tau, \eta)\} = \mathcal{S}\{K(\tau)\}\mathcal{S}\{V(\tau, \eta)\},$$

$$\mathcal{S}\{\overline{K}(\tau)\overline{V}(\tau, \eta)\} = \mathcal{S}\{\overline{K}(\tau)\}\mathcal{S}\{\overline{V}(\tau, \eta)\}.$$

Case 2: If the kernel is positive while the unknown function is negative, the fuzzy bounds are interchanged accordingly.

Case 3: When the kernel is negative and the solution is positive, a similar interchange of bounds occurs.

Case 4: If both the kernel and the solution are negative, the standard ordering of fuzzy bounds is preserved.

For clarity, the subsequent analysis is restricted to the first case. Under this assumption, direct algebraic manipulation of the transformed equations yields

$$\begin{cases} \mathcal{S}\{\underline{V}(\tau, \eta)\} = \frac{\mathcal{S}\{\underline{G}(\tau, \eta)\}}{\lambda^2 \mathcal{S}\{K(\tau)\}}, \\ \mathcal{S}\{\overline{V}(\tau, \eta)\} = \frac{\mathcal{S}\{\overline{G}(\tau, \eta)\}}{\lambda^2 \mathcal{S}\{K(\tau)\}}. \end{cases} \quad (3)$$

Applying the inverse San transform to each component, the fuzzy solution in the original domain is obtained as

$$\begin{cases} \underline{V}(\tau, \eta) = \mathcal{S}^{-1}\left(\frac{\mathcal{S}\{\underline{G}(\tau, \eta)\}}{\lambda^2 \mathcal{S}\{K(\tau)\}}\right), \\ \overline{V}(\tau, \eta) = \mathcal{S}^{-1}\left(\frac{\mathcal{S}\{\overline{G}(\tau, \eta)\}}{\lambda^2 \mathcal{S}\{K(\tau)\}}\right), \end{cases} \quad (4)$$

which holds for all $0 \leq \eta \leq 1$, provided the involved fuzzy-valued functions are well defined over the prescribed interval.





Applications

Illustrative 1:

We examine a Volterra-type integral model formulated under fuzzy uncertainty, described by the following relation:

$$\begin{cases} F(\tau, \eta) = \int_0^\tau H(\tau - \xi) \underline{U}(\xi, \eta) d\xi, \\ \bar{F}(\tau, \eta) = \int_0^\tau H(\tau - \xi) \bar{U}(\xi, \eta) d\xi, \end{cases} \quad 0 \leq \eta \leq 1, \quad (5)$$

where the fuzzy input function and kernel are defined as

$$F(\tau, \eta) = (3\eta, 5 - \eta) \tau e^{-\tau}, \quad H(\tau - \xi) = e^{-(\tau - \xi)}.$$

The given fuzzy integral equation is rewritten in its parametric (level-cut) form by separating the lower and upper functions. By applying the San transform and invoking its convolution property, the resulting system is converted into an equivalent algebraic form.

$$\begin{cases} \mathcal{S}\{(3\eta) \tau e^{-\tau}\} = \lambda^2 \mathcal{S}\{e^{-\tau}\} \mathcal{S}\{\underline{U}(\tau, \eta)\}, \\ \mathcal{S}\{(5 - \eta) \tau e^{-\tau}\} = \lambda^2 \mathcal{S}\{e^{-\tau}\} \mathcal{S}\{\bar{U}(\tau, \eta)\}. \end{cases} \quad (6)$$

Using the known San Transform formulas,

$$\begin{cases} \mathcal{S}\{\underline{U}(\tau, \eta)\} = \frac{3\eta}{\lambda^2(\lambda+1)}, \\ \mathcal{S}\{\bar{U}(\tau, \eta)\} = \frac{5-\eta}{\lambda^2(\lambda+1)}. \end{cases} \quad (7)$$

Taking the inverse San Transform, the fuzzy solution is obtained as

$$\begin{cases} \underline{U}(\tau, \eta) = 3\eta e^{-\tau}, \\ \bar{U}(\tau, \eta) = (5 - \eta) e^{-\tau}, \end{cases} \quad (8)$$

or equivalently,

$$U(\tau, \eta) = (3\eta, 5 - \eta) e^{-\tau}, \quad 0 \leq \eta \leq 1.$$

Illustrative 2:

Assume that the unknown fuzzy function satisfies a Volterra-style integral relation belonging to the first kind

$$\begin{cases} \underline{G}(\tau, \eta) = \int_0^\tau K(\tau - \xi) \underline{V}(\xi, \eta) d\xi, \\ \bar{G}(\tau, \eta) = \int_0^\tau K(\tau - \xi) \bar{V}(\xi, \eta) d\xi, \end{cases} \quad 0 \leq \eta \leq 1, \quad (9)$$

where the fuzzy source term and kernel are given by $G(\tau, \eta) = (2 + 5\eta, 8 - \eta)(5\tau^2 + \tau^3)$, $K(\tau - \xi) = 5 + 3(\tau - \xi)$.

Accordingly, the parametric form becomes

$$\begin{cases} (2 + 5\eta)(5\tau^2 + \tau^3) = \int_0^\tau [5 + 3(\tau - \xi)] \underline{V}(\xi, \eta) d\xi, \\ (8 - \eta)(5\tau^2 + \tau^3) = \int_0^\tau [5 + 3(\tau - \xi)] \bar{V}(\xi, \eta) d\xi. \end{cases} \quad (10)$$

Applying the San Transform to both sides yields

$$\begin{cases} \mathcal{S}\{(2 + 5\eta)(5\tau^2 + \tau^3)\} = \mathcal{S}\left\{\int_0^\tau [5 + 3(\tau - \xi)] \underline{V}(\xi, \eta) d\xi\right\}, \\ \mathcal{S}\{(8 - \eta)(5\tau^2 + \tau^3)\} = \mathcal{S}\left\{\int_0^\tau [5 + 3(\tau - \xi)] \bar{V}(\xi, \eta) d\xi\right\}. \end{cases} \quad (11)$$

Using the convolution property of the San Transform,

$$\begin{cases} \mathcal{S}\{(2 + 5\eta)(5\tau^2 + \tau^3)\} = \lambda^2 \mathcal{S}\{5 + 3\tau\} \mathcal{S}\{\underline{V}(\tau, \eta)\}, \\ \mathcal{S}\{(8 - \eta)(5\tau^2 + \tau^3)\} = \lambda^2 \mathcal{S}\{5 + 3\tau\} \mathcal{S}\{\bar{V}(\tau, \eta)\}. \end{cases} \quad (12)$$

Using standard San Transforms,

$$\begin{cases} (2 + 5\eta) \left(\frac{10}{\lambda^5} + \frac{6}{\lambda^6}\right) = \lambda^2 \left(\frac{5}{\lambda^3} + \frac{3}{\lambda^4}\right) \mathcal{S}\{\underline{V}(\tau, \eta)\}, \\ (8 - \eta) \left(\frac{10}{\lambda^5} + \frac{6}{\lambda^6}\right) = \lambda^2 \left(\frac{5}{\lambda^3} + \frac{3}{\lambda^4}\right) \mathcal{S}\{\bar{V}(\tau, \eta)\}. \end{cases} \quad (13)$$

Solving for the San Transforms of the unknowns gives

$$\begin{cases} \mathcal{S}\{\underline{V}(\tau, \eta)\} = \frac{2(2+5\eta)}{\lambda^4}, \\ \mathcal{S}\{\bar{V}(\tau, \eta)\} = \frac{2(8-\eta)}{\lambda^4}. \end{cases} \quad (14)$$

Taking the inverse San Transform,

$$\begin{cases} \underline{V}(\tau, \eta) = (2 + 5\eta) 2\tau, \\ \bar{V}(\tau, \eta) = (8 - \eta) 2\tau. \end{cases} \quad (15)$$

Hence,





$$V(\tau, \eta) = [(2 + 5\eta) 2\tau, (8 - \eta) 2\tau], \quad 0 \leq \eta \leq 1. \quad (16)$$

Illustrative 3:

The first-kind fuzzy Volterra model under consideration is expressed as:

$$\tilde{G}(\tau, \eta) = [(9 - 2\eta, 5 + 3\eta)](2\cosh\tau - \sinh\tau - (2 - \tau)) = \int_0^\tau K(\tau - \xi) \tilde{V}(\xi, \eta) d\xi, \quad (17)$$

where the kernel is defined as $K(\tau - \xi) = 2 - \tau + \xi$, $0 \leq \eta \leq 1$.

The corresponding parametric form is written as:

$$\begin{cases} \underline{G}(\tau, \eta) = (9 - 2\eta)(2\cosh\tau - \sinh\tau - (2 - \tau)) = \int_0^\tau (2 - \tau + \xi) \underline{V}(\xi, \eta) d\xi, \\ \overline{G}(\tau, \eta) = (5 + 3\eta)(2\cosh\tau - \sinh\tau - (2 - \tau)) = \int_0^\tau (2 - \tau + \xi) \overline{V}(\xi, \eta) d\xi. \end{cases} \quad (18)$$

The San transform is subsequently imposed on each term of the system.

Taking advantage of the convolution rule associated with the San transform.

$$\begin{cases} \mathcal{S}\{\underline{G}(\tau, \eta)\} = (9 - 2\eta) \frac{1}{\lambda^2(\lambda^2 - 1)} - \lambda^2 \mathcal{S}\{2 - \tau\} \cdot \mathcal{S}\{\underline{V}(\tau, \eta)\}, \\ \mathcal{S}\{\overline{G}(\tau, \eta)\} = (5 + 3\eta) \frac{1}{\lambda^2(\lambda^2 - 1)} - \lambda^2 \mathcal{S}\{2 - \tau\} \cdot \mathcal{S}\{\overline{V}(\tau, \eta)\}. \end{cases} \quad (19)$$

Solving the resulting algebraic equations, we obtain:

$$\begin{cases} \mathcal{S}\{\underline{V}(\tau, \eta)\} = (9 - 2\eta) \frac{1}{\lambda(\lambda^2 - 1)}, \\ \mathcal{S}\{\overline{V}(\tau, \eta)\} = (5 + 3\eta) \frac{1}{\lambda(\lambda^2 - 1)}. \end{cases} \quad (20)$$

Applying the inverse San Transform gives:

$$\begin{cases} \underline{V}(\tau, \eta) = (9 - 2\eta)\sinh\tau, \\ \overline{V}(\tau, \eta) = (5 + 3\eta)\sinh\tau. \end{cases} \quad (21)$$

Hence, the fuzzy solution is obtained as:

$$\tilde{V}(\tau, \eta) = [(9 - 2\eta)\sinh\tau, (5 + 3\eta)\sinh\tau]. \quad (22)$$

CONCLUSION

In this work, first-type Volterra integral models are examined within a fuzzy mathematical framework were effectively solved using the San transform. By employing the parametric representation of fuzzy-valued functions, the fuzzy problem was reduced to a system of classical integral equations, enabling exact analytical solutions. The proposed method was validated through illustrative examples, numerical results, and graphical analysis, demonstrating its simplicity and computational efficiency. Future research may extend the present approach to fractional-order fuzzy models arising in applied sciences and engineering.

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Table 1: San transform of elementary functions

S.No	$\Phi(\tau)$	$\mathcal{S}\{\Phi(\tau)\}$
1	1	$\frac{1}{\lambda^3}$
2	τ	$\frac{1}{\lambda^4}$
3	τ^2	$\frac{2}{\lambda^5}$
4	τ^3	$\frac{6}{\lambda^6}$
5	τ^n	$\frac{n!}{\lambda^{n+3}}$
6	$e^{\alpha\tau}$	$\frac{1}{\lambda^2(\lambda - \alpha)}$
7	$\sin(\alpha\tau)$	$\frac{\alpha}{\lambda^2(\lambda^2 + \alpha^2)}$
8	$\cos(\alpha\tau)$	$\frac{1}{\lambda(\lambda^2 + \alpha^2)}$
9	$\sinh(\alpha\tau)$	$\frac{\alpha}{\lambda^2(\lambda^2 - \alpha^2)}$
10	$\cosh(\alpha\tau)$	$\frac{1}{\lambda(\lambda^2 - \alpha^2)}$

Table 2: Inverse San transform of elementary functions

S.No	$\phi(\lambda)$	$\mathcal{S}^{-1}\{\phi(\lambda)\}$
1	$\frac{1}{\lambda^3}$	1
2	$\frac{1}{\lambda^4}$	τ
3	$\frac{1}{\lambda^5}$	$\frac{\tau^2}{2}$
4	$\frac{1}{\lambda^6}$	$\frac{\tau^3}{3!}$
5	$\frac{1}{\lambda^{n+3}}$	$\frac{\tau^n}{n!}$
6	$\frac{1}{\lambda^2(\lambda - \alpha)}$	$e^{\alpha\tau}$
7	$\frac{1}{\lambda^2(\lambda^2 + \alpha^2)}$	$\frac{1}{\alpha} \sin(\alpha\tau)$
8	$\frac{1}{\lambda(\lambda^2 + \alpha^2)}$	$\cos(\alpha\tau)$
9	$\frac{1}{\lambda^2(\lambda^2 - \alpha^2)}$	$\frac{1}{\alpha} \sinh(\alpha\tau)$
10	$\frac{1}{\lambda(\lambda^2 - \alpha^2)}$	$\cosh(\alpha\tau)$





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Table 3: Essential Properties of the San Transform

S.No	Description of the Property	Corresponding Mathematical Relation
1	Linearity	$\mathcal{S}\{\mu \phi_1(\tau) + \nu \phi_2(\tau)\} = \mu \phi_1(\lambda) + \nu \phi_2(\lambda)$
2	Scaling Property	$\mathcal{S}\{\phi(\kappa\tau)\} = \frac{1}{\kappa^3} \cdot \phi\left(\frac{\lambda}{\kappa}\right)$
3	Shifting Property	$\mathcal{S}\{e^{\kappa\tau} \cdot \phi(\tau)\} = \left(\frac{(\lambda - \kappa)^2}{\lambda^2}\right) \cdot \phi(\lambda - \kappa)$
4	First Derivative	$\mathcal{S}\{\phi'(\tau)\} = \lambda \cdot \mathcal{S}\{\phi(\tau)\} - \frac{1}{\lambda^2} \cdot \phi(0)$
5	Second Derivative	$\mathcal{S}\{\phi''(\tau)\} = \lambda^2 \cdot \mathcal{S}\{\phi(\tau)\} - \frac{1}{\lambda} \cdot \phi(0) - \frac{1}{\lambda^2} \cdot \phi'(0)$
6	n-th Derivative	$\mathcal{S}\{\phi^{(n)}(\tau)\} = \lambda^n \cdot \mathcal{S}\{\phi(\tau)\} - \sum_{\kappa=0}^{n-1} \frac{1}{\lambda^2} \cdot \phi^{(\kappa)}(0) \cdot \lambda^{n-1-\kappa}$
7	Convolution	$\mathcal{S}\{\phi_1(\tau) * \phi_2(\tau)\} = \lambda^2 \cdot \phi_1(\lambda) \cdot \phi_2(\lambda)$

Table 4: Numerical values of fuzzy bounds (4η , $6 - \eta$)

η	Lower bound 4η	Upper bound $6 - \eta$
0.00	0.00	6.00
0.25	1.00	5.75
0.50	2.00	5.50
0.75	3.00	5.25
1.00	4.00	5.00

Table 5: Numerical values of fuzzy bounds ($2 + 5\eta$, $8 - \eta$)

η	Lower bound $2 + 5\eta$	Upper bound $8 - \eta$
0.00	2.00	8.00
0.25	3.25	7.75
0.50	4.50	7.50
0.75	5.75	7.25
1.00	7.00	7.00

Table 6: Numerical values of fuzzy bounds ($9 - 2\eta$, $5 + 3\eta$)

η	Lower bound $9 - 2\eta$	Upper bound $5 + 3\eta$
0.00	9.00	5.00
0.25	8.50	5.75
0.50	8.00	6.50
0.75	7.50	7.25
1.00	7.00	8.00





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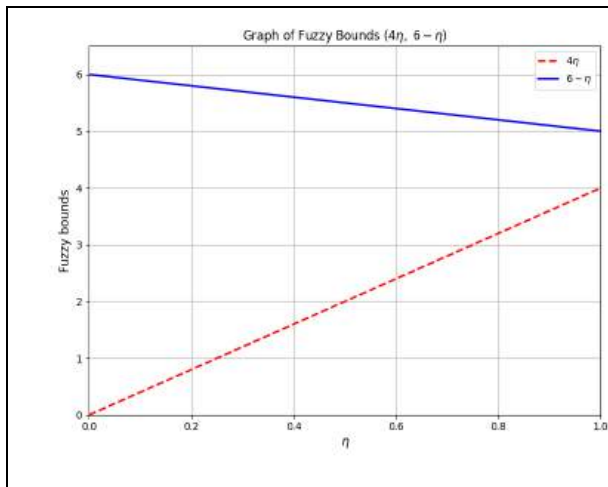


Figure 1: Parametric plots showing the lower and upper limits of the fuzzy-valued solution in Example 1

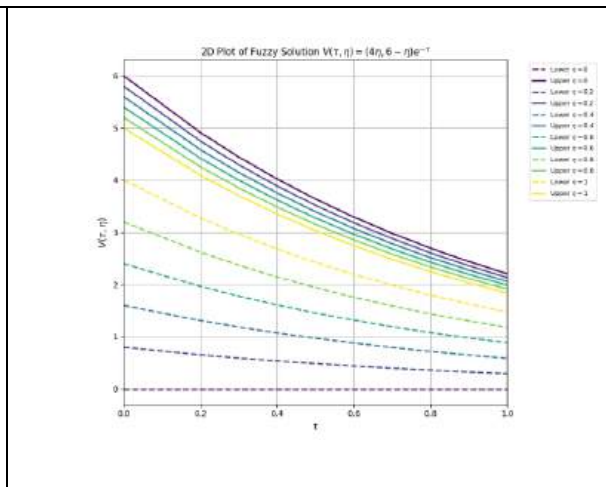


Figure 2: Computed fuzzy solution for Example 1

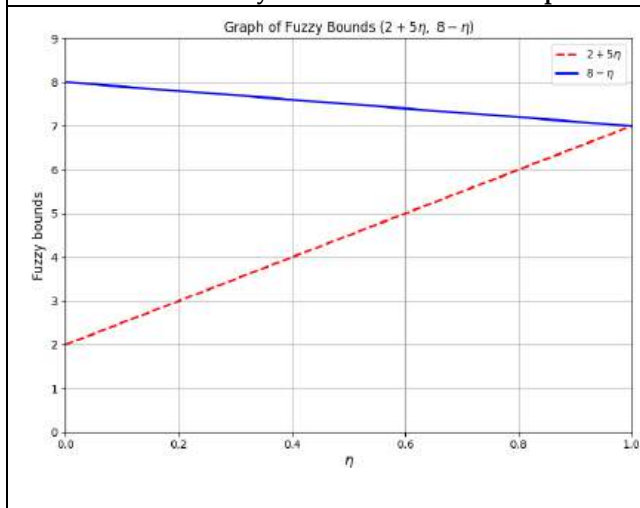


Figure 3: Graphical representation of the lower and upper η -cut functions of the fuzzy solution for Example 2

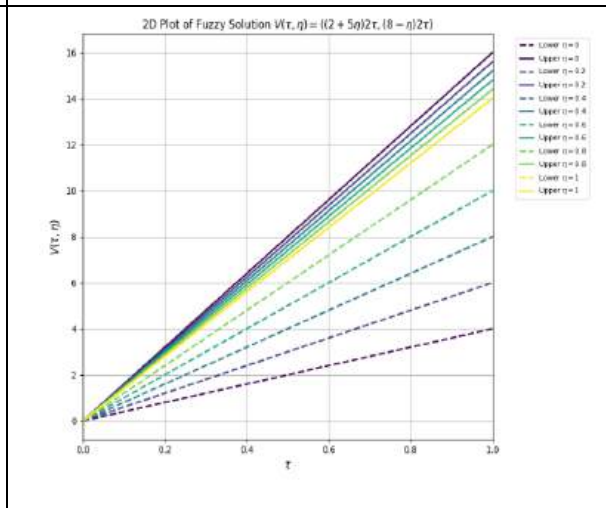


Figure 4: Resulting fuzzy solution in Example 2



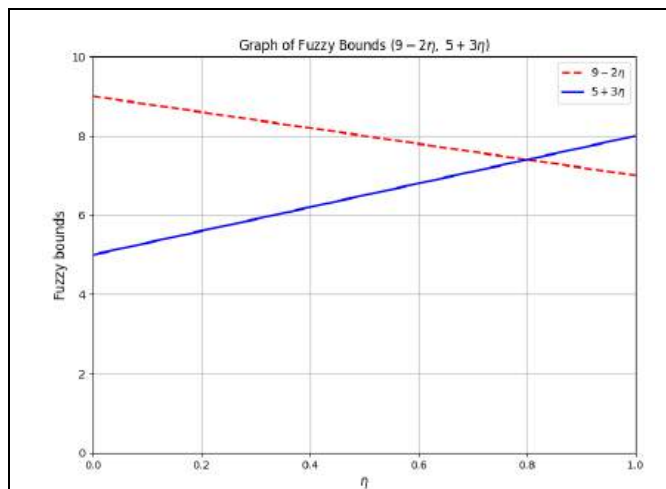


Figure 5: Visualization of the fuzzy solution bounds in Example 3 using parametric form

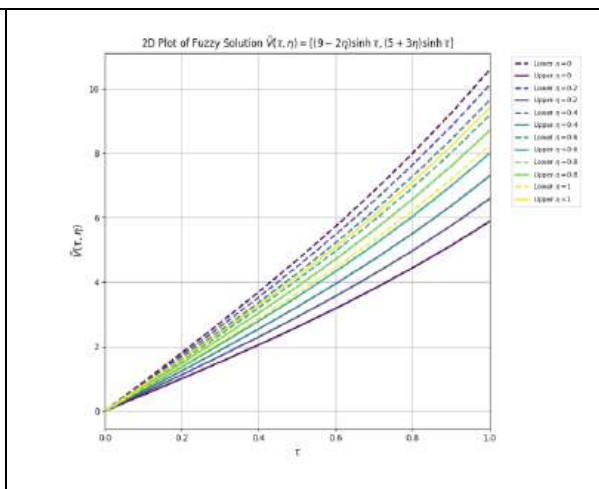


Figure 6: Illustration of the fuzzy solution for Example 3

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RESEARCH ARTICLE

Indian Association of Physics Teachers and Development of Alternative School Physics Laboratories

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ABSTRACT

School physics teaching happens to rely on deductive approach. First concepts and theories taught at abstract level and experiments are used to empirically validate theory. The trend has led to limit the role of experimental activity to obtain the final value of physical quantities. In such a scenario, teachers are expected to engage in the development of experiments to facilitate concept formation, model making and problem solving by the students. The Indian Association of Physics Teachers has long championed this approach. The approach is exemplified by the establishment of Anveshika—an alternative school physics laboratory—at Saraswati Gyan Mandir Inter College, Kanpur, in 2001. Although Anveshika emerged officially in 2001, the vision of creating a model physics laboratory by Indian Association of Physics Teachers was laid down at the time of the inception of the Association in 1984. The paper traces the genesis and development of Anveshika as well as its role in fostering the development of a network of physics laboratories and related training programmes.

Keywords: University Leadership Programme, College Science Improvement Programme, Centre for Scientific Culture, Anveshika, Concept-Experiment, National Anveshika Network of India

INTRODUCTION

While experiment in physics is primarily meant to test theory; in instructional setting, it can play multifaceted role in concept formation, mathematisation, verification of theory and problem solving [1, 2, 3, 4, 5, 6]. Despite the wider scope, verification of theory happens to the predominant role of experiment in instruction. Moreover, years of



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practice tends to mechanize experimental activity to obtain final value of the physical quantity [7]. With a view to widen the scope of experiment in teaching-learning process, Indian Association of Physics Teachers (IAPT) has undertaken concrete measures towards the renewal of physics instruction. In fact, renewal of physics laboratory has been a main pedagogical concern of the association. As IAPT represents the concern and involvement of a vast majority of Indian physics teachers, examination of the nature and extent of its work in this regard assumes significance. Anveshika—an alternative physics laboratory jointly brought about by Saraswati Gyan Mandir (SGM) Inter College at Kanpur and IAPT, epitomizes this work. The paper traces the genesis, establishment, and proliferation of Anveshika and its networking activities.

Historical Context

Probably Education Commission (1966) was first in comprehensively redefining the role of education in independent India [8]. Following the recommendations of the Commission, a nationwide rethinking was triggered to further specify and take relevant measures to reform education at all stages. In tertiary physics, D. S. Kothari, earlier the chairman of the Education Commission, led the Indian physics education community to deliberate upon the specific nature of the problems confronting physics education and prepare a plan of action towards this end at Srinagar in June 1970. Renewal of undergraduate physics laboratory was one of the major issues deliberated in the conference. Laboratory activities were recommended to move beyond the routine experiments aimed to verify theory and enable students to investigate physical phenomena, deduce relationships, and apply knowledge to solve new problems. In a few cases, projects or open-ended experiments were suggested for an in-depth study of physical phenomenon. Provision was made for a well-established workshop for fabrication and maintenance of experimental devices and equipment to provide students first hand experiences in carrying out a worthwhile laboratory work. This was supposed to be the part of the 'science teaching centre' meant to prepare relevant curricular material in the universities. Such centres were not only envisaged to develop prototype experimental equipment, kits, film strips and curricular material such as textbooks, teacher guides, laboratory manuals, and methods of teaching but also provide support to the affiliated colleges in adopting it [9, p. 22]

Soon after Srinagar Conference (1970), University Grant Commission (UGC) initiated the University Leadership Programme (ULP) and College Science Improvement Programme (COSIP) for developing the required curricular material. ULP and COSIP programme ran for almost a decade. The textbooks, laboratory manual, demonstrations, and experiments were reportedly produced by the several of the universities and affiliated colleges that were assigned the projects [10]. Notable contributions were made by the ULP centres at the Punjab, Pune and Rajasthan Universities [11, 12]. The development of several innovative experiments for the undergraduate and post-graduate physics courses under the leadership of Babulal Saraf at the Rajasthan University was termed as exemplary among all the ULP and COSIP work [13, 14]. The centre earned appreciation from wide and across the country for accomplishing this task. Subsequently, several colleges and institutions affiliated to the University of Rajasthan and around the country bought the replicas of the experiments relating to mechanics, statistical physics, Waves and Oscillations and thermodynamics [15, 16, 17]. COSIP and ULP groups working in other parts of the country were gravitated towards the centre. Consequently, centre became a site for the interaction among the physics teachers across the country. The decade long engagement in COSIP and ULP projects was concluded with an international conference, on the 'Role of Laboratory in physics Education', at Rajasthan University during 28th December, 1983 to 2nd January 1984 [18]. It was also the defining moment for the pedagogy of physics in India. Experimentation as a methodology of teaching physics was contested in a big way by physics educators.

Iapt and Renewal of Physics Laboratory

Indian Association of Physics Teachers (IAPT) was formed on 9th March, 1984 [19, p. 2-3]. Implicitly though, the recommendations of Srinagar deliberation (1970), coupled with the work accomplished on experiments during ULP and COSIP projects were reframed as the major objectives by the association [20]. This paved the way for the reappraisal of the laboratory work carried out at different parts of the country and its translation into a



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comprehensive reconstruction programme on experiments. Formation of alternative physics laboratories—Centre for Scientific Culture (CSC) at Midnapore (in 1993) and Anveshika, at Kanpur (in 2001); adding experimental component in the National Standard Examination in Physics (NSEP) (in 1992) and National Graduate Physics Examination (NGPE) (in 1993); conducting a nationwide orientation programs for school and college teachers from 1997 to 1999; as well as initiating National Competition for Innovative Experiments in Physics (NCIEP) (in 2003), are the programmes run by the IAPT to achieve the end [21].

Anveshika: An Alternative School Physics Laboratory

The programme to develop four (4) model physics laboratories or alternatively, what was named as the Centre for Scientific Cultures (CSCs) in different parts of the country was conceptualised by IAPT way back in 1986 and subsequently in 1988 and 1991. It is a general observation that experiments in the school and college science laboratories are bought from the manufacturing agencies and teachers do not engage in the reconstruction of experiments. Taking sharp contrast, CSC was conceived as a functioning laboratory where a wide range of experiments meant to relate the empirical and theoretical component not only of physics but also other allied scientific disciplines would be developed by the teachers themselves. Pedagogically, these experiments would not only be deployed to exhibit qualitative component of concepts but translate the data generated from experimental activity into mathematical relations in a lucid and substantial manner [22, 23, 24]. In fact, this was one of the major objectives framed by the association during 1984 [25]. Though concerted efforts were invested to bring out four (4) CSCs during 1992-1993, the programme failed as anticipated. Centre for Scientific Culture (CSC) at Midnapore and Nagpur were among the two centres opened [26, p. 284]. Developmental activities at CSC Nagpur dwindled after few years. Eventually, CSC Midnapore remains to be the only centre sustaining till date [27].

Emergence of Anveshika—an alternative physics laboratory at Kanpur, in 2001, boosted the idea of CSC from long drawn-out passivity in the intervening period. Unlike CSC, Anveshika did not arise because of a deliberate plan of action by the association. It was all by coincidence that IAPT happened to find a patron and a site for reconstruction of physics experiments at Saraswati Gyan Mandir (SGM) School in Kanpur in 1999. This was exactly lacking during the attempts to form CSCs during 1992-93. Desirable response did not come either from the schools and college showing eagerness to house and run the CSCs. IAPT members in charge of the project on CSCs do not seem to display innovative thinking and action on their part. Now in two years time span from 1999 to 2001, it became apparent that unlike the case with CSCs during 1992-1993, the conditions were ripe for developing an alternative physics laboratory. Ram Narayan Agrawal, the owner of SGM School, turned out to be the patron as desired and R. N. Kapoor, one of the active members of IAPT, as the actor taking the task of developing a repertoire of experiments at the school premise. R. N. Kapoor was one of the close associates of D. P. Khandelwal (the founder of the association). Till around the age of 70, he had already improvised and designed several experiments. When invited by Ram Narayan Agarwal, he was more than happy to take up reconstruction of experiments at SGM School. Beginning the work on the development of experiments during 1999, he came up with an active mini-laboratory in next two years, captivating the imaginations of teachers, students, and IAPT members from in and around the Kanpur. Subsequently, a formal beginning was made to develop this laboratory as a joint venture between Saraswati Gyan Mandir (SGM) Inter College and IAPT, in the year 2001. The laboratory was named as 'Anveshika'—a Hindi translation for the investigatory laboratory. Since then, SGM School and IAPT decided to jointly fund the workshop [28].

To begin with R. N. Kapoor took up whatever idea appealed to him in devising experiments. As a result, a sizable number of demonstrations and experiments in mechanics, optics, electromagnetic etc were developed. Progressively, more experiments covering the domains of mechanics, electromagnetism and optics were added to Anveshika in the succeeding years. Though most of the experiments cover the school physics, few of them are also meant for undergraduate physics. Besides construction of experiments, Kapoor has devoted a part of his time for teaching school children on a regular basis. This enhanced the synergistic relationship between the SGM School and Anveshika. Having housed and nurtured Anveshika, the school too has earned laurel not only from the teachers and



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students around the Kanpur but also other parts of the country. Indeed, Anveshika has become an exemplar of a cooperative activity between IAPT and Community School (i. e. SGM), the way CSC was envisaged during 1992-93. R. N. Kapoor has been the lifeline of Anveshika from the time work was initiated there in 1999 to 2013—the year he retired around 80 years of age. The first sight of Anveshika appears to induce a feeling of break away from conventional laboratory. Very often, visitors (teachers and students) interested to explore or conduct experimental and demonstration activities at Anveshika are facilitated to find plausible answers to their questions. Anveshika seems to make them aware that learning physics by demonstration and experiments can be an exciting experience and something which happens to be missing at their schools (impression is based on researcher's interaction with the visitors on first visit to Anveshika in 2011). Accordingly, the physics teachers from the schools and colleges around the Kanpur and other parts of the country are oriented to use of experiments for concept development at Anveshika [29, 30]. As claimed, experiments and demonstrations placed at the Anveshika are not meant for pursuing predetermined objectives, processes and outcomes as is the case with conventional experiments in school and college physics laboratories; rather they are meant to encourage exploration of concepts in an open-ended manner. While endorsing the dictum that 'to see is to believe', R. N. Kapoor asserts, teaching through demonstration and experiments enhances the understanding of concepts as well as reduces the time expended in teaching to significant extent. Consequently, it helps the teacher finish syllabi well before time and invest the left-over time in other important activities.

Anveshika and Teachers' Orientation Programmes

With the course of time Anveshika evolved to fit well in IAPT's long-term objective of bringing out a Model Physics Laboratory or Centre for Scientific Culture (CSC). The teachers from Indian Institute of Technology (IIT), Kanpur and local colleges joined hands in supporting and extending the activities at Anveshika. H. C. Verma, a faculty at IIT Kanpur, played a leading role in this respect. Animated by the developments at Anveshika, H. C. Verma, in close association with R. N. Kapoor and other IAPT members, took up the task of popularizing the work conducted at Anveshika in other parts of the country. Verma set out to evolve a series of orientation programmes to help teachers integrate demonstration and experiments in their teaching. The workshop was initiated by him in the year 2002-03 [31]. Since then, different modules of orientation programmes vis-a-vis 'one-day', 'three-days', 'four-days' and 'six-days' workshops for the school and college teachers have been conducted [32]. 'One-day workshop' termed as 'Utsahi Physics Teachers' is introductory in nature and aims to provide exposure to the participants using experiments for concept formation. The workshop is conducted throughout the year across the country. The thrust of the programme is to facilitate participants collect and devise a repertoire of experiment and integrate them in their teaching. To help participants make a beginning in this regard, they are provided with an experimental 'kit' termed as 'Physics Show Bag'. In turn, participants in the long run are expected to assemble and improvise more experiments at their own. Having learned the intended knowledge and skills in the preliminary workshop, they are invited for the next phases of the training via 3-days and 6-days module workshops. Occasionally around one-month workshops for those at the verge of entering teaching profession (like fresh M.Sc. postgraduates), have also been conducted [33, 34]. The difference among the two types of orientation programmes lies in the depth and comprehensiveness of the procedural knowledge relating the use of experiments for concept formation. External agencies such as Vigyan Prasar, Takshila Education Society or Bharti Bhawan (a publication house) etc from time to time have collaborated with Anveshika in conducting workshops. Occasionally, manufacturers of laboratory equipment also get involved in orientation programmes.

National Anveshika Network of India (Nani)

Notwithstanding the various constraints and impediments faced by teachers in workplace, some of them oriented at Anveshika do feel the need to break away from the traditional method of teaching physics. They happen to be motivated enough to collect and develop a repertoire of demonstrations and experiments. Some of them over the years also have developed an expertise in conducting orientation programmes for other teachers. For instance, A. D. Mahajan (from Latur), R. K. Awasthi (from Agra), R. K. Mitra (from Lucknow), Sanjeeve Kumar (from Bhagalpur), B. C. Rai (from Patna), Bregech Dixhit from Auriya and Rakesh Kumar Singh from Patna are said to have developed



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such expertise. Overwhelmed by the response from the participants teachers and their institutions from various places across the country, IAPT in 2010, initiated a programme to facilitate them to finding space and housing the repertoire of experiments and demonstration they have developed there. In essence this is an endeavor to replicate Anveshika like physics laboratories in different parts of the country. The programme was launched at the Annual National Convention of IAPT at Rajkot in October 2010 and named as '*Anveshika Loving Teachers Orientation Programme*' (ALTOP) [35]. According to Verma and Kapoor (2010): "*ALTOP is a workshop planned for the potentially key persons who have the commitment for physics teaching and can play the pivotal role in starting and running such a centre at their own place.*" (36, p. 313). Following this, the first 4-day *Anveshika Loving Teachers Orientation Programme* (ALTOP) was organised from 30th October to 2nd November in 2010. Since then, this programme has become a regular feature of Anveshika's activities. Each of the newly emerging Anveshika like centres is expected to run shows on use of demonstrations and experiments for teaching concepts.

In a year they are expected to devote 100 hours for these shows. While Anveshika Kanpur has a building of its own, new Anveshikas are housed in a room or in a corner of the laboratory of the institution (school or college), as was observed to be the case with M. S. Marwaha from Shri Guru Govind Singh College (SGGSC), Chandigarh. Sometimes because of the lack of space or lack of adequate support from the parent institution, the newly emerging Anveshikas are housed at the residence of teachers, for instance, Anveshika founded by R. K. Mitra at Lucknow. The upcoming of new Anveshikas are being networked together under a programme called '*National Anveshika Network of India (NANI)*' (Ibid). The table below gives the location and names of the teachers enacting the developmental work at newly founded Anveshikas under the National Anveshika Network of India (NANI). The information holds true till 20th June, 2017. similar work. Inspiration in some of these teachers has galvanized into the replication of the work accomplished at Anveshika. Very often lack of funding for this work is cited as a stumbling block. As A. W. Joshi (2008) – one of the prominent members of the association, observes that the engagement of these teachers demonstrated that with the accomplishment of a concrete and significant piece of work, support relating funds and infrastructure comes from the interested institutions and the individuals [38].

DISCUSSION

Popularisation and expansion of the use of experiment to study physical phenomenon was adopted as the salient objective by IAPT since its formation in 1984. To give a practical shape to the idea, several programmes have been conducted by the association. The attempt to open four (4) model physics laboratories or what were named as the centres for scientific culture (CSC) in different parts of the country during 1992-1993, is one of them. Practical realisation of the model physics laboratories demanded not only intensive pedagogical involvement but also the generation of funds and infrastructure. Though ample amount of funds was ensured by Ministry of Human Resource (MHRD) for opening these centres for scientific culture (CSC), IAPT did not appear to succeed in displaying the pedagogical engagement and social skills to get infrastructural support from the schools and colleges enlisted for the project. Consequently it could only manage to open two CSCs of which CSC Midnapore remains to be the centre surviving. Moderate pedagogical engagement appears to be reported from CSC Midnapore [37].

Fulfillment of conditions proved vital for the advent of Anveshika and subsequently its networking activities. Firstly, the space and funding provided by the Saraswati Gyan Mandir (SGM) School. Secondly, R. N. Kapoor's intense involvement in improvising and devising demonstrations and experiments—the trait rarely displayed by a physics teacher. Anveshika appears to break with the large-scale failure experienced by IAPT while attempting to open four (4) CSCs during 1992-93. As a result, it has inspired a large section of the teachers to undertake similar work. Inspiration in some of these teachers has galvanized into the replication of the work accomplished at Anveshika. Very often lack of funding for this work is cited as a stumbling block. As A. W. Joshi (2008) – one of the prominent members of the association, observes that the engagement of these teachers demonstrated that with the accomplishment of a concrete and significant piece of work, support relating funds and infrastructure comes from the interested institutions and the individuals [38].





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Pedagogically, the bulk of the experiments developed by Anveshika and its networking sites happen to be qualitative in nature. Higher conceptual gains have been claimed by the Anveshika workers by integration of demonstrations and experiments in teaching physics. However, rather than scientific investigation and collection of evidence, they seem to rely more on perceptual feedback. When scholarly research in physics pedagogy has made inroads into the physics instruction since 1970s, IAPT members need to subject the claims made by fellow members to scientific testing, peer review, criticism and revision. The first step in this direction would be to conduct meticulous and comprehensive documentation of the work accomplished at Anveshika and its networking sites. Secondly, like American Association of Physics Teachers (AAPT), IAPT also need to adopt research perspective on physics education. AAPT members engaging in Physics Education Research (PER) not only have the perspective of physics teachers as practitioners but also are informed by the developments in philosophy of science, psychology of learning and science education [39, 40]. Adoption of research perspective by IAPT is expected to better equip its members engage with the problems confronting physics education in India. Making relevant changes by the Anveshika and its sister laboratories may help physics teachers make shift towards model-building and problem-solving via experimental activity instead of limiting it on concept formation.

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**Table 1: Locations of the Newly Emerging Anveshikas**

S.No	Name of Anveshika	Place	Coordinators Name
1.	SGM-IPT Anveshika	Kanpur	Mr. Amit Kumar Bajpai
2.	Pt. G. D. V. IAPT Anveshika	Dehradun	Mr. Rohit Sharma
3.	TAXXILA -IAPT Anveshika	Kolkata	Dr. Amit Kumar Jana
4.	BYN-IAPT Anveshika	New Delhi	Mrs. Pragya Nopany
5.	Patna-IAPT Anveshika	Patna	Dr. Amrendra Naryan & Dr. Rakesh Sing
6.	KIIT-IAPT Anveshika	Odisha	Mrs.Rajashree Mohapatra,
7.	Ammanni- IAPT Anveshika	Bangalore	Dr. Sarmistha Sahu
8.	Vibha-IAPT Anveshika	Hyderabad	Mr. Jitender Singh
9.	GCG-IAPT Anveshika	Gadhinglaj	Dr. Shivanand Masti
10.	Mitra-IAPT Anveshika	Lucknow	Dr. R. K. Mitra,
11.	SGGS-IAPT Anveshika	Chandigarh	Mr. Ms Marwaha
12.	Raman-IAPT Anveshika	Agra	Dr. R. K. Awasthi
13.	Go & Go- IAPT Anveshika	Auraiya	Mr. Brajesh Dixit
14.	Ohm-IAPT Anveshika	Gwalior	Mr. Devendra Sharma
15.	VSS-IAPT Anveshika	Munger	Dr. K. N. Rai
16.	Vidya-IAPT Anveshika	Dhanbad	Mr. Arvind Pathak,
17.	BPS-IAPT Anveshika	Pilani	Mr. Manoranjan Kumar
18.	Focus IAPT Anveshika	Andra Pradesh	Mr. J. Chandrasekhar Rao
19.	SSSB-IAPT- Anveshika	Bhilawadi	Mr. Gajanan Balounda Patil
20.	Samadhan-IAPT Anveshika	Pilibheet	Mr. Laxmikant Sharma
21.	Siwan-IAPT Anveshika	Siwan	Mr. Ragive Ranjan,
22.	Happy-IAPT Anveshika	J&K	Mr. Mineesh Gulati

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REVIEW ARTICLE

Gastro Retentive Drug Delivery System : Formulation Strategies and Clinical Relevance

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ABSTRACT

Because of the ease of use and patient compliance, oral medication delivery methods continue to be the most popular dosage forms. However, for medications with short absorption windows, quick gastrointestinal transit, or volatility in intestinal circumstances, traditional oral formulations sometimes fall short of producing sufficient therapeutic results. To overcome these restrictions, gastro retentive systems for drug delivery have been created. By extending the duration of dosage forms in the stomach, GRDDS enhances drug absorption and bioavailability. The physiological principles governing gastric retention, the categorization and mechanisms of gastro retentive systems, formulation strategies, polymers and excipients, evaluation techniques, clinical applications, marketed products, recent technological advancements, regulatory challenges, and future perspectives are all thoroughly discussed in this review.

Keywords: Gastroretentive drug delivery systems (GRDDS), oral drug delivery, gastric retention, bioavailability enhancement and controlled drug release.





INTRODUCTION

Due to ease of use, non-invasiveness, affordability, and high patient compliance, oral drug delivery is the most commonly used method for systemic pharmacotherapy. Nonetheless, traditional oral dosage forms like pills and capsules have unpredictable gastric emptying that leads to inconsistent absorption of drugs and the reduction of therapeutic activity for certain drugs¹. Rapid passage through the gastrointestinal tract also limits absorption of many drugs that only seen in the proximal small intestine or stomach². Conventional dosage forms of drugs having narrow absorption windows, inadequate solubility of drug molecule in the intestinal pH range, limited action at the stomach or unstable under basic conditions are most at risk for poor bioavailability. GRDDS are made to remain in the stomach for a longer period of time, which overcomes these issues and ultimately boosts the therapeutic outcomes, lowers the dosing frequency and improves the absorption of medication³.

Rational for GRDDS

The design and optimization of GRDDS are controlled by a wide range of pharmacokinetics and pharmacodynamics that need to be properly evaluated in the development process. It prolong gastric residence time, enhancing bioavailability and therapeutic efficacy for drugs with narrow absorption windows in the upper GIT, poor solubility in high pH, or local stomach action. They offer sustained, controlled release, reduce dosing frequency, and improve patient compliance

Drugs Suitable for GRDDS

Drugs preferably have a limited absorption window in the upper gastrointestinal tract, have a limited solubility at alkaline pH, have a local action in the stomach and are likely to be rapidly degraded by exposure to the intestinal environment. Examples of such agents include levodopa, ranitidine, metformin, ciprofloxacin, amoxicillin, ketorolac, tromethamine⁴⁻⁵.

Therapeutic Benefits

- Enhanced bioavailability
- Less plasma concentration fluctuation resulting in more sustained therapeutic effect
- Reduced prescribed dose & less administrations needed per treatment cycle
- Increased patient compliance with the prescribed medication regimen⁶.

Anatomy and Physiology of the Gastro-Intestinal Tract

A detailed understanding of the anatomy and physiology of the stomach is essential when rational design of gastro retentive systems is undertaken.

Anatomy of the stomach:

The stomach is divided into the antrum, body, fundus, and pylorus anatomically. Antrum is important in the grinding up of ingested material and its transfer to the pyloric sphincter, although the fundus and body are mainly reservoirs for the gastric contents⁷.

Gastric motility:

Gastric motility shows great differences between a fed and fasting state.

Fasting state- During fasting, the migrating motor complex (MMC) occurs in four distinct phases and repeats every 90-120 minutes. In the third stage, which is often called the "housekeeping wave," has the ability to move foreign dose forms out of the gastric lumen.

Fed state - In contrast, after a meal MMC being delayed and resulting in slow down of gastric emptying⁸⁻⁹.

Classification of GRDDS

GRDDS are categorized according to the manner they manage to remain in the stomach. There are several major types as they all strive to achieve the same goal¹⁰.



**Gautam Verma et al.,****Floating GRDDS**

Because the bulk density of floating drug delivery systems is lower than that of the gastric fluid, they have the benefit of being able to float on the contents of the stomach for extended periods of time¹¹. Following oral administration, the dosage form expands or produces gas; as a result, its density is reduced. This mechanism allows for continuous release of the drug in the gastric environment since the buoyant force is constantly keeping the system afloat^{12,13}. Different mechanisms of floating system are shown in figure 1.

Types of floating GRDDS**Effervescent floating systems-**

These systems contain gas - producing agents such as citric acid, sodium bicarbonate that react with gastric acid to produce CO₂. The gas thus obtained is entrapped within the polymer matrix and hence imparting flotation¹⁴. It offers benefits like rapid buoyancy, easy formulation and has limitations such as dependency on gastric pH and possibility of dose dumping¹⁵.

Non- effervescent floating systems-

To realise low density and adhere to buoyancy, such systems are based on swelling polymers like Carbopol and HPMC¹⁶. It offers benefits like more stable buoyancy action, better pH tolerance and has limitation of delay in floating action¹⁷.

Bilayer floating tablets-

In bilayer systems, the immediate release layer is the rapid onset component while the floating layer maintains prolonged release. The structure of bilayer floating tablets is shown in figure 2. This design is used to enhance the therapeutic efficacy by providing a first loading dose and then sustained release¹⁸.

Mucoadhesive GRDDS

By attaching to the gastric mucosa, the mucoadhesive systems prolong the gastric residence of a drug significantly¹⁹. Mucoadhesion consists of polymer swelling, wetting, mucus, polymer chain interpenetration, and hydrogen bonding as well as electrostatic interactions²⁰. Mechanism of mucoadhesion is shown in figure 3. The advantage of this strategy includes delivery location specificity and increased bioavailability. The limitations are mucus generation and variable adhesion strength²¹. Examples of polymers used in mucoadhesive GRDDS are chitosan, carbopol, polycarbophil and HPMC.

Expandable GRDDS

Expandable systems are designed to expand following ingestion, and hence do not pass through the pylorus²². Two types of expandable systems are that get bloated and that get expand. The mechanism of expandable gastro retentive system is shown in figure 4. The system must be easily taken by mouth, should expand rapidly, and must disintegrate safely after being released of medication²³. It offers benefit such as drug retention regardless of gastric pH and has limitations like risk regarding gastric obstruction as well as the complicated nature of manufacturing²⁴.

High - density GRDDS

Because they are heavier than the gastric contents (density of >1.5 g cm⁻³), high-density gastro retentive systems have an internal design to stay inside the stomach by composing to the bottom of the gastric cavity. Unlike the floating systems that are relying on buoyancy, these dosage forms take advantage of the force of gravity to prevent gastric emptying²⁵. Highly dense inert excipients are added to the formulation like barium sulphate, zinc oxide, titanium dioxide or iron powder to obtain the necessary mass²⁶. The mechanism of gastric retention of high - density GRDDS is shown in figure 5. A high density dosage form is resistant to peristaltic movements and gastric emptying after oral administration due to sinking at the lower region of the stomach especially in the region of the antral stomach²⁷. It



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offers benefit that formulation maintains its activity regardless of the pH of the stomach and has limitations like attaining the ideal density is not easy, there is the risk of mucosal irritation and clinical evidence of efficacy has been limited²⁸.

Raft forming GRDDS

These raft forming assemblies are mostly used in the treatment of gastric reflux disease (GERD), which acts locally within the stomach, therefore providing a mechanical barrier²⁹. The mechanism of raft forming GRDDS is shown in figure 6. These systems consist of gel-forming agents (sodium alginate), agents that release gas (e.g. sodium bicarbonate) and a viscous gel (raft) which forms and floats on the stomach contents on contact with gastric juice and thus can act as a physical barrier to prevent reflux³⁰. In the modern clinic, treatment of GERD is intended mostly at protecting the mucosa of the esophagus through long-term local pharmacotherapy, as reported in reference³¹.

Hydrogel type GRDDS

Super porous is an excellent technology that provides-shift material with thousand times higher porosity than a conventional hydrogel. Superporous hydrogels (SPH) are the most suitable examples of advanced swellable gastro retentive systems with very fast swelling performance as a result of their strongly connected pore architecture as described in reference³². Through capillary action, these hydrogels quickly imbibe gastric fluid and thus delay gastric emptying. Composite formulations also further augment their mechanical robustness³³. The advantages include like swelling is observed rapidly with rapid responsiveness, formulation exhibits high levels of mechanical integrity and prolonged gastric retention hence a sustained release profile. It has limitations like tedious synthesis; the high production cost and limited commercial availability³⁴.

GRDDS made by using polymer and excipients

Polymers have a significant effect on the swelling behaviour, buoyancy, muco adhesion, kinetics of drug release, and the mechanical strength of gastro retentive systems³⁵. Natural polymers used in GRDDS are sodium alginate, chitosan, xanthan gum and guar gum. Synthetic polymers offer better reproducibility and controlled functionality. Example of synthetic and semi-synthetic polymers are HPMC (K4M, K15M, K100M), Carbopol, Polyethylene oxide and Eudragit RL/RS. The use of gas-generating agents is essential in the case of effervescent forms of floating dosage forms. Sodium bicarbonate and calcium carbonate are the common components used, and accompanied by acidic excipients, which are citric acid and tartaric acid. When exposed to gastric juice, the following combinations cause CO₂ to further evolve and become trapped in the polymeric structure when exposed to gastric juice³⁶.

Formulation Approaches For GRDDS

Single unit systems

Single unit systems include tablets and capsules that help in maintaining its presence in the gastric milieu³⁷.

Multiple unit systems

Pellets, beads, and microspheres are multiparticulate systems that provide a more homogenous distribution of systems in the stomach as shown in figure 7. Advantages of it include low chances of dosage dumping and increased homogeneity of gastric retention³⁸.

Drug release criteria and kinetics

The diffusion, polymer erosion and swelling controlled mechanisms control the release of pharmaceutical agents through GRDDS, thus determining the overall drug release pattern. Mathematical expressions are used to assess drug release data quantitatively. Those models are predictive in nature and allow it to maximize the release kinetics³⁹.

In-Vitro Evaluation of GRDDS

Physical characterization

Assessment of physical properties includes dimension, tensile strength, and weight variability which offer vital quality parameters to the dosage form.





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Floating properties

The lag time that is needed by the system to be made to float as well as the total time of flotation is measured to achieve satisfactory gastric residence¹⁵.

Swelling index

The behaviour of swelling is measured in pH 1.2 simulated gastric fluid medium as this enables to measure polymerial expansion in gastric conditions.

In-vitro drug release studies

The profiles of drug release are developed through the standardised dissolution tests simulating the gastrointestinal conditions in accordance with the USP apparatus specifications⁴⁰.

Mucoadhesive strength

Mucosal adhesion degree is established by the employment of customized balance efflux techniques or texture analyzers to ensure gastric mucosa has enough adhesion⁴¹.

In-Vivo Evaluation of GRDDS

In-vivo experimentation cannot be compromised and it is essential to verify the gastric residence time, blood dynamics, and pharmacokinetic performance of GRDDS under physiological conditions.

Radiographic (x-ray) studies

A dosage form is merged with a radio-opaque marker e.g. barium sulphate, through which the visualisation is observed through X-ray imaging. Serial radiographs monitor the positioning of the stomach, and the retention time. This technique is easy and cost-efficient but the precision of this technique has limitations when it comes to real-time monitoring because of the limitation on radiation exposure⁴².

Gamma scintigraphy

Formulation is followed using a gamma camera and it is radio labelled with things like the isotope. Real time tracking offers quantitative analysis correctness. However, the procedure is expensive and needs specialised facilities⁴³.

Ultrasound imaging

Ultrasound imaging is a non radiation-free, non-invasive modality that is used in the *in-silico* monitoring of GRDDS. This technique is very operator-limited ⁴⁴.

Pharmacokinetic studies

Traditional dosage administration form and the ensuing plasma drug concentration-time curve are both evaluated so as to evaluate the enhancement of variables, biodegradability, half-life, and mean dwell time⁴⁵.

Clinical Applications of GRDDS

Drugs with thinner absorptive nature

These systems are especially beneficial in those medications that are mostly absorbed in the proximal or stomach lumen small intestine including levodopa, riboflavin and metformin⁴⁶.

Drugs with local impacts on the stomach

GRDDS can be used for prolonged exposure to local minor doses of drugs, and thus favour the orientation of gastrointestinal disorders using antacid agents, proton pump blockers, and amoxicillin to eliminate Helicobacter



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pylori. The gastrointestinal tract's retention in an acidic environment stabilises the alkali labile, but acid stable compounds to improve their overall bioavailability⁴⁷.

Chronotherapy

GRDDS are applicable to the management of illnesses that require precise drug administration timing, including in the field of Parkinson's disease and nocturnal acid break through, where time-sensitive dosing is essential.

Commercialised gastro retentive formulations

Several gastro retentive drug formulations are at the moment in the commercial market which has been proven to be clinically viable [48]. List of such marketed products are shown in table-1.

Recent Advancement in GRDDS

Nanotechnology based GRDDS

Recent research has highlighted the potential application of nano-flooding systems and nano-mucoadhesive carriers to be utilized in order to achieve better levels of gastric retention, enhance the solubility of medications taken orally, and enhance accuracy of delivery to the stomach targets. It is through these nano scale platforms that it is feasible to modify particle buoyancy and surface chemistry that enables one to prolong the duration of gastric residency while also helping in protecting the therapeutic agent against its early degradation [49].

3D Printing technology

With the acquisition of 3D printing, there is chance to create gastro retentive dosage vectors with geometrically adjusted finely besides being able to control densities and programmable drug-release kinetics. This is because of the nature of personalization that may be found in the 3D printing technology, allowing the development of customized treatment plans that are not just designed based on the pharmacokinetic needs of the drug, but also individual physiological characteristics of the patient.

Intelligent systems and stimulus response

Responsive gastro retentive drug delivery systems in response to gastric pH, temperature and enzymatic activity are an exciting future in oral therapeutics. These smart formulations recognise the local physiological and cause site selective release events, resulting in the tightening of space and temporal control of drug delivery in the upper gastrointestinal tract [50].

Considerations of regulatory and quality

These include a thorough assessment of gastric-retention, in-vivo in-vitro correlation (IVIVC) and safety implication of long-term stomach exposure needed by the regulators. Simultaneously, Quality-by-Design approaches have been integrated more commonly in GRDDS development, which is offering a procedural organisation to risk evaluation, process verification, and to continuous enhancement [51].

GRDDS weaknesses and challenges

GRDDS contain a number of constraints even with the attributes they have interpersonal differences in gastric physiology, relativity on the eating habit, the possibility of gastrointestinal discomfort or obstruction and limited applicability to some pharmacological agents are critical stumbling blocks that can only be overcome by detailed formulation design and extensive clinical assessment[52].

Future Prospective

Future research will focus on the combination of artificial-intelligence-based formulation optimisation, hybrid gastro-retentive systems that jointly involve the usage of several retention systems, and the production of long-acting one-week dosage systems that are compatible with patient-centred dosage schedules. The predictive capacity of the





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GRDDS performance tests is probably further enhanced with the developments in the imaging modalities and biopharmaceutical modelling⁵³.

CONCLUSION

Gastro retentive delivery devices are promising much with regard to enhancing oral bioavailability and achieving the therapeutic effects of suitable drug candidates. GRDDS reduce the drawbacks of stomach's quick emptying, release the contents in a controlled and site-specific manner within the stomach and upper intestinal tract. The future opportunities involved with additional advancements in material science, nanotechnology, and additive manufacturing and such oral dosage forms are probably going to become more widely available.

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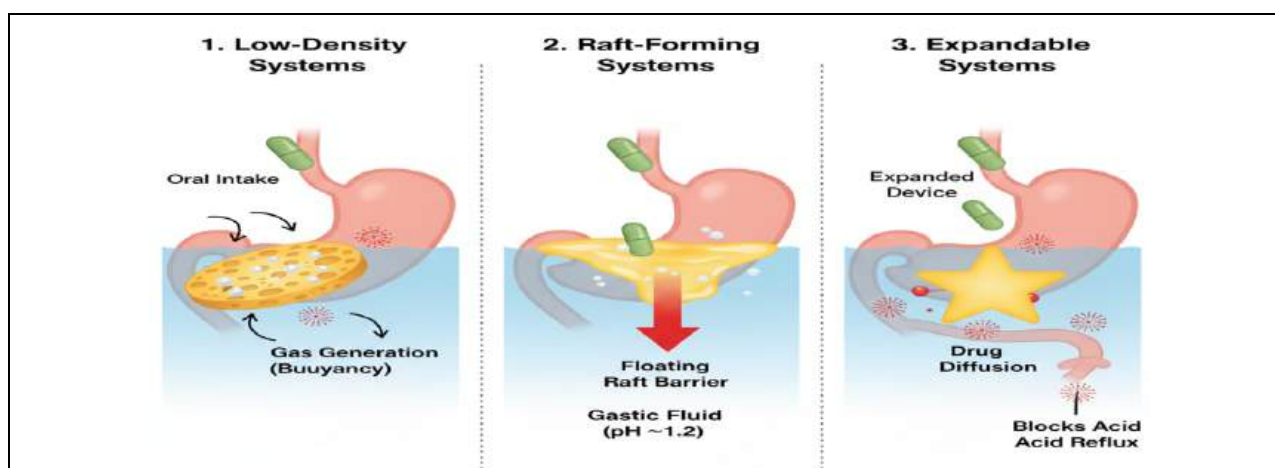
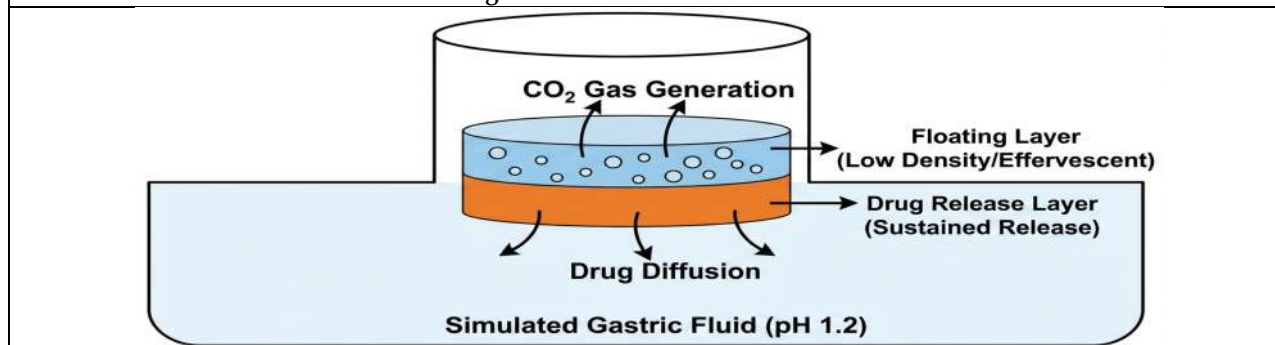




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Table -1 Marketed gastro retentive drug products

Brand Name	Drug	GRDDS Type
Madopar® HBS	Levodopa	Floating Capsule
Glumetza®	Metformin	Swellable system
Cipralex® GR	Ciprofloxacin	Floating table
Valrelease®	Diazepam	Floating system
Topalkan®	Antacid	Raft-forming system

**Figure -1 Mechanisms of GRDDS****Figure -2 Structure of bilayer floating tablet**

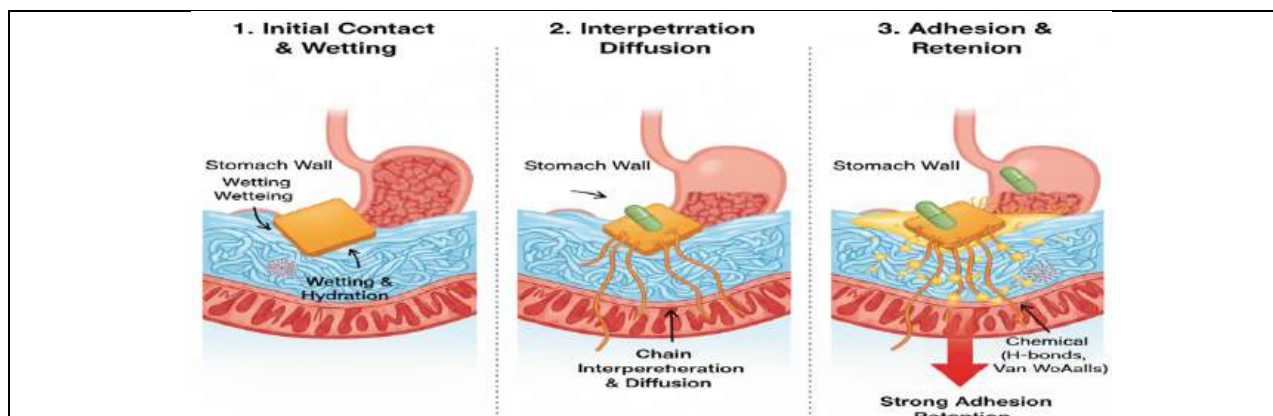
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Figure - 3 Mechanism of mucoadhesion for gastro retentive system

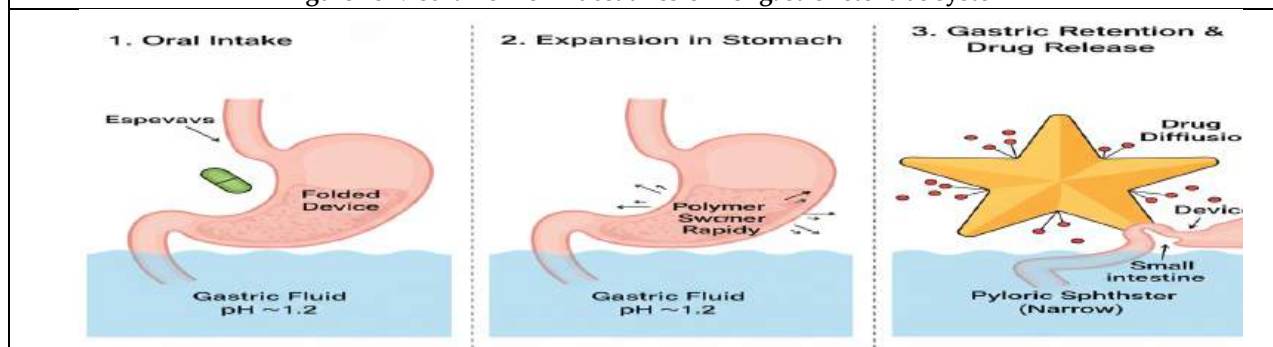


Figure - 4 Expandable GRDDS in stomach

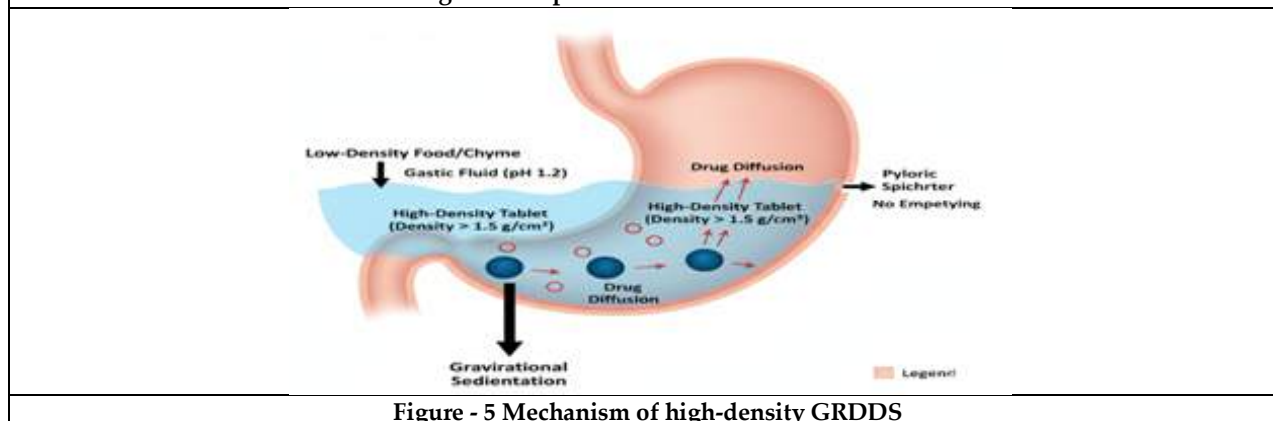


Figure - 5 Mechanism of high-density GRDDS



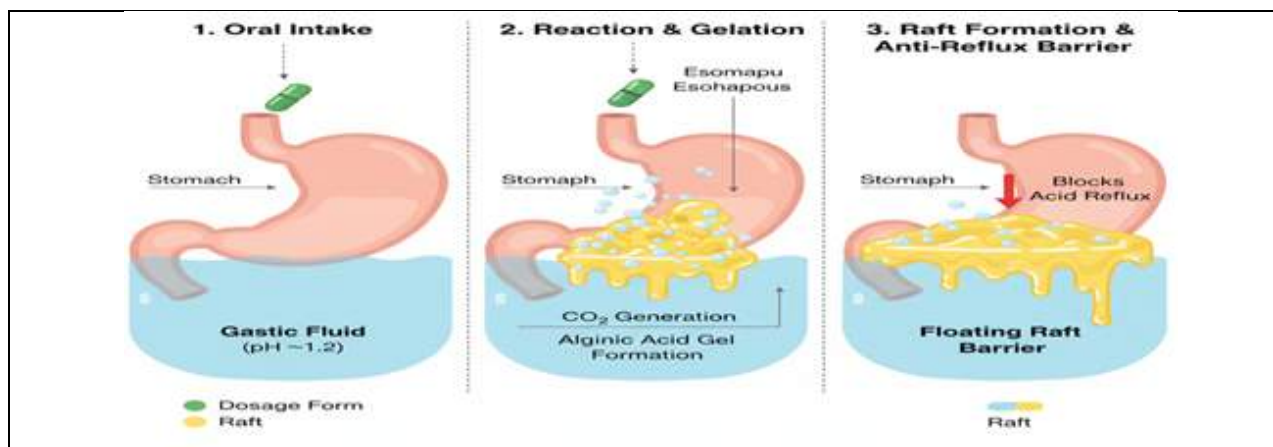


Figure - 6 Mechanism of the raft forming GRDDS

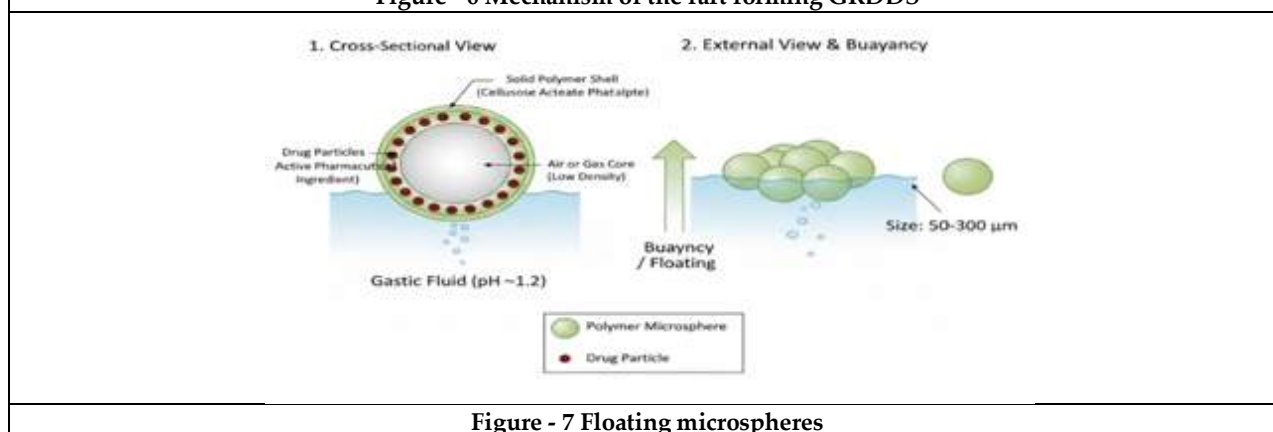


Figure - 7 Floating microspheres

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RESEARCH ARTICLE

Exploring Bioethics and Genetic Manipulation in Margaret Atwood's *Oryx and Crake*

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ABSTRACT

Oryx and Crake by Margaret Atwood presents a dystopian future shaped by rapid developments in genetic engineering, corporate biotechnology, and scientific ambition unchecked by ethical responsibility. The novel anticipates contemporary debates surrounding gene editing, synthetic biology, and the commodification of life. This paper explores the bioethical implications of genetic manipulation in the narrative, focusing on transgenic experimentation, the creation of the Crakers, corporate biopower, and the engineered pandemic that eradicates humanity. Drawing on bioethical principles such as autonomy, beneficence, non-maleficence, and justice, along with post-humanist and biopolitical theory, this study argues that Atwood critiques not science itself but its detachment from moral accountability. Through speculative fiction, Atwood constructs a cautionary vision of a world in which genetic engineering becomes a tool of corporate domination and existential redesign. Ultimately, the novel calls for ethical integration in scientific advancement and urges a reconsideration of what it means to be human in the age of biotechnology.

Keywords: Posthumanism, Biotechnology, Genetic Engineering, Hybrid Species, Margaret Atwood, *Oryx and Crake*

INTRODUCTION

The present paper explores wisdom fabrication and climactic novels from the Post human period. The literature of this period establishes a connection between humans and non-humans. Before probing in the post-human age in

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literature, it is essential to understand what humanism is. Humanism is a popular and ethical worldview that prioritizes mortal enterprises over godly or supernatural bones. The post human period is characterized by technology's dominance over indeed the most intellectual beings, reshaping every aspect of life, with Artificial Intelligence ultimately replacing humans. Trans humanist testaments fantasize a un born shaped by technologies that exclude geriatric and enhance mortal intellectual, physical, and cerebral capacities. These developments also lead to inheritable engineering, nuclear munitions, and bio-weapons. The outbreak of Covid as an epidemic prompts reference to Atwood's *Oryx and Crake*. Literature, especially wisdom fabrication and climactic novels, serves as a reflection, reproduction, and predictor of mortal life and Earth's future. These stripes explore imaginative scientific generalities similar as inheritable engineering, transhumanism, and bio-weapons. thus, Posthumanism also offers a reflection on humanism. In traditional humanism, man was central to all erudite creation. But over time, changes in mortal life, society, and literature have passed. Revolutions in study and scientific inventions have impelled humans to transcend traditional passions and advance beyond humanism. Accordingly, posthumanism, in its critical form, is a new conceptualization of humanity. It examines artistic representations, power relations, and dialogues that have historically deposited humans above other life forms and under their control.

Oryx and Crake, written by Margaret Atwood, urges compendiums to claw into the narrative of Jimmy, also appertained to as Snowman, who was abandoned by his community and M. Usha Bharathi and et al., brazened with the consequences of unbridled biotechnology trial. The book intricately weaves together Jimmy's recollections before and after the terrible event. Jimmy, wearing a bed distance, lived like a neolithic man on a tree, exposed to sun, eating food, and securing Crakers genetically modified hominids designed to replace humans while ignoring about a pre-disaster world where unrestricted biotechnology created mongrel beast workers for the ultimate thing. still, everything ended when Crake, a genetically altered mortal, created an incorrigible contagion to annihilate the mortal population and make way for the Crakers to take over. Atwood's book highlights the contemporary advancements in biotechnology and cautions compendiums about the unrecoverable consequences that could pose a trouble to mortal survival. According to Atwood, this novel is a combination of fact and fabrication, and it follows a route that's formerly apparent to us. She describes it as academic fabrication that delves into the ongoing discussion girding inheritable advancements and presents a pictorial depiction of the imminent disastrous downfall of civilization as a consequence.

Literature has constantly endeavored to anticipate and portray the possibilities of unborn scientific advancements indeed before they materialize in written form. Warwick asserts that wisdom fabrication has the capability to give alleviation to scientists and duly depict possible unborn situations. mongrel brutes have been a recreating theme in literature for a considerable period of time, starting with the publishing of H. G. Wells' *The Island of Doctor Moreau* in 1896. This book presents the conception of mongrel brutes in a manner that's exceptionally believable and true to life. This is a dystopian narrative set in the near future, where a Biotechnology Corporation governs the world until it's fully annihilated. *Oryx and Crake* introduces the anthology to a range of mongrel brutes, including rakunks (a blend of raccoons and skunks), wolvogs (combining the aggression of wolves with the appearance and geste of tykes), pigoons (organisms that induce mortal organs), and Crakers (a genetically modified species of humans). When humans do n't intermediate, these creatures ultimately come willful as the deadly contagion spreads and kills everyone, constantly venturing Jimmy.

Like Atwood, cold-blooded creatures have traditionally been depicted in literature as peculiar, uncanny, intimidating, and a emulsion of mortal and beast, as well as mortal and machine. These cold-blooded creations challenge the being societal divisions between the natural and artificial (man-made) and between creatures and humans. A child born through surrogacy or in vitro fertilization is presently facing a dilemma between artificial and natural birth, or a combination of both, which is causing significant solicitude. This admixture challenges the generally recognized conception of mortal identity. According to the Oxford Dictionary, a human is defined as a person, distinct from both creatures and machines. In the period of biotechnology, humans have started to surpass their natural limitations by integrating artificial organs from creatures (known as xeno plantation) and mechanical support (cyborgs) into their bodies. This has led to the emergence of the post human period, when humans are no





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longer separate from machines. As Francis Fukuyama writes, The most significant trouble posed by contemporary biotechnology is the possibility that it'll alter mortal nature and thereby move us into a ' posthuman stage of history. (7) The idea of the mortal body has experienced a substantial change, moving from its natural state to one that's artificial or man- made. This makes a new post human perspective on the mortal body necessary.

In the 20th century, scientific styles and technological advancements made substantial benefactions to the field of posthumanism. Humans and robots have been in a cooperation for ages. In the history, machines were employed to distinguish between non-human creatures and people. But in the post-humanist period of moment, there's a debate about how the lines separating the mortal body from technology are getting hazier. As Donna J. Haraway writes Late twentieth- century machines have made completely nebulous the difference between natural and artificial, mind and body, self -developing and externally designed, and numerous other distinctions that used to apply to creatures and machines. Our machines are disturbingly lively, and we ourselves frighteningly inert, (152) inheritable engineering has been around since the early 1980s, when scientists developed an on course specifically for studying cancer. Over the course of the once twenty times, scientists have successfully developed colourful genetically modified beast species that retain profitable characteristics. These include scapegoats that produce anti-clotting protein, fish with accelerated growth, and gormandizers that are environmentally friendly. inheritable engineering is driven by a strong desire for its implicit benefits, similar as furnishing a source for mortal organ transplants, studying conditions like cancer and heart complaint, producing substances for Medicinals, and indeed creating faces inheritable engineering thrives not only on its mentioned benefits, but on the comprehensive network that supports it. "While I will not be suitable to cover every single bone , I can give some sapience into a named many. I'll explore the content of mongrel creatures in relation to their part in labour, the influence of biotechnology on society, the commercial docket, the commercialization of these creatures, and the absence of effective programs to regulate them".

Throughout the history of humanity, creatures have served as a source of food and as a means of labour. From studying the relations between humans and creatures, it's apparent that creatures have frequently been viewed as unresistant beings, exploited for mortal gain. In moment's technologically advanced world, the significance of colourful aspects has been lowered, including mortal labour. still, creatures continue to play a prominent part in the pool. creatures have endured a significant increase in their liabilities. In the history, they were primarily utilized for husbandry, packing, and food consumption. still, they now also bear the weight of being subordinated to trials, used to develop mortal organs, napkins, and cells, and serve as a source of protein that can be altered or created to fulfil mortal solicitations.

As Steven Best and Douglas Kellner call attention to the transformative power of biotechnology which created a surreal zoo of mutations that includes tobacco shops with firefly genes, mice and gormandizers with mortal genes, potatoes with funk genes, fish and tomatoes with antifreeze genes, and dozens of different genetically modified foods spliced with bacteria, contagions, antibiotic- resistant marker genes, and nonentity genes.(Atwood 134) The foremost runners of the new opens with youthful Jimmy recollections of a " campfire was an enormous pile of cows and lamb and gormandizers "(Atwood 18). Devastated by the contagion that was designedly fitted , the creatures suffered a woeful fate, leading to their mass decimation in order to guard mortal lives. In Britain during the 1980s and again in themed-1990s, there was a significant incident involving the disposal of cows due to enterprises about the spread of Bovine Spongiform Encephalopathy(BSE), a mortal complaint. Through trial, the utilization of beast labour transitioned from being a natural process to being positioned on the fringe of mortal intervention. Oryx and Crake considerably examine the content of mongrel, genetically modified brutes. Pigeons, a gormandizer created to grow an" multifariousness of reliable mortal- towel organs in transgenic knockout gormandizer host- organ"(Atwood 25) that would defend against the attack of contagions. These organisms were designed to grow snappily, allowing mortal organs to be available for transplantation as soon as possible. There's presently a strong interest in the scientific community to develop a system for growing and conserving multiple feathers at formerly, with the thing of customizing them for individual cases. These gormandizers were designedly bred to be larger and further robust to more accommodate redundant organs. At first sight, they may feel a bit



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intimidating with their pink eyes, nimble movements, and a tendency to suck into humans rather fleetly. The Pigeon is involved in the product of mortal organs, which are latterly vended as goods for consumption by buyers. In the history, beast exploration concentrated on draining the beast's energy, but unfortunately, it ended up taking the beast's life for the sake of mortal gain. Along with long life, mortal emphasizes on the idea of beauty, and youngness. This design under Nooskins design Pigeons to replace the aged epidermis with a newer one," a genuine launch- over thing that would be wrinkle and mark-free "(Atwood 62). This design is centered around the interesting miracle observed in algae, where youngish skin cells ingest aged cells and produce duplicates to take their place. The progress in biotechnology has generated distinct beauty criteria that value perfect skin as the ultimate hand of attractiveness. Regrettably, this has redounded in sentiments of insufficiency and apprehension, which latterly have bolstered the expansion of this sector. One fresh remarkable mongrel critter is the wolvog, which merges the traits of a canine and a lupine. Wolvogs began as a result of raising competition among enterprises and their intrusion into one other's disciplines. These brutes are specifically finagled to cover and secure business goods. While describing Crake says that They are n't tykes , they just look like tykes . They're wolvogs they're bred to deceive. Reach out to stroke them, they'll take your hand off. There's a large hole- bull element. Yeah better than an alarm system- no way of disarming them, not like real tykes .(Atwood 241) These brutes were salutary and manageable indeed though they were kept in a pen and under constant observation. But when the humans went defunct, they were set free and started attacking Jimmy.

As a result of their hostility, Jimmy is now impelled to seek safety in a tree. While genetically changing creatures has really been greatly told by technology, they organically evolved into different brutes after they were left to fend for themselves without mortal intervention or care. They started acting in ways that went against their ingrained tendencies as Pigeons were supposed to be tusk-free, but may they were returning to type now they'd gone feral, a fast forward process considering their rapid maturity genes.(Atwood 43) generality of meat Everything that was formerly supposed an unrealistic and sarcastic conception ten times a gone is now within the realm of possibility. The notion of meat has experienced a metamorphosis in the macrocosm of Oryx and Crake. Chickie nobs, a genetically modified strain of funk, is specifically bred and cultivated for mortal consumption. The depiction of chickens in the book is n't fully fictional; laboratory- cultivated, in vitro meat has indeed been created for both artificial and remedial purposes. likewise, this synthetic system of product not only holds significant fiscal significance but also acts as a means to assuage environmental and beast weal organizations who explosively expostulate to the cruel and dangerous conditioning of the beast assiduity. As Crake says " beast weal freaks wont be suitable to say a word, because this thing feels no pain "(Atwood 238). The lack of pain is because of neurological revision, and the physical differences are to similar extent the bystander feels shocked and pity at the same time. While describing them There's a mouth opening at the top, they(workers) leave the nutrients in there. No eyes or bleak or anything, they do not need those. they'd removed all the brain function that had nothing to do with digestion, assimilation and growth. You get funk bone in two weeks.(Atwood 238) Humans have demonstrated a significant position of freedom when it comes to creating genetically finagled species. Limiting beast options to match mortal preferences through neurological and physical differences. All of them have been designed to mimic cravens, but they're missing pivotal functionalities. They've no branches, no head, and can be described as a " meat tube" a living, walking mass of meat that's specifically acclimated for mortal consumption. As the design advances, the precious traditional system of plant husbandry for " genuine" funk is sluggishly being phased out in the request.

Oryx and Crake has emphasized the notable inclination towards meat input and the caregiving of cattle. The characters in the narrative sustained for a world where factual meat was, which served as a memorial of a time when life held lesser complexity and significance. Access to genuine meat is limited to individualities who retain honor and wealth. Jimmy is astounded when he substantiations the genuine donation of meat at the prestigious Watson-Crick Institute. When Jimmy joins Crake for regale, he's astounded by Crake's selection of authentic Japanese beef, a rare delicacy similar in failure to diamonds, at this Jimmy thinks that " It must have bring him a fortune "(Atwood 289). In the world of the story, eating real meat is only permitted for the flush members of society. This demonstrates the patient social taboos girding food access, especially in the setting of industrialization, when women and children





were constantly barred from meat consumption while the manly head of the family indulged in it. Indeed though beef created instinctively is extensively available, the product nonetheless has to live up to the smirch of being unnatural. When Jimmy returned home with a bucket of deep-fried chicken nuggets, his roommates weren't amused and they did not talk for a week. All the forenamed genetically modified creatures are expressly designed for mortal consumption. Humans have beyond the limitations of introductory work and have entered the sphere of designing and producing work. The mortal brain is humanity's most precious resource, a awful wellspring of measureless eventuality. Due to the nippy progress of technological developments, people have exceeded their essential constraints and are presently plying deliberate control over nature.

Crake's narrative involves the creation of a significant portion of the mortal population as a relief for humans after the deadly contagion spreads. Crake adroitly combined colorful traits from different species, giving rise to a remarkable mongrel organism. Crackers, analogous to pussycats, retain the remarkable capability to heal themselves by purring, a skill that Cracker has diligently honed over the times. Just like rabbits, crackers have the capability to survive in food-scarce conditions by rehearsing coprophagy. The reproductive geste of crackers is structured to act that of baboons in order to address issues related to racism, scale, and territoriality. The lady's abdomen changes colour to a vibrant blue, emitting pheromones that naturally draw the attention of males. A conventional cotillion is performed, during which the womanish chooses a group of males to engage in sexual intercourse with, taking turns until the blue colour fades. There's a lack of clarity girding the lineage of the seed. The crackers have an impeccable design, complete with UV-resistant skin and a erected-in nonentity repellent, making them visually appealing. They're (Crakers) every known colour from the deepest black to whitest white, they're colourful heights, but each one of them is admirably proportioned. Each is sound of tooth, smooth of skin. No ripples of fat around their middles, no bulges, no dimples orange-skin cellulite on their shanks. No body hair, no bushiness. They look like retouched fashion prints, or advertisements for high priced drill programs. (Atwood 115)

Because of their rigidity, they choose not to make homes or use tools, which would latterly develop into fiefdoms, clans, and materialistic solicitations. Crake posits that God is simply a cluster of neurons that he has uprooted from the minds of Crakers, appertained to as the Gspot in the brain. Crake's main ideal is to exclude art due to his belief that any type of emblematic cognition has the implicit to bring about the downfall of humanity. With art "next they'd be contriving icons, and sepulchers, and grave goods, and the afterlife, and sin, and Linear B, and lords, and also slavery and war" (Atwood 361). After all his sweats they still do dream and sing, and they're only introduced to plain and simple language. Upon leaving their defended mortal niche and encountering the wild terrain, the Crakers initiated a process of evolutionary change. At first, Crake effectively canceled their questioning about where they came from. Crakers have started to misdoubt their origins and the reality responsible for their creation. Like wise, crackers are designedly finagled to retain a harmonious frame, devoid of any individualities taking on leadership positions or blindly conforming to others. This has the capability to cultivate a strong desire for power and control. nonetheless, Jimmy notices that one of the crackers, dubbed Abraham Lincoln, is gradationally acquiring the characteristics of a leader. They hold the establishment conviction that there's no advanced reality and do not engage in hero deification. nonetheless, formerly Jimmy did not come back from his adventure within a short period of time, the crackers created an hero and started sharing in religious rituals and reciting prayers.

Although Crake made significant attempts to enhance the mortal species, they nonetheless have an essential propensity to acquire knowledge and acclimate as necessary. Crake explains to Jimmy that the crakers are simply prototypes, allowing humans to choose the asked traits for their unborn generations. It's about designing babies, as per the parent demand, "They'd be suitable to produce completely chosen babies that would incorporate any point, physical or internal or spiritual, that the buyer might wish to elect" (Atwood 357). I've enterprises about three specific problems. Originally, major advancements in scientific knowledge generally number a significant fiscal burden that's accessible only to individualities with substantial coffers and influence. This society is enabling the rich to enhance the internal and physical capabilities of their seed, so making them stronger and further intelligent. This is aggravating the formerly crummy educational experience and farther extending the socioeconomic difference. My alternate concern is that over time, as these changes come wide and accessible to everyone,



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individualities will come indistinguishable from one another, as they would each retain rates similar as intelligence, youngness, attractiveness, and intelligence. This will erode the distinctness that makes each person unique and render it insolvable to maintain individuality. Incipiently, my concern pertains to power dynamics what if those in authority clandestinely manipulate individualities, rendering them intellectually disabled, biddable, and subservient, in order to form sizable cohorts? As Crake says Whole population could be created that would have pre-selected characteristics. Beauty, of course; that would be high in demand. And acquiescence several world leaders has expressed interest in that. (Atwood 358)

The thirst for power has been a constant fight throughout mortal history. Power has transitioned from clans to pots. The arrival of biotechnology has significantly converted the realm of mass regulation. As Haraway says “The social thing of new life lores was easily statically control of the millions” (46). originally, humanity has always harbored a desire to retain holy capacities, particularly in the realm of creation. This aspiration is now being realized through the advancements in biotechnology. Using it, each existent within a community can be modified according to one's wishes. As Jimmy recalls There'd been a lot of chaffing around these days produce- an- beast was important fun, said the guys doing it; it made you feel like a god. A number of the trials were destroyed because they were too dangerous to have around (Atwood 57) The alternate aspect of the new focuses on the power of surveillance. In this macrosom, a bio-firm governs and controls the population through collaboration and regular monitoring. There are strict security measures in place, which involve regular monitoring of online conditioning.

Power constantly encounters resistance, while cooperation encounters obstacles when its opponent infiltrates its home and threatens its experimenters. Oryx and Crake portrays the lasting schism in society, with a unique and conspicuous divagation. In this environment, individualities are separated according to their degree of specialized advancement. The proponents and contributors of technological advancement in pots live in a secure and strictly kept community, where they enjoy the advantages of legal protection, robust security measures, and a health-conscious way of life. Again, individualities who are n't employed within these enclosed areas and primarily serve as guests for companies occasionally live in the outskirts, which are sometimes described as less advanced or uncultivated. Atwood underscores the internal difference among the working class by portraying Jimmy and Crake as representative characters. In this environment, the pivotal determinant of one's position is whether they choose to work for the business or not, rather than the conventional distinction between the bourgeoisie and the riffraff. Technological advancements have had a huge impact on the request and its ways of progress and deals. The primary and noteworthy change is the relief of homemade labour with internal labour. In Atwood's new Oryx and Crake, the pot views Crake, a character with exceptional cognitive capacities, as a precious asset. The establishment will exploit its capability for invention (intellectual value) for its own gain, while Jimmy, a character lacking any tendency towards creativity, gets marginalized. The cognitive labour in the textbook is being exploited grounded on the power of their invention. In the new Oryx and Crake, the Watson- Crick Institute claims power of the creation made by the scholars by patenting it under their own name, therefore replacing the scholars' power. Pots frequently gain patents for their workers' creations, leading to a race among financiers to acquire as numerous patents as they can, in order to come the exclusive directors of a particular product.

This covetousness results in the creation of several inventions that are fully redundant. The story successfully illustrates how technology and the desire for power directly led to the Crake action. He has established his power through the use of technology, both by eradicating particular populations that former autocrats have always asked but were unfit to negotiate, and by producing bio-engineered organisms. This is how he envisions the perfect world. “All it takes... is the elimination of one generation. One generation of anything.... Break the link in time between one generation and the next, and it's game over ever”. (Atwood 223) He's responsible for creating the Blyss pluss Pill, a largely sought- after drug that aims to drop population situations by adding sexual desire, furnishing protection against sexually transmitted conditions, and dragging youngness. also, he orchestrates an act of bioterrorism. In addition, the lozenge includes a haemorrhagic contagion that was specifically created to annihilate the mortal population, but this information is not revealed. Limited biotechnology has the implicit to enable a single person to ingest a lozenge and annihilate the whole mortal population without discovery. Biotechnology is deceptive to those





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who are fluently wisecracked; it makes false pledges and achieves results it cannot legitimately assert. The proliferation of genetically finagled creatures can be attributed to the influence of commercial dominance. Not only does a colossal pot have power over the request, but it also exercises dominion over every hand of the general population's actuality. This includes their access to food, clothes, security, and education, as well as their social control and indeed the manipulation of genetics to shape the asked kind of consumer for the plutocrat. This signified the inception of the time of colonizing actuality on Earth.

The collaboration's profit is deduced from the exploitation of both mortal beings and the terrain. The theoretical converse girding the correlation between capitalism and living organisms has persisted for an extended period of time. In her book *Life as supernumerary Biotechnology and Capitalism in the Neoliberal period*, Melinda Cooper argues that the frugality's expansion beyond natural limits has led to its redundant state. The devaluation of humanity has passed as a result of inordinate financial influence. As she writes As long as life wisdom product is subject to the imperatives of capitalist accumulation, the pledge of a fat of life will be rested on a corresponding move to depress life.(Atwood 45) This commercialization can only be enforced in a society that opposes public and governmental hindrance and lawyers for the neoliberal request. The whole mortal population was cancelled due to the commercialization of life. Consumption is the primary force behind the request, encompassing the deliberate product of goods and services for the purpose of consumption. Atwood's work specifically questions the principle of failure in the frugality, fastening on the complaint request. In this request, pots designedly produce the illness and also introduce a more expensive and limited result. This miracle generates an inclination towards collaboration and consumption." moping ails" are considered the most profitable type of disease from a marketable perspective(Atwood 248). The commercialization easily demonstrates the paternalism displayed by companies.

The novel delves into a series of political assassinations, strange circumstances, and unexplained vanishings that can be attributed to the power held by the Cooperation. These events easily illustrate that those who are against cooperation are fleetly silenced, discredited, or made to vanish. Jimmy's mama, a microbiologist, constantly voices her disagreement before leaving the installation to pursue activism. She's pursued relentlessly by a pot for several times until they eventually track her down and exclude her. The ineffectiveness of these forms of action is apparent in the Happicuppa coffee kick. The creation of Happicuppa coffee was a result of Healthwyzer's desire to simplify the process of collecting completely grown coffee sap on a large-scale ranch. The genetically modified bean presented a substantial trouble to a humble coffee planter. The demonstration lasted for several days, with screams and multiple losses, but no palpable issues were achieved. As Uncle Pete said They'll get tired of it, they'll settle down. Everybody wants a cheaper mug of coffee – youcan't fight that.(Atwood 212)

CONCLUSION

Upon completing the new Oryx and Crake, it becomes apparent that technology has the implicit to bestow bliss, albeit with certain restrictions. Unrestrained trial possesses the capacity to precipitate the collapse of humanity. Crake was suitable to execute his unrighteous scheme because there were no ethical morals or regulations in place. The inquiry that requires a response is; what's the maximum extent or boundary? What's the threshold for being considered inordinate, and what's the limit for going beyond respectable boundaries? It's pivotal for them to establish clear limits that must not be violated. Atwood warns compendiums about the essential pitfalls of biotechnology and its profound influence on the mortal race. Considering the present position of specialized progress, it's pivotal to break and contemplate whether this is authentically essential at this juncture. Is this truly essential for the well-being of mortal beings? The correlation between wealth and influence energizes the quick progress in different sectors. Atwood expresses apprehension on the possibility of a disastrous future characterized by inheritable manipulation and natural control in the advancing period. She emphasizes the threats of scientists assuming the part of a deity by manipulating the abecedarian factors of life, while the rest of us, like Jimmy, remain unconscious to the possible impacts we might encounter.





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RESEARCH ARTICLE

Complex Intuitionistic Fuzzy Madm Model For Diagnosing Cancer Causes In Non-Smokers

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ABSTRACT

The risk of cancer in nonsmokers has increased by several factors. This risk is increased by viral infections, genetic predispositions, and environmental exposures. Prevention and early detection can be facilitated by knowledge and comprehension of these aspects. For non-smokers, routine health examinations and screenings are essential. Finding risk factors can enhance results and lower the incidence of cancer. Aims to analyze the influential and dominant results and attributes of some innovative and valuable concepts using CIF information and we introduce the “Complex Intuitionistic FuzzySorted Set Weighted Averaging (CIFSSWA),Complex Intuitionistic FuzzySorted Set Ordered Weighted Averaging (CIFSSOWA),Complex Intuitionistic FuzzySorted SetOrdered Weighted” Geometric (CIFSSOWG),Complex Intuitionistic FuzzySorted SetWeighted Geometric (CIFSSWG),Complex Intuitionistic FuzzySorted SetHybrid Averaging (CIFSSHA), Complex Intuitionistic FuzzySorted Set Hybrid Geometric (CIFSSHG) aggregation operators. Therefore, analyzing the issue of determining the cause of cancer in people is the primary focus of diagnostic operations. To increase the value of the analyzed methods with a specific leading result.

Keywords: Non-Smoker, MADM, Weighted Averaging Operators, Weighted Geometric Operators, Medical Decision Support System.





INTRODUCTION

Modern decision-making necessitates robust models capable of handling vagueness or ambiguity inherent in real-world data, particularly in uncertain, imprecise, and dynamic environments. Traditional binary logic and crisp mathematical techniques often fall short in such contexts, prompting the development of more adaptive paradigms such as fuzzy set theory, intuitionistic fuzzy sets (IFSs), and their various extensions. Zadeh (1965) introduced fuzzy set theory, laying the foundation for representing partial truths wherein elements can belong to a set to varying degrees. Building upon this, Atanassov (1986) proposed IFSs, which incorporate member, non-membership degree, and a hesitation margin—offering a more nuanced representation of uncertainty, particularly valuable in multi-attribute decision-making (MADM). In subsequent years, researchers like Xu, Yager, Wang, and Garg have significantly advanced this domain by developing a variety of aggregation operators—essential tools in collective decision-making within intuitionistic fuzzy frameworks. These include geometric, hybrid weighted, Einstein, Hamacher, and Aczel–Alsina operators, each tailored to different computational and interpretative needs (Xu, 2007; Xu & Yager, 2006). To capture periodic, oscillatory, and phase-dependent data that real-valued fuzzy sets cannot address, the foundation of complex fuzzy sets was laid by Ramot *et al.* in their 2002 study, and subsequently developed into (CIFs) and interval-valued models by scholars such as Alkouri & Salleh (2012, 2013) and Garg & Rani (2019). These models have shown enhanced expressiveness and precision, especially in domains like control systems, medical diagnostics, and computational intelligence.

Additionally, advanced frameworks enable deeper modeling of human reasoning under extreme uncertainty. Various decision-making frameworks, including TOPSIS, COPRAS, and set pair analysis, when integrated with fuzzy and intuitionistic fuzzy settings, yield practical tools capable of handling incomplete, linguistic, and contradictory information. For instance, Zhang (2018) successfully applied the Dempster–Shafer theory within an intuitionistic fuzzy environment to enhance group decision-making by aggregating conflicting expert judgments. More recently, researchers like Mahmood *et al.* (2021–2023) have introduced applications of bipolar fuzzy, complex fuzzy, and hybrid aggregation operators in medical diagnostics and knowledge-based systems, demonstrating notable improvements in classification accuracy and decision robustness. This evolving body of literature reflects a paradigmatic shift in decision science—from deterministic frameworks to those that embrace the full spectrum of uncertainty in human cognition and real-world phenomena. The referenced works collectively offer a comprehensive foundation of theoretical insights, algorithmic innovations, and practical implementations, underscoring the central role of fuzzy and intuitionistic fuzzy theories in intelligent decision-making.

Definition 1. Let F be the IFS defined on X_u is $F = \{(p(X_E), e(X_E)) : X_E \in X_u\}$ where $p, e: X \rightarrow [0,1]$ which p is membership values and e is non-membership values and $p + e \leq 1$ for each $u \in X$.

Definition 2. Let X_u be the universal set

A Complex Intuitionistic Fuzzy Set (CIFS) C is defined on X is given as

$$C = \{(p_c(X_E), e_c(X_E)) : X_E \in X_u\} \quad (1)$$

$$\text{where } (p_R(X_E)) = (p_R(X_E))e^{i2\pi(p_I(X_E))} \text{ and } e_c(X_E) = e_R(X_E)e^{i2\pi(e_I(X_E))},$$

$$0 \leq (p_R(X_E) + e_R(X_E)) \leq 1, \quad 0 \leq p_I(X_E) + e_I(X_E) \leq 1.$$

$$C = (p_{R_j}e^{i2\pi(p_{I_j})} + e_{R_j}e^{i2\pi(e_{I_j})}), j = 1, 2, \dots, n.$$

Definition 3. A CIFNs $C_1 = (p_{R_j}e^{i2\pi(p_{I_j})} + e_{R_j}e^{i2\pi(e_{I_j})})_{j=1}$, score value (SV) and accuracy (AV)

$$m_{SV}(C_1) = (p_{R_1} + p_{I_1} - e_{R_1} - e_{I_1}), \quad m_{SV}(C_1) \in [0,1] \quad (2)$$

$$n_{SV}(C_1) = (p_{R_1} + p_{I_1} + e_{R_1} + e_{I_1}) \in [0,1] \quad (3)$$

Complex Intuitionistic Fuzzy Sorted Set in Weighted Averaging and Geometric Operators

Definition 6. If the CIFNs





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$C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$, $j = 1, 2, \dots, n$, then the CIFSSWA operator is

$\text{CIFSSWA}(C_1, C_2, \dots, C_j) = WC_1 \oplus WC_2 \oplus WC_j = \bigoplus_{j=1}^n (WC_j)^w$ (4) $W = (W_1, W_2, \dots, W_n)^T$. The rule is $\sum_{j=1}^n \frac{W_j}{\sum_{i=1}^m W_i} = 1$.

Theorem 1. If the CIFSC $_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$, $j = 1, 2, \dots, n$, then the operator

$$\text{CIFSSWA} = \left(\left(1 - \prod_{j=1}^n (1 - p_{R_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right) e^{i2\pi \left(1 - \prod_{j=1}^n (1 - p_{I_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right)}, \right. \\ \left. \left(\prod_{j=1}^n (e_{R_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right) e^{i2\pi \left(\prod_{j=1}^n (e_{I_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right)} \right) \quad (5)$$

Proof. Using mathematical induction, based on established laws. We prove the equation first, we have to check for $n=3$, then.

$$\begin{aligned} w_1 C_1 &= \left((1 - (1 - p_{R_1})^{w_1}) e^{i2\pi(1 - (1 - p_{I_1})^{w_1})}, ((e_{R_1})^{w_1}) e^{i2\pi((e_{I_1})^{w_1})} \right) \\ w_2 C_2 &= \left((1 - (1 - p_{R_2})^{w_2}) e^{i2\pi(1 - (1 - p_{I_2})^{w_2})}, ((e_{R_2})^{w_2}) e^{i2\pi((e_{I_2})^{w_2})} \right) \\ w_3 C_3 &= \left((1 - (1 - p_{R_3})^{w_3}) e^{i2\pi(1 - (1 - p_{I_3})^{w_3})}, ((e_{R_3})^{w_3}) e^{i2\pi((e_{I_3})^{w_3})} \right) \\ \text{CIFSSWA}(C_1, C_2, C_3) &= \left((1 - (1 - p_{R_1})^{w_1}) e^{i2\pi(1 - (1 - p_{I_1})^{w_1})}, ((e_{R_1})^{w_1}) e^{i2\pi((e_{I_1})^{w_1})} \right) \\ &\quad \oplus \left((1 - (1 - p_{R_2})^{w_2}) e^{i2\pi(1 - (1 - p_{I_2})^{w_2})}, ((e_{R_2})^{w_2}) e^{i2\pi((e_{I_2})^{w_2})} \right) \\ &\quad \oplus \left((1 - (1 - p_{R_3})^{w_3}) e^{i2\pi(1 - (1 - p_{I_3})^{w_3})}, ((e_{R_3})^{w_3}) e^{i2\pi((e_{I_3})^{w_3})} \right) \end{aligned}$$

Now $n = k$, then

$$\text{CIFSSWA}(C_1, C_2, \dots, C_k) = \left(\left(1 - \prod_{j=1}^k (1 - p_{R_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right) e^{i2\pi \left(1 - \prod_{j=1}^k (1 - p_{I_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right)}, \right. \\ \left. \left(\prod_{j=1}^k (e_{R_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right) e^{i2\pi \left(\prod_{j=1}^k (e_{I_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right)} \right)$$

Further, $n=k+1$. $\text{CIFSSWA}(C_1, C_2, \dots, C_{k+1}) = \text{CIFSSWA}(C_1, C_2, \dots, C_k) \oplus w_{k+1} C_{k+1}$

$$\begin{aligned} &= \left(\left(1 - \prod_{j=1}^k (1 - p_{R_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right) e^{i2\pi \left(1 - \prod_{j=1}^k (1 - p_{I_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right)}, \right. \\ &\quad \left. \left(\prod_{j=1}^k (e_{R_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right) e^{i2\pi \left(\prod_{j=1}^k (e_{I_j})^{\frac{W_j}{\sum_{i=1}^m W_i}} \right)} \right) \\ &\quad \oplus \left((1 - (1 - p_{R_{k+1}})^{w_{k+1}}) e^{i2\pi(1 - (1 - p_{I_{k+1}})^{w_{k+1}})}, ((e_{R_{k+1}})^{w_{k+1}}) e^{i2\pi((e_{I_{k+1}})^{w_{k+1}})} \right) \end{aligned}$$





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$$= \left(\left(1 - \prod_{j=1}^{k+1} (1 - p_{R_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left(1 - \prod_{j=1}^{k+1} (1 - p_{I_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)}, \right. \\ \left. \left(\prod_{j=1}^{k+1} (e_{R_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left(\prod_{j=1}^{k+1} (e_{I_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)} \right)$$

Which “is true for $n=k+1$ ”.

Moreover, this CIFSSWA Operator has three properties, which are Idempotency, Boundedness, Monotonicity, and these three properties apply to the six operators.

Idempotency Property: If C be “another CIFN such that

$C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$ then we have

$\text{CIFSSWA}(C_1, C_2, \dots, C_j) = C$

Proof. Let $C_j = C = (p_R e^{i2\pi(p_I)} + e_R e^{i2\pi(e_I)})$ then”

$$\text{CIFSSWA}(C_1, C_2, \dots, C_j) = \left(\left(1 - \prod_{j=1}^n (1 - p_{R_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left(1 - \prod_{j=1}^n (1 - p_{I_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)}, \right. \\ \left. \left(\prod_{j=1}^n (e_{R_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left(\prod_{j=1}^n (e_{I_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)} \right) \\ = \left(\left(1 - (1 - p_R)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left(1 - (1 - p_I)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)}, \right. \\ \left. \left((e_R)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left((e_I)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)} \right) = \left(\left((p_R)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left((p_I)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)}, \right. \\ \left. \left((e_R)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left((e_I)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)} \right)$$

The equation CIFSSWA, satisfied “for $i=1$. We get.

$$= \left(\left((p_R)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left((p_I)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)}, \right. \\ \left. \left((e_R)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left((e_I)^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)} \right) = (p_R e^{i2\pi(p_I)} + e_R e^{i2\pi(e_I)}) = C$$

Hence, $\text{CIFSSWA}(C_1, C_2, \dots, C_j) = C$

. This Property of the CIFSSWA Operator would be called Idempotency.

Boundedness Property: If $C_j = (\min_j p_{R_j} e^{i2\pi(\min_j p_{I_j})}, \max_j p_{R_j} e^{i2\pi(\max_j p_{I_j})})$ and

$C_j^+ = (\max_j p_{R_j} e^{i2\pi(\max_j p_{I_j})}, \min_j p_{R_j} e^{i2\pi(\min_j p_{I_j})})$ such that

$C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$, $j = 1, 2, \dots, n$ and

then $C_j \leq \text{CIFSSWA}(C_1, C_2, \dots, C_j) \leq C_j^+$.

Proof. Suppose that $C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$,

Let $C_j = (\min_j p_{R_j}, \max_j p_{R_j})$ and”

$C_j^+ = (\max_j p_{R_j}, \min_j p_{R_j})$,

“then $C_j \leq (C_1, C_2, \dots, C_n) \leq C_j^+$, here

$\min \leq () \leq \max$

$1 - \min \geq 1 - () \geq 1 - \max$





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$$(1 - \min_j \frac{w_i}{\sum_{i=1}^m w_i}) \geq (1 - \prod_{j=1}^n (1 - p_{R_j})^{\frac{w_i}{\sum_{i=1}^m w_i}}) \geq (1 - \max_j \frac{w_i}{\sum_{i=1}^m w_i})$$

$$1 - \min_j p_{R_j} \geq \left(\prod_{j=1}^n (1 - p_{R_j})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) \geq 1 - \max_j p_{R_j}$$

$$1 - \min_j p_{R_j} \geq \left(1 - \prod_{j=1}^n (1 - p_{R_j})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) \geq 1 - \max_j p_{R_j}$$

Similarly, for the other function, i.e.,

$$1 - \min_j p_{I_j} \geq \left(1 - \prod_{j=1}^n (1 - p_{I_j})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) \geq 1 - \max_j p_{I_j}$$

$$1 - \min_j e_{R_j} \geq \left(1 - \prod_{j=1}^n (1 - e_{R_j})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) \geq 1 - \max_j e_{R_j}$$

$$1 - \min_j e_{I_j} \geq \left(1 - \prod_{j=1}^n (1 - e_{I_j})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) \geq 1 - \max_j e_{I_j}$$

The Score Function'' $m_{SV}(C_j)$,

$$m_{SV}(C_j) = (p_{R_j} + p_{I_j} - e_{R_j} - e_{I_j}), \quad m_{SV}(C_j) \in [0, 1]$$

$$= \max_j p_{R_j} + \max_j p_{I_j} - \min_j e_{R_j} - \min_j e_{I_j} = m_{SV} C_j^+$$

$$m_{SV}(C_j) = (p_{R_j} + p_{I_j} - e_{R_j} - e_{I_j}), \quad m_{SV}(C_j) \in [0, 1]$$

$$= \min_j p_{R_j} + \min_j p_{I_j} + \max_j e_{R_j} + \max_j e_{I_j} = m_{SV} C_j^-$$

Elaborate "the following cases;

Case 1: If $m_{SV} C_j^+ > m_{SV} C_j$ and $m_{SV} C_j^- < m_{SV} C_j$

then, based on the comparison rule, we obtain

$$m_{SV}(C_j^-) \leq \text{CIFSSWA}(C_1, C_2, \dots, C_j) \leq m_{SV}(C_j^+)$$

Case 2: If $m_{SV}(C_j^+) = m_{SV}(C_j)$ and $m_{SV}(C_j^-) = m_{SV}(C_j)$

then, based on the Accuracy Value, it is similar to the Score Value,

$$n_{AV}(C_j^-) = \text{CIFSSWA}(C_1, C_2, \dots, C_j) = n_{AV}(C_j^-)$$

Therefore, we obtain the result such that.

$$n_{AV}(C_j^-) \leq \text{CIFSSWA}(C_1, C_2, \dots, C_j) \leq n_{AV}(C_j^-)$$

This Property of the **CIFSSWA** Operator would be called Boundedness.

Monotonicity Property: If $\text{CIFSSWA}(C_j) = \text{CIFSSWA}(C_j')$

such that $C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$, $j = 1, 2, \dots, n$ and then

$$\text{CIFSSWA}(C_1, C_2, \dots, C_j) \leq \text{CIFSSWA}(C_1', C_2', \dots, C_n').$$

Proof. Let $C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$ and $C_j' = (p_{R_j}' e^{i2\pi(p_{I_j}')} + e_{R_j}' e^{i2\pi(e_{I_j}')})$,

If such that $p_{R_j} \leq p_{R_j}'$, $p_{I_j} \leq p_{I_j}'$, $e_{R_j} \leq e_{R_j}'$, $e_{I_j} \leq e_{I_j}'$

then $\text{CIFSSWA}(C_1, C_2, \dots, C_j) \leq \text{CIFSSWA}(C_1', C_2', \dots, C_n')$

This Property of the **CIFSSWA** Operator would be called Monotonicity.

Theorem 2. If the CIFS $C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$, $j = 1, 2, \dots, n$, and the operator

$$\text{CIFSSWA} = \left(\left(1 - \prod_{j=1}^n (1 - p_{R_{k(j)}})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left(1 - \prod_{j=1}^n (1 - p_{I_{k(j)}})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)}, \right. \\ \left. \left(\prod_{j=1}^n (e_{R_{k(j)}})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right) e^{i2\pi \left(\prod_{j=1}^n (e_{I_{k(j)}})^{\frac{w_i}{\sum_{i=1}^m w_i}} \right)} \right) \quad (6)$$





Proof. Omitted. ■

Theorem 3. If the CIFS $C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$, $j = 1, 2, \dots, n$, and the operator

$$\text{CIFSSWG} = \left(\begin{array}{l} \left(\prod_{j=1}^n (p_{R_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} e^{i2\pi \left(\prod_{j=1}^n (p_{I_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)}, \\ \left(1 - \prod_{j=1}^n (1 - e_{R_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} e^{i2\pi \left(1 - \prod_{j=1}^n (1 - e_{I_j})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)} \end{array} \right) \quad (7)$$

Proof. Omitted. ■

Theorem 4. If “the CIFSC $_j = (p_{R_{k(j)}} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})})$, $j = 1, 2, \dots, n$, and the operator

$$\text{CIFSSOWG} = \left(\begin{array}{l} \left(\prod_{j=1}^n (p_{R_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} e^{i2\pi \left(\prod_{j=1}^n (p_{I_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)}, \\ \left(1 - \prod_{j=1}^n (1 - e_{R_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} e^{i2\pi \left(1 - \prod_{j=1}^n (1 - e_{I_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)} \end{array} \right) \quad (8)$$

Proof. Omitted. ■

Theorem 2.5. If the CIFSC $_j = (\ddot{p}_{R_j} e^{i2\pi(\ddot{p}_{I_j})} + \ddot{e}_{R_j} e^{i2\pi(\ddot{e}_{I_j})})$, $j = 1, 2, \dots, n$, and the operator **CIFSSHA** =

$$\left(\begin{array}{l} \left(1 - \prod_{j=1}^n (1 - \ddot{p}_{R_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} e^{i2\pi \left(1 - \prod_{j=1}^n (1 - \ddot{p}_{I_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)}, \\ \left(\prod_{j=1}^n (\ddot{e}_{R_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} e^{i2\pi \left(\prod_{j=1}^n (\ddot{e}_{I_{k(j)}})^{\frac{w_j}{\sum_{i=1}^m w_i}} \right)} \end{array} \right) \quad (9)$$

Proof. Omitted. ■

Theorem 2.6. If the CIFSC $_j = (\ddot{p}_{R_j} e^{i2\pi(\ddot{p}_{I_j})} + \ddot{e}_{R_j} e^{i2\pi(\ddot{e}_{I_j})})$, $j = 1, 2, \dots, n$, then the operator

$$\text{CIFSSHG} = \left(\begin{array}{l} \left(\prod_{j=1}^n (\ddot{p}_{R_{k(j)}})^{\frac{u_j}{\sum_{i=1}^m u_i}} e^{i2\pi \left(\prod_{j=1}^n (\ddot{p}_{I_{k(j)}})^{\frac{u_j}{\sum_{i=1}^m u_i}} \right)}, \\ \left(1 - \prod_{j=1}^n (1 - \ddot{e}_{R_{k(j)}})^{\frac{u_j}{\sum_{i=1}^m u_i}} e^{i2\pi \left(1 - \prod_{j=1}^n (1 - \ddot{e}_{I_{k(j)}})^{\frac{u_j}{\sum_{i=1}^m u_i}} \right)} \end{array} \right) \quad (10)$$

Proof. Omitted. ■

Application “Non Smokers getting Cancer using Approaches based on Complex Intuitionistic Fuzzy Information”

Secondhand smoke, sometimes referred to as smoke from nearby smokers, is a smoke inhaled directly. Although dangerous compounds are present in all forms of smoke, side-stream smoke is even more deadly due to its lower burning temperature and lack of lung filtering. Tobacco use is frequently the first risk factor that people think of when they think of cancer, especially lung cancer. Although smoking is the primary cause of many cancers, particularly lung cancers, a sizable and increasing proportion of cancer cases are in people who have never smoked.





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These "non-smoker" malignancies bring up significant issues regarding genetic predispositions, environmental exposures, additional risk factors, and new research directions. Another significant risk factor is air pollution. An increased risk of lung, bladder, and even breast cancer has been associated with prolonged exposure to particulate matter and pollutants like sulfur dioxide and nitrogen dioxide. Exposure to silica, diesel exhaust, asbestos, and other chemicals, such as benzene, at work can raise the risk of developing cancer. These carcinogens are frequently found in industrial settings such as manufacturing, mining, and construction. For nonsmokers who live or work in areas where smoking is common, even secondhand smoke, while indirect, greatly raises their chance of developing lung cancer. The familial cancer syndromes can make people more susceptible to colorectal, endometrial, brain, and other malignancies. In some situations, a person's DNA pattern causes cancer rather than external toxins. Family history can be a significant risk factor even when there isn't a definite hereditary cancer syndrome. Patterns of cancer occurrence within families may result from shared genes and surroundings, particularly when paired with comparable food and lifestyle choices. Fibers of asbestos can lodge in the lungs or other organs after being breathed. These fibers eventually result in scarring and persistent inflammation. They are difficult for the immune system to eliminate, which can cause cellular damage that could eventually turn into cancer. Asbestos-related malignancies are especially deadly because of the lengthy latency period, which is frequently 20 to 50 years between exposure and diagnosis. The disease may have progressed by the time symptoms show up.

DECISION-MAKING PROCEDURE

The CIFS assumption has been applied to individual contexts by a number of intellectuals. We experimented with a decision-making procedure to look into the advantageous ideal. We can take "n" different alternatives to create an MADM "problem $C = (C_1, C_2, \dots, C_n)$ under "m" the criteria $C' = (C'_1, C'_2, \dots, C'_n)$ with vector of weight, $W = (W_1, W_2, \dots, W_n)^T$. The rule $\sum_{i=1}^n \frac{W_i}{\sum_{i=1}^m W_i} = 1$. The given set of criteria is divided into two disjoint sets, namely, (H_1) and (H_2) such that $H_1 \cap H_2 = \emptyset$ and $H_1 \cup H_2 = E$. Evaluate the alternatives $C_j, j = 1, 2, \dots, m$ under C'_p and gives the CIFNs. $C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})}) j = 1, 2, \dots, n$. Where $0 \leq p_{R_j} + e_{R_j} \leq 1$ and $0 \leq p_{I_j} + e_{I_j} \leq 1$. To identify the best options among the ones provided, and then used developed operators.

Step 1: Arranging the decision matrix $(\gamma_{jk})_{m \times n}$.

$$S = \begin{matrix} C_1 \\ \vdots \\ C_n \end{matrix} \begin{pmatrix} \gamma_{11} & \cdots & \gamma_{1n} \\ \vdots & \ddots & \vdots \\ \gamma_{m1} & \cdots & \gamma_{mn} \end{pmatrix}$$

Step 2: Use the following formula to normalize the rating data if necessary.

$$\alpha_{rs} = \begin{cases} (e_{R_{rs}}, (e_{I_{rs}}); \text{ if } C'_s \in H_1 \\ ((p_{R_{rs}}), (p_{I_{rs}}); \text{ if } C'_s \in H_2 \end{cases} \quad (11)$$

Step 3: Utilizing either geometric operators or averaging, combine "the values of each alternative under the various criteria" to obtain the collective value and for example, the CIFSSWA operators, which change "by α_r , $C_r = (p_{R_r} e^{i2\pi(p_{I_r})} + e_{R_r} e^{i2\pi(e_{I_r})})$ as"

$$\text{CIFSSWA} = \left(\left(1 - \prod_{s=1}^n (1 - p_{R_{rs}})^{\frac{W_s}{\sum_{s=1}^m W_s}} \right) e^{i2\pi \left(1 - \prod_{k=1}^n (1 - p_{I_{rs}})^{\frac{W_s}{\sum_{s=1}^m W_s}} \right)}, \right. \\ \left. \left(\prod_{k=1}^n (e_{R_{rs}})^{\frac{W_s}{\sum_{s=1}^m W_s}} \right) e^{i2\pi \left(\prod_{k=1}^n (e_{I_{rs}})^{\frac{W_s}{\sum_{s=1}^m W_s}} \right)} \right)$$

On other hand also similar to it, "CIFSSWG operator





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$$\text{CIFSSWG} = \left(\begin{array}{c} \left(\prod_{s=1}^n (p_{R_{rs}})^{\frac{w_s}{\sum_{s=1}^n w_s}} e^{i2\pi \left(\prod_{k=1}^n (p_{I_{rs}})^{\frac{w_s}{\sum_{s=1}^n w_s}} \right)}, \right. \\ \left. \left(1 - \prod_{k=1}^n (1 - e_{R_{rs}})^{\frac{w_s}{\sum_{s=1}^n w_s}} e^{i2\pi \left(1 - \prod_{k=1}^n (1 - e_{I_{rs}})^{\frac{w_s}{\sum_{s=1}^n w_s}} \right)} \right) \right) \end{array} \right)$$

Step 4: Solve “the Score values of α_r ($r=1,2,\dots,n$)”

$$m_{SV}(C_r) = (p_{R_r} + p_{I_r} - e_{R_r} - e_{I_r}), m_{SV} \in [0,1]$$

If the score fails for the decision values and we can use accuracy value.

$$n_{SV}(C_r) = (p_{R_r} + p_{I_r} + e_{R_r} + e_{I_r}), n_{SV} \in [0,1]$$

Step 5: Choosing the best alternatives by the Score and Accuracy values.

NUMERICAL ILLUSTRATION

The developed method is validated through a numerical example, and its results are compared with existing studies”. In this case, we can concentrate on five main causes represented in the shape of attributes, which are explained below:

C₁: Tobacco Use, C₂: Asbestos exposure, C₃: Air pollution,

C₄: Genetic factors, C₅: Second hand smoke

By the CIFSS, we can arrange the vector of weights as

$$W = (0.3, 0.3, 0.2, 0.1, 0.1)^T, U = (0.3, 0.2, 0.2, 0.2, 0.1)^T$$

Step 1: We represented Complex Intuitionistic Fuzzy data in a matrix structure

$$C_j = (p_{R_j} e^{i2\pi(p_{I_j})} + e_{R_j} e^{i2\pi(e_{I_j})}). \text{ See Table 1.}$$

Step 2a: We apply CIFSSWA operator equation (5) with W, the collective values are CIFSSWA,

$$C_1' = \left(\begin{array}{c} \left((1 - ((1 - 0.3)^{0.3}, (1 - 0.1)^{0.3}, (1 - 0.6)^{0.2}, (1 - 0.8)^{0.1}, (1 - 0.4)^{0.1})) \right) \\ e^{i2\pi((1 - ((1 - 0.4)^{0.3}, (1 - 0.5)^{0.3}, (1 - 0.3)^{0.2}, (1 - 0.2)^{0.1}, (1 - 0.6)^{0.1}))}, \\ ((0.7)^{0.3}, (0.9)^{0.3}, (0.4)^{0.2}, (0.2)^{0.1}, (0.4)^{0.1}) \\ e^{i2\pi((0.5)^{0.3}, (0.3)^{0.3}, (0.2)^{0.2}, (0.3)^{0.1}, (0.5)^{0.1})} \end{array} \right)$$

$$C_1' = (0.4137e^{i2\pi(0.4210)}, 0.5630e^{i2\pi(0.3393)}), C_2' = (0.6224e^{i2\pi(0.3894)}, 0.3776e^{i2\pi(0.4198)}), C_3' = (0.4881e^{i2\pi(0.4147)}, 0.5406e^{i2\pi(0.4288)}),$$

$$C_4' = (0.6435e^{i2\pi(0.2083)}, 0.2896e^{i2\pi(0.4991)}), C_5' = (0.5101e^{i2\pi(0.5031)}, 0.2259e^{i2\pi(0.3879)}).$$

Score values of aggregated number the above equation are

$$m_{SV}(C_1) = -0.0677, m_{SV}(C_2) = 0.2143, m_{SV}(C_3) = -0.0666,$$

$$m_{SV}(C_4) = 0.0630, m_{SV}(C_5) = 0.3994.$$

Step 2 b: Apply to CIFSSWA, CIFSSWG, CIFSSOWG, CIFSSHA, and CIFSSHG to combine the result with the matrix.

Step 3: The data was acquired to calculate the SV.

Step 4: Evaluate and prioritize alternatives to determine the best decision.

Well-known studies have identified key risk factor for cancer in non smokers is called C₅: Second hand smoke.

CONCLUSION

Nonsmokers may still be at risk of developing cancer due to environmental exposures, genetic predispositions, viral infections, and other lifestyle choices. Awareness and comprehension of these hazards can assist individuals in taking preventative actions, promoting early identification, and encouraging healthy practices to minimize the risk of cancer. Regular health checks and screenings can also help with early diagnosis and treatment. Individuals can lower their risk and improve their general well-being by putting their health first and taking proactive measures. Furthermore, remaining up to date on cancer research and breakthroughs can help people make informed health





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decisions, and support from healthcare experts, family, and friends can be invaluable in cancer prevention and treatment. People must live a wholesome life that includes a food diet, routine exercise, and controlling stress. Escaping carcinogens like certain chemicals and radiation can also help lower the risk of cancer. Nonsmokers can lower their risk of acquiring cancer while also improving their all over health and well-being by following these tips. Early detection and treatment are key in improving cancer outcomes, so remain cautious and seek medical assistance if any symptoms appear. To examine the relationship between non-smokers and cancer development, utilizing power AOs within the CIFSS framework. Further, we framed the **CIFSSWA, CIFSSOWA, CIFSSWG, CIFSSOWG, CIFSSHA, CIFSSHG** Operators and evaluated their resulting three properties. Next, employing approaches based on operators, we found that the final result is C_5 That is Second hand smoke. It is the main cause for the cancer.

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Table 1: Represented the CIFS information

	$\mathcal{E}_1'$	$\mathcal{E}_2'$	$\mathcal{E}_3'$	$\mathcal{E}_4'$	$\mathcal{E}_5'$
$\mathcal{E}_1$	$\begin{pmatrix} 0.3e^{i2\pi(0.4)} \\ 0.7e^{i2\pi(0.5)} \end{pmatrix}$	$\begin{pmatrix} 0.1e^{i2\pi(0.5)} \\ 0.9e^{i2\pi(0.3)} \end{pmatrix}$	$\begin{pmatrix} 0.6e^{i2\pi(0.3)} \\ 0.4e^{i2\pi(0.2)} \end{pmatrix}$	$\begin{pmatrix} 0.8e^{i2\pi(0.2)} \\ 0.2e^{i2\pi(0.3)} \end{pmatrix}$	$\begin{pmatrix} 0.4e^{i2\pi(0.6)} \\ 0.4e^{i2\pi(0.5)} \end{pmatrix}$
$\mathcal{E}_2$	$\begin{pmatrix} 0.6e^{i2\pi(0.1)} \\ 0.4e^{i2\pi(0.5)} \end{pmatrix}$	$\begin{pmatrix} 0.8e^{i2\pi(0.3)} \\ 0.2e^{i2\pi(0.5)} \end{pmatrix}$	$\begin{pmatrix} 0.2e^{i2\pi(0.4)} \\ 0.8e^{i2\pi(0.3)} \end{pmatrix}$	$\begin{pmatrix} 0.7e^{i2\pi(0.6)} \\ 0.3e^{i2\pi(0.1)} \end{pmatrix}$	$\begin{pmatrix} 0.4e^{i2\pi(0.8)} \\ 0.6e^{i2\pi(0.7)} \end{pmatrix}$
$\mathcal{E}_3$	$\begin{pmatrix} 0.3e^{i2\pi(0.2)} \\ 0.7e^{i2\pi(0.6)} \end{pmatrix}$	$\begin{pmatrix} 0.5e^{i2\pi(0.2)} \\ 0.6e^{i2\pi(0.2)} \end{pmatrix}$	$\begin{pmatrix} 0.7e^{i2\pi(0.4)} \\ 0.3e^{i2\pi(0.9)} \end{pmatrix}$	$\begin{pmatrix} 0.2e^{i2\pi(0.5)} \\ 0.8e^{i2\pi(0.3)} \end{pmatrix}$	$\begin{pmatrix} 0.6e^{i2\pi(0.9)} \\ 0.4e^{i2\pi(0.5)} \end{pmatrix}$
$\mathcal{E}_4$	$\begin{pmatrix} 0.4e^{i2\pi(0.1)} \\ 0.6e^{i2\pi(0.5)} \end{pmatrix}$	$\begin{pmatrix} 0.6e^{i2\pi(0.2)} \\ 0.2e^{i2\pi(0.8)} \end{pmatrix}$	$\begin{pmatrix} 0.8e^{i2\pi(0.1)} \\ 0.2e^{i2\pi(0.5)} \end{pmatrix}$	$\begin{pmatrix} 0.4e^{i2\pi(0.6)} \\ 0.6e^{i2\pi(0.3)} \end{pmatrix}$	$\begin{pmatrix} 0.9e^{i2\pi(0.2)} \\ 0.1e^{i2\pi(0.2)} \end{pmatrix}$
$\mathcal{E}_5$	$\begin{pmatrix} 0.2e^{i2\pi(0.2)} \\ 0.1e^{i2\pi(0.5)} \end{pmatrix}$	$\begin{pmatrix} 0.8e^{i2\pi(0.2)} \\ 0.2e^{i2\pi(0.7)} \end{pmatrix}$	$\begin{pmatrix} 0.1e^{i2\pi(0.9)} \\ 0.6e^{i2\pi(0.3)} \end{pmatrix}$	$\begin{pmatrix} 0.6e^{i2\pi(0.3)} \\ 0.4e^{i2\pi(0.2)} \end{pmatrix}$	$\begin{pmatrix} 0.4e^{i2\pi(0.5)} \\ 0.3e^{i2\pi(0.1)} \end{pmatrix}$

Table 2: Represented the collected values

OPERATOR	C1'	C2'	C3'	C4'	C5'
CIFSSWA	$\begin{pmatrix} 0.4137e^{i2\pi(0.4210)} \\ 0.5630e^{i2\pi(0.3393)} \end{pmatrix}$	$\begin{pmatrix} 0.6224e^{i2\pi(0.3894)} \\ 0.3776e^{i2\pi(0.4198)} \end{pmatrix}$	$\begin{pmatrix} 0.4881e^{i2\pi(0.4147)} \\ 0.5406e^{i2\pi(0.4288)} \end{pmatrix}$	$\begin{pmatrix} 0.6435e^{i2\pi(0.2083)} \\ 0.2896e^{i2\pi(0.4991)} \end{pmatrix}$	$\begin{pmatrix} 0.5101e^{i2\pi(0.5031)} \\ 0.2259e^{i2\pi(0.3879)} \end{pmatrix}$
CIFSSOWA	$\begin{pmatrix} 0.3988e^{i2\pi(0.4743)} \\ 0.5324e^{i2\pi(0.3719)} \end{pmatrix}$	$\begin{pmatrix} 0.5905e^{i2\pi(0.5480)} \\ 0.4095e^{i2\pi(0.4330)} \end{pmatrix}$	$\begin{pmatrix} 0.4732e^{i2\pi(0.5107)} \\ 0.5564e^{i2\pi(0.4043)} \end{pmatrix}$	$\begin{pmatrix} 0.6674e^{i2\pi(0.2176)} \\ 0.2702e^{i2\pi(0.4554)} \end{pmatrix}$	$\begin{pmatrix} 0.4467e^{i2\pi(0.6251)} \\ 0.3464e^{i2\pi(0.2443)} \end{pmatrix}$
CIFSSWG	$\begin{pmatrix} 0.5293e^{i2\pi(0.3850)} \\ 0.4707e^{i2\pi(0.3534)} \end{pmatrix}$	$\begin{pmatrix} 0.6435e^{i2\pi(0.4456)} \\ 0.3565e^{i2\pi(0.3331)} \end{pmatrix}$	$\begin{pmatrix} 0.4082e^{i2\pi(0.5226)} \\ 0.5918e^{i2\pi(0.4000)} \end{pmatrix}$	$\begin{pmatrix} 0.5856e^{i2\pi(0.3569)} \\ 0.3912e^{i2\pi(0.4300)} \end{pmatrix}$	$\begin{pmatrix} 0.5083e^{i2\pi(0.4044)} \\ 0.3994e^{i2\pi(0.3456)} \end{pmatrix}$





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CIFSSOWG	$(\frac{0.2781e^{i2\pi(0.4379)}}{0.6860e^{i2\pi(0.4004)}})$	$(\frac{0.4721e^{i2\pi(0.4095)}}{0.5279e^{i2\pi(0.5241)}})$	$(\frac{0.4198e^{i2\pi(0.3174)}}{0.6074e^{i2\pi(0.5259)}})$	$(\frac{0.5694e^{i2\pi(0.1692)}}{0.3793e^{i2\pi(0.5685)}})$	$(\frac{0.2980e^{i2\pi(0.4260)}}{0.4128e^{i2\pi(0.319)}})$
CIFSSHA	$(\frac{0.4536e^{i2\pi(0.4329)}}{0.4041e^{i2\pi(0.3534)}})$	$(\frac{0.5905e^{i2\pi(0.5480)}}{0.4095e^{i2\pi(0.4330)}})$	$(\frac{0.4213e^{i2\pi(0.5546)}}{0.5894e^{i2\pi(0.4384)}})$	$(\frac{0.6674e^{i2\pi(0.2176)}}{0.2702e^{i2\pi(0.4554)}})$	$(\frac{0.4467e^{i2\pi(0.6251)}}{0.3464e^{i2\pi(0.2443)}})$
CIFSSHG	$(\frac{0.3776e^{i2\pi(0.3728)}}{0.5735e^{i2\pi(0.3799)}})$	$(\frac{0.4721e^{i2\pi(0.3728)}}{0.5279e^{i2\pi(0.5241)}})$	$(\frac{0.3495e^{i2\pi(0.3812)}}{0.6582e^{i2\pi(0.5384)}})$	$(\frac{0.5694e^{i2\pi(0.1692)}}{0.3793e^{i2\pi(0.5685)}})$	$(\frac{0.2980e^{i2\pi(0.4260)}}{0.4128e^{i2\pi(0.319)}})$

Table 3: Score values

OPERATOR	$m_{SV}(C_1)$	$m_{SV}(C_2)$	$m_{SV}(C_3)$	$m_{SV}(C_4)$	$m_{SV}(C_5)$
CIFSSWA	-0.0677	0.2143	-0.0666	0.0630	0.3994
CIFSSOWA	-0.0312	0.2960	0.0232	0.1593	0.4811
CIFSSWG	-0.4049	-0.2017	-0.4787	-0.2547	0.1742
CIFSSOWG	-0.3704	-0.1703	-0.3961	-0.2091	-0.0081
CIFSSHA	0.2190	0.296	-0.0519	0.1593	0.4811
CIFSSHG	-0.2030	-0.1703	-0.4659	-0.2091	-0.0081

Table 4: Ranking Values

OPERATOR	Ranking Values
CIFSSWA	$C_5' > C_2' > C_4' > C_3' > C_1'$
CIFSSOWA	$C_5' > C_2' > C_4' > C_3' > C_1'$
CIFSSWG	$C_5' > C_2' > C_4' > C_1' > C_3'$
CIFSSOWG	$C_5' > C_2' > C_4' > C_1' > C_3'$
CIFSSHA	$C_5' > C_2' > C_1' > C_4' > C_3'$
CIFSSHG	$C_5' > C_2' > C_1' > C_4' > C_3'$





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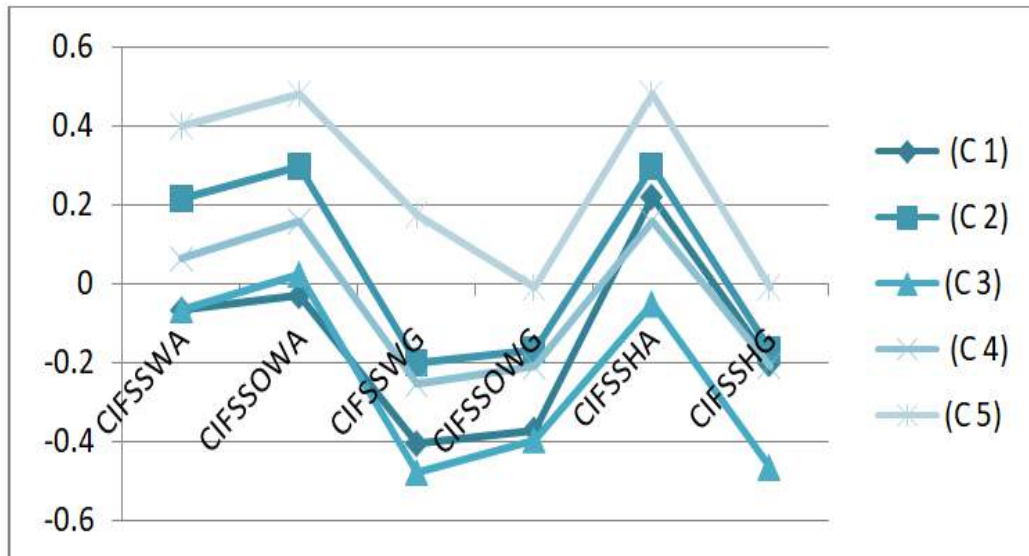


Figure 1: Graphical Expression of The Information In Table 3

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RESEARCH ARTICLE

Formulation and Evaluation of Polyherbal Tablets with Antimicrobial Activity

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ABSTRACT

The study aimed to formulate and test polyherbal tablets containing neem (*Azadirachta indica*), tulsi (*Ocimum sanctum*), turmeric (*Curcuma longa*), and ginger (*Zingiber officinale*) with the actions against microbes. Tablet preparation was done through wet granulation and evaluated in terms of physicochemical parameters, FTIR, and antimicrobial characteristics. The results of the formulation were satisfactory with respect to weight (0.395 ± 0.010 g), thickness (5.00 ± 0.25 mm), compactness (5.0 ± 0.2 kg/cm²), and friability ($0.1 \pm 0.01\%$). FTIR analysis showed that all ingredients are compatible without any significant chemical interactions. Antimicrobial activity showed better results for the combination formulation, where inhibition zones were 1.57 ± 0.057 mm (*Bacillus subtilis*) and 3.93 ± 0.665 mm (*Escherichia coli*), as compared to individual powder and a marketed tablet. The results indicated that phytoconstituents are synergistic, and together they can increase therapeutic efficacy. Also, the polyherbal tablets showed potential drug stability and treatment benefits as a safe alternative in the treatment of microbial infections.

Keywords: Polyherbal tablets, granulation, physicochemical, antimicrobial, alternative.



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INTRODUCTION

Global health is at risk from infectious diseases, which are treated with antibiotics and antiviral drugs. However, microbial resistance persists, leading to problems and recurring infections (1). The present trends for living a long and healthy life are fully reliant on the blend of multiple herbs in a specific proportion, which provides an appealing therapeutic outcome. This is because the strong phytochemical components of single plants are insufficient to attain the advantageous outcome (2,3). The polyherbal formulations are widely used due to their extensive therapeutic range, effectiveness at minimal doses, safety at elevated doses, and fewer side effects (4, 5). Ayurveda is recognized as one of the most beneficial systems in conventional medicinal practices because it incorporates various inherent components that address the key factors of illness by restoring balance and preventing future occurrences (6). This research study considered the preparation and assessment of polyherbal tablets using neem, tulsi, ginger, and turmeric. The combination of multiple herbs, which includes two or more herbs with various phytoconstituents having comparable or different therapeutic potentials. Neem (*Azadirachta indica*) is well known in traditional medicine due to its antimicrobial effects. Tulsi (*Ocimum sanctum*) has been found to have an adaptogenic effect and helps to reduce stress. Tulsi contains bioactive compounds like eugenol, ursolic acid, and carvacrol, which give it strong antimicrobial properties. Turmeric (*Curcuma longa*) has potential antimicrobial properties. Ginger (*Zingiber officinale*) has gingerol, shogaol, and zingerone compounds, which are the ones that make it have an antimicrobial effect (7, 8).

MATERIALS AND METHODS

Materials

Neem leaf powder, Tulsi leaf powder, Ginger stem powder, Turmeric stem powder, Water soluble starch (Sisco Research Laboratories Pvt Ltd, Maharashtra), Magnesium stearate (Sisco Research Laboratories Pvt Ltd, Maharashtra), Talc (Sisco Research Laboratories Pvt Ltd, Maharashtra), Microcrystalline Cellulose (Loba Chemie Pvt Ltd, Mumbai), Sodium Starch Glycolate (Loba Chemie Pvt Ltd, Mumbai), Amoxil (Zydus Corporate Park, Ahmedabad, Gujarat, India) were utilized for the research. The plants were identified and authenticated by Acharya Jagadish Chandra Bose Indian Botanical Garden, Shibpur, Howrah- 711103.

Microorganisms

Escherichia coli, a gram-negative bacterium, and *Bacillus subtilis*, a gram-positive bacterium, were collected from the microbiology lab of the department of Pharmaceutical Technology, Brainware University, Barasat, 700125.

Instruments

Electronic Weighing Balance (Vinayak Enterprise, Surat, Gujarat, India), Sieve of 12, 20 and 60 mesh (Sheetal Sales Corporation, Maharashtra, India), Hot Air Oven (Lab Care Equipments, New Delhi, India), Tablet Compression Machine (Kambert Machinery Co. Pvt Ltd, Gujarat, India), Friability Tester (Globe Scientific Instruments, Haryana, India), Monsanto Type Tablet Hardness Tester (M D Traders, Kolkata, India), Stainless Steel Digital Vernier Caliper (M D Traders, Kolkata, India), Laminar Air Flow Cabinet (Glowmax Engineers, Mumbai, India), Autoclave (Labgo, Baddi, India), Incubator (Vinayak Enterprise, Gujarat, India), Agar Well Diffusion Setup (Himedia Laboratories Pvt Ltd, India), FTIR (Bruker Germany Alpha II, Rudolf-Plank-Straße 27, 76275 Ettlingen, Germany) were employed in the study.

Formulations

Here, the significance of every component used in the development of a polyherbal tablet is emphasized. Rich in curcumin, turmeric possesses antibacterial qualities. The tablet's antimicrobial spectrum is strengthened with neem, which has antibacterial, antiviral, and antifungal properties and promotes skin with immunological health. Tulsi



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reduces microbial infections. Gingerol", which is present in ginger, acts as an antimicrobial agent. Microcrystalline Cellulose acts as a diluent, and water-soluble starch acts as a binder. By keeping materials from adhering to punches and dies, magnesium stearate, used as a lubricant, enhances surface finish and manufacturing efficiency. Talc works as a glidant that helps improve powder flow. Sodium Starch Glycolate facilitates the quick dissolution of tablets used as a disintegrant (9,10). The polyherbal tablet formula is shown in Table 1.

Preparation of Turmeric root powder

The process involved peeling, cleaning, grating, straining, drying, and sifting turmeric roots and storing them in a container.

Preparation of Neem leaf powder

The neem leaves were cleaned and dried over a period of two days to remove moisture content, and then they were crushed into a fine powder form and stored.

Preparation of Tulsi powder

The tulsi leaves were cleaned and dried for two days, ground into powder, and kept in a well-closed container.

Preparation of Ginger powder

The process involved peeling, cleaning, grating, straining, drying, and sifting ginger roots and storing them in a container.

Preparation method of polyherbal Tablet

To guarantee consistent particle size, herbal powders such as ginger, tulsi, neem, and turmeric powders were passed through a sieve with a size 60 during the herbal medication production process. After that, the binder (starch) solution was made with warm water, and microcrystalline cellulose with sodium starch glycolate was added to it. Then the wet mass was passed through a sieve with a size 12 to formulate granules and dried at 40–50°C, which were the steps in the wet granulation process. For even dispersion, the dry granules were subsequently sized by using sieve size 20 and combined with magnesium stearate and talc. To maintain consistent weight, hardness, and thickness, the granules were then compressed into tablets using a tablet punching machine (8 mm punch size). Figure 1 represents the preparation process of polyherbal tablets against bacterial infections (11).

Evaluation of Herbal Tablets**Organoleptic Characterization**

Physical features, including nature, colour, and odour, were meticulously assessed to determine the product's organoleptic characteristics (12).

Rheological properties determination

Physical characteristics, including untapped density (D'), tapped density (D), and angle of repose (θ), were used to assess the rheological characteristics of herbal powders before compression (13).

Bulk Density & Tapped Density

A pre-weighed quantity of powder was transferred into a 100 mL graduated cylinder without tapping or compacting. The volume occupied was noted, and the bulk density was calculated using the formula. By mechanically tapping a container, the rheological quality of a powder sample was ascertained, producing an improved bulk density called "tapped density." Until only slight alterations were observed, this procedure was repeated (14,15). Bulk Density (D') = Bulk volume/Mass, Tapped Density (D) = Tapped volume/Mass Hausner's ratio = D/D' , Carr's Index = $(D-D')/D \times 100$





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Angle of Repose

Its main role is to assess the flowability of powders by measuring the angle formed when piled. It was determined using the fixed funnel method. A funnel was fixed at a specific height, and the powder was allowed to flow freely through the funnel to form a cone on a flat surface. The height (h) and radius (r) of the resulting pile were measured, and the angle of repose (θ) was calculated using the formula (16).

$$\theta = \tan^{-1} \left(\frac{h}{r} \right)$$

FTIR Test

The FTIR (Fourier Transform Infrared Spectroscopy) analysis was performed on the formulated polyherbal tablets to confirm the compatibility of the herbal ingredients and to ensure that no significant chemical interaction occurred between the components during the compression process.

Thickness test

The thickness of the tablets was measured using a Vernier Caliper. 10 tablets were randomly selected, and their thickness was measured individually. It was calculated using the formula

$$\text{Mean Thickness} = \frac{\sum T_i}{n}$$

Where,

T_i = Thickness of each tablet.

n = Total number of tablets measured.

$\sum T_i$ = Sum of the thickness of all tablets.

Weight variation test

Twenty tablets were randomly selected and weighed individually. The individual weights were compared with the average weight to assess weight variation. The percentage deviation was calculated and evaluated in accordance with the Indian Pharmacopoeia (IP) specifications. It was calculated using the formula

$$\% \text{ Weight variation} = \left(\frac{\text{Individual Weight} - \text{Average Weight}}{\text{Average Weight}} \right) \times 100$$

Hardness test

10 tablets were selected randomly. Tablet hardness was determined using a Monsanto hardness tester, and the results were expressed in kg/cm^2 . The hardness can be expressed using the following formula

$$\text{Hardness (kg/cm}^2\text{)} = \frac{\text{Breaking Force (kg)}}{\text{Surface Area of Contact (cm}^2\text{)}}$$

Friability test

Tablet friability was assessed using a Roche Friabilator. Twenty tablets were initially weighed and placed in the friabilator, which was operated at 25 rpm for 4 minutes, completing a total of 100 rotations. After the test, the tablets were reweighed to calculate the percentage weight loss. The weight loss should not be more than 1.0%. It was calculated using the formula

$$\text{Friability (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \text{ Where,}$$

W_1 = Initial weight of the tablets before the test (usually in grams).

W_2 = Final weight of the tablets after the test (after dedusting).

Disintegration Test

Disintegration time is the period required for a tablet to break down into small particles and pieces by using a disintegration test apparatus. There is 900 mL of medium that is maintained at 37 °C in the basket. These were measured in time per tube, as there were six tablets per tube (5, 16).

Antimicrobial test

The antimicrobial activity of the formulated polyherbal tablets was evaluated using the agar well diffusion method. The test was conducted against selected microbial strains, including Gram-positive bacteria (e.g., *Bacillus subtilis*) and Gram-negative bacteria (e.g., *Escherichia coli*), and the marketed tablet was Amoxicillin. Mueller-Hinton agar and



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agar agar bacto were prepared and inoculated with the respective microorganisms using a sterile swab. Fresh microbial cultures were prepared in nutrient broth and incubated at 37 °C for 24 hours. After incubation, the zones of inhibition around the wells were measured in millimetres (15, 17).

Stability studies

The stability of the formulation was tested over a course of 6 months of storage at different temperatures. The formulation was filled in an air-tight foil bag, and the physical characteristics, such as colour, odour, hardness, etc., were inspected. They were also stored at different temperatures of $25 \pm 2^\circ\text{C}$ and relative humidity (RH) of $60 \pm 5\%$ or at $40 \pm 2^\circ\text{C}$ and $75 \pm 5\%$. After six months, the parameters of the samples were assessed, such as thickness, hardness, and friability (18).

RESULTS

Organoleptic Characterization

The colour of the tablets was green, the texture was smooth, and the shape was round.

Thickness test

Ten tablets were randomly selected, and their thickness was calculated using the formula. The average thickness was found to be 4.75mm to 5.25mm, and the result is shown in Table 2.

Weight variation test

Twenty tablets were individually weighed, with an average weight of 0.395g, which was found to be within the acceptable limits. The result is shown in Table 2.

Hardness test

Five tablets were tested, and the average hardness was found to be 5.0 kg/cm². The result is shown in Table 2.

Friability test

The friability test was conducted for 4 minutes, using a Roche friabilator to assess their ability to withstand mechanical stress during handling and transportation, and the percentage weight loss was 0.1%. The result is shown in Table 2.

Disintegration test

The disintegration test data is mentioned in Table 2 by using the disintegration apparatus.

FTIR test

The results of the FTIR analysis indicate that all the key functional groups of neem, tulsi, turmeric, and ginger remained the same in the tablet formulation. The presence of broad O-H stretching bands indicates phenolic groups, whereas the presence of the overlapping C-H, C=O, C = C, and C-O signals indicates that the aliphatic, carbonyl, aromatic, and ether functions are stable. Excellent overlap was also observed in the fingerprint region ($<900\text{ cm}^{-1}$), indicating no new bond formation and compatibility of ingredients in the formulation (Figure 2). Table 3 represents the peak assignment of individual herbal components and polyherbal formulation.

Antimicrobial test

The antimicrobial activity of the individual herbal extracts, the marketed tablet, and the combined polyherbal formulation was evaluated against *Bacillus subtilis* (Gram-positive) and *Escherichia coli* (Gram-negative). For *B. subtilis*, the combined formulation exhibited the highest zone of inhibition ($1.57 \pm 0.057\text{ mm}$), which was greater than any single extract or the marketed tablet, indicating superior efficacy. Among the individual extracts, neem ($1.20 \pm 0.173\text{ mm}$) and turmeric ($1.17 \pm 0.152\text{ mm}$) showed moderate activity, while Tulsi demonstrated the lowest inhibition



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(0.97 ± 0.057 mm). A similar trend was observed against *E. coli*, where the combined formulation displayed a significantly larger zone of inhibition (3.93 ± 0.665 mm) compared to all other samples. The marketed tablet (1.17 ± 0.057 mm) and Tulsi (1.17 ± 0.152 mm) showed the least activity, whereas neem (1.33 ± 0.057 mm) exhibited slightly higher inhibition among the individual extracts. The markedly enhanced activity of the combined formulation against both bacterial strains reflects a synergistic effect, suggesting that the multiple phytoconstituents from different herbs may interact positively to potentiate antimicrobial efficacy beyond the activity of individual components (Figure 3 & Table 4).

Stability Study

The polyherbal tablets showed smooth, uniform appearance with characteristic odour, no discoloration after accelerated study, acceptable weight variation, and hardness with proper disintegration. Stability studies results are shown in Table 5.

DISCUSSION

The objective of the current research was to develop and evaluate a polyherbal tablet that has action against bacterial infections. The parameters of post-compression evaluation, such as weight change (0.395 ± 0.010 g), thickness (5.00 ± 0.25 mm), hardness (5.0 ± 0.2 kg/cm²), disintegration (12 ± 2 min), and friability ($0.1 \pm 0.01\%$), were within the acceptable pharmacopoeia's range, which supported the mechanical strength and reproducibility of the formulation. The continuous green colour, smoothness, and roundness also showed that the prepared tablets were well organoleptically acceptable. The FTIR analysis revealed that there was no substantial chemical activity of the herbal constituents, indicating that the polyherbal blend was stable and compatible. The antimicrobial analysis indicated that the polyherbal formulation was more inhibitory, as evidenced by the results of Gram-positive (*Bacillus subtilis*, 1.57 ± 0.057 mm) and Gram-negative (*Escherichia coli*, 3.93 ± 0.665 mm) microorganisms than the individual and a commercially available tablet. The increased activity implies that there is synergy between the phytochemicals, especially flavonoids, terpenoids, alkaloids, and phenolic compounds present in the herbs that were chosen. Karole et al., (2019) and Paul et al., (2023) found that polyherbal formulations are more effective against microbes in comparison to single-herb preparations because they are multitargeted and interact synergistically (19,20). Curcumin and gingerol, obtained by hydrolyzing turmeric and ginger, have already been documented to have potent antimicrobial effects, and neem and tulsi provide immunomodulatory and antioxidant applicability (21). The accelerated stability analysis revealed no alterations in the colour, odour, hardness, and friability of the tablets in half a year, which proved that the tablets were robust and had a long shelf-life. This profile of stability is essential to large-scale development and clinical use. In general, the results of this study confirmed the design approach of using a single dosage of a neem, tulsi, turmeric, and ginger mixture to obtain anti-microbial activity.

CONCLUSION

The physical appearance, thickness, weight variation, hardness, friability, and disintegration time of a polyherbal tablet containing tulsi, ginger, turmeric, and neem extracts were all assessed. The tablet was successfully shown to be safer than chemical treatments. These results substantiated the existence of a synergistic effect of the phytoconstituents resulting in an optimistic antimicrobial activity. To improve quality and safety, more research is required.

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No conflicting interests are disclosed by the authors.

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Table 1. Formulation of Polyherbal Tablets

Ingredients	Quantity (gm)
Turmeric stem powder	7.5
Neem leaf powder	10
Tulsi leaf powder	5
Ginger stem powder	7.5
Starch (water Soluble)	5
Magnesium Stearate	1
Talc	1
Microcrystalline Cellulose	10
Sodium Starch Glycolate	3
Total	50

Table 2. Post-compression evaluation of Polyherbal Tablets

Test	Method Used	Observation (Mean ± SD)
Organoleptic Characterization	Visual inspection	Green colour, smooth texture, round shape
Thickness (n=10)	Vernier Calliper	5.00±0.25 mm
Weight Variation (n=20)	Electronic balance	0.395±0.010 g
Hardness (n=5)	Monsanto hardness tester	5.0±0.2 kg/cm ²
Friability	Roche friabilator, 4 min	0.1±0.01 %
Disintegration Test	Disintegration apparatus	12±2 min

Table 3. FTIR Peak Assignment of Individual Herbal Components and Polyherbal Tablet Formulation

Functional group / Assignment	Neem (cm ⁻¹)	Tulsi (cm ⁻¹)	Turmeric (cm ⁻¹)	Ginger (cm ⁻¹)	Tablet (cm ⁻¹)	Interpretation
O–H stretching (phenolic/alcohol)	~3320	~3340	~3305	~3315	~3330	Broad peak retained in all spectra → confirms phenolic groups present in formulation
C–H stretching (aliphatic –CH ₂ /–CH ₃)	2922, 2850	2920, 2852	2924, 2851	2921, 2850	2923, 2851	Aliphatic C–H bands overlap → no change in formulation
C=O stretching (carbonyl, ester)	1735	1718	1705	1720	1722	Neem/turmeric/ginger peaks appear in formulation → intact carbonyl groups
C=C stretching (aromatic, conjugated)	1605	1608	1625, 1605	1607	1620, 1608	Strong overlapping confirms stability of aromatic phytochemicals
Aromatic skeletal vibrations	1515	1518	1512	1517	1515	All spectra show retention of aromatic ring modes
C–O stretching (phenols, ethers)	1260–1025	1245–1050	1270–1210	1220–1105	1250–1050	Overlap across all → ether and phenolic C–O groups stable
Fingerprint region (C–H bending, mixed)	<900	<900	<900	<900	<900	Complex region overlaps well, showing no new bonds formed



**Table 4. Zone of inhibition (mm) of different herbal components and combined formulation against *B. subtilis* (Gram-positive) and *E. coli* (Gram-negative)**

Sample	<i>B. subtilis</i> (Gram-positive)		<i>E. coli</i> (Gram-negative)	
	Mean Value (mm)	± SD (mm)	Mean Value(mm)	± SD(mm)
Marketed Tablets	1.07	0.115	1.17	0.057
Turmeric	1.17	0.152	1.30	0.264
Ginger	1.13	0.057	1.27	0.057
Tulsi	0.97	0.057	1.17	0.152
Neem	1.20	0.173	1.33	0.057
Polyherbal Formulation	1.57	0.057	3.93	0.665

Values are expressed as mean ± standard deviation (n=3). Against *B. subtilis*, the combined polyherbal formulation showed the highest inhibition (1.57 ± 0.057 mm)

Table 5. Stability Study for Polyherbal Tablets

Test	Observation (Mean ± SD)	Observation (Mean ± SD) after 6 months
Organoleptic Characterization	Green colour, smooth texture, round shape	Green colour, smooth texture, round shape
Thickness (n = 10)	5.00±0.25 mm	5.00±0.25 mm
Weight Variation (n = 20)	0.395±0.010 g	0.395±0.010 g
Hardness (n = 5)	5.0±0.2 kg/cm ²	5.0±0.2 kg/cm ²
Friability	0.1±0.01 %	0.1±0.01 %
Disintegration test	12±2 min	11±1.5 min





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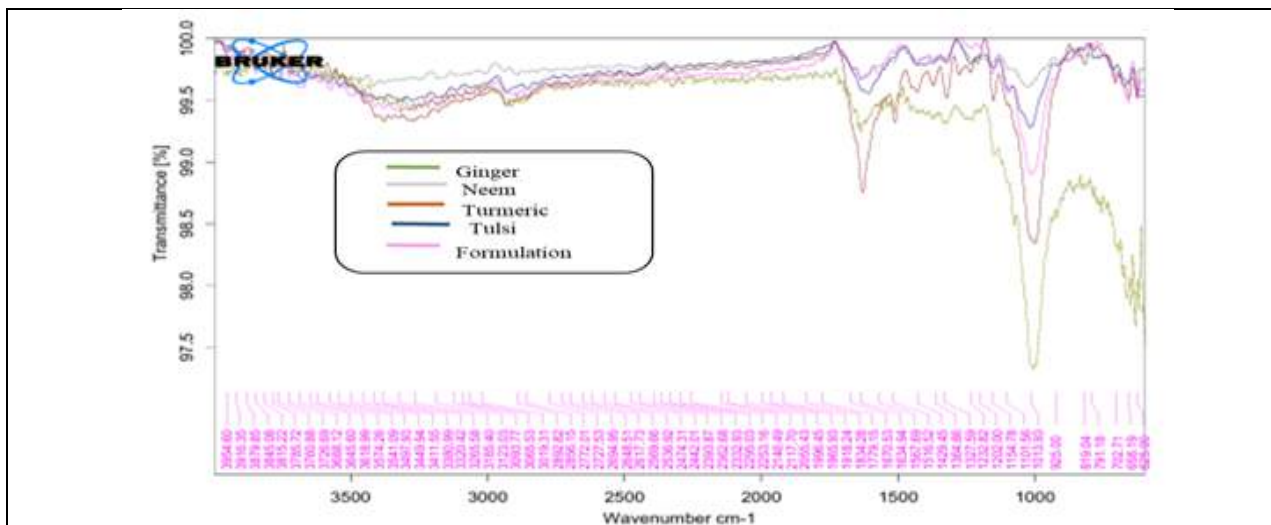
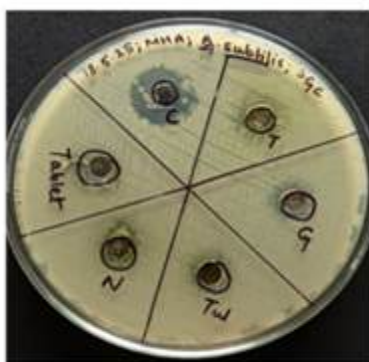


Figure 2. Observation of the FTIR analysis of herbal formulation



A



B

Figure 3. Antimicrobial activity of the combined polyherbal formulation compared with the marketed tablet: (A) Zone of inhibition against Gram-positive bacteria (*Bacillus subtilis*), (B) Zone of inhibition against Gram-negative bacteria (*Escherichia coli*)

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RESEARCH ARTICLE

Importance of Rasa of Ahara According to Various Seasons : An Answer to Dietary Disorders

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ABSTRACT

Enough solid evidences exist now a days to offer several fundamental strategies for healthy eating. They include emphasizing healthful unsaturated fats, whole grains, good protein foods and vegetables and multivitamins etc. as nutritional safety net while limiting the consumption of trans fats and saturated fats, highly refined grains and sugary beverages. Proper nutrition offers one of the most effective and least costly ways to decrease the burden of many diseases and their associated risk factors. Researches related to nutrition hold the keys in increasing our understanding of the cause of diet related disorders and its related comorbidities. Besides all these advancements, Ayurveda, a traditional system of medicine that originated thousands of years old, offers an insight about food and health based on certain unique conceptual as well as theoretical positions. In this article, we are discussing about intake of *Ahara* (food) depending on their taste (*Rasa*) and also according to various *Ritus* (seasons) according to Ayurveda. It states the importance of six tastes (*Shadrasas*) in *Ahara* and their judicial application according to various body types as well as seasons.

Keywords: *Rasa, Aahar, Ritu*, Season, Taste





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INTRODUCTION

According to Ayurveda, the best preventive medicine and support of the natural healing process is a diet and lifestyle specific to the constitutional needs of the individual and in line with the seasons and cycles of nature. Nutrition according to *Ayurveda* is different from conventional nutrition in a way that it is not caloric count only. Also, it states that one man's medicine can be another man's poison, Ayurveda validates this statement by enlightening about the diversity and *Doshik* influence of the six different tastes or the *ShadRasas*[1] in *Ahara*. In *Ayurveda*, diet forms the important component of life as it is included in the *Tri-Upastambha* [2] (three pillars of life) along with *Nidra* and *Brahmcharya*. It is also mentioned in *Ayurveda* that any material in the universe, is composed of five basic elements, the *PanchaMahabhootas*[3], namely *Prithvi* (Earth), *Apa* (Water), *Teja* (Fire), *Vayu* (Air) and *Akasha* (Ether). The *Tridoshas* (Biological Humors) i.e., *Vata*, *Pitta* & *Kapha* which constitutes the body are also made up of these five elements. So according to the above statement, each food article has either *Dosha* aggravating or pacifying or balancing action on human body[4]. To maintain the homeostasis of *Doshas* (health), *Ayurveda* has described specific diet according to various *Ritus* (seasons) also. The first step to learn Ayurvedic nutrition is to learn about tastes and *Rasas*. *Rasa* is that subtle component of the food which is perceived mainly in dry and fresh stages of the substance and in the beginning and end of the gustatory processes. *Madhur* (sweet), *Amla* (sour), *lavana* (salt), *Tikta* (bitter), *Katu* (pungent) and *Kasaya* (astringent) are the six *Rasas* (tastes) present in the different food substances, the daily intake of which regulates the elements and *doshas* of our body through their specific effects on the various body tissues [5]. According to *Ayurveda*, these various tastes result into nurturing and regulating various actions in the body system[6]. It is therefore recommended to take a wholesome diet means *Shadrasahara* according to Ayurveda to stay healthy.

Different type of Rasas (taste)

Sweet taste (*MadhuraRasa*)

The sweet taste as in wheat, rice, potatoes is believed to increase the general body resistance against diseases. All the carbohydrates and pulses are the examples of *Madhur Rasa*. This specific taste helps to nourish all the body tissues and as a consequence is the vital energy reserve of the body and mind. This taste aids in increasing not only immunity, but also the general health of an individual and keeps aging at a distance. *MadhuraRasa* is conducive of life span, pleasing to six sense organs, promotes strength and lusture, pacifies thirst and heat, beneficial for skin, hair, throat and enhances strength in the body. It promotes healing of wounds and acts as stabilizer and vitalizer[7]. Though the major portion of our food must be *Madhura Rasa* in the form of *Chapati*, rice *Dal* etc, it should not be consumed in excess. In excess it can produce obesity, laxity, lassitude, over sleep, heaviness, loss of desire for food, decreased appetite, dyspnoea, cough, coryza, fever with shivering, hardness in bowels, sweetness in mouth, nausea, vomiting[8] and thyroid disorder like goitre etc.

Sour Taste (*Amla Rasa*)

Sour taste increases the digestive power. The example of it is *Amla*, lemon, vinegar, tomatoes and citrus fruits like oranges, *Mausami*, kiwi etc. According to modern science, they are rich in vitamin C and hence enhance immunity. According to *Ayurveda*, *AmlaRasa* makes the food *Hridya* (palatable) and stimulates the excretion of enzymes well enough to aid the digestion process. All pickles, chutneys and condiments are actually having sour tastes and hence makes the food tasty and produces a feeling of satiety. It exhibits a sharp taste, which stimulates salivation and increases the appetite. It promotes strength and stability of tissues. It regulates peristalsis and downward movement of *Vata* and helps in the digestion of food. It awakes mind, makes the sense organs alert, promotes strength, moisten and digest food, gives satisfaction, and is light, hot and unctuous[9]. Though endowed with so many qualities, if used in excess it sensitises teeth, causes vertigo, thirst, liquefies *Kapha*, aggravates *Pitta*, produces inflammation and itching in emaciated and debilitated person, leads to suppuration of wounds, skin diseases like pustules, and cause burning sensation in throat, chest and cardiac region[10]. So, it must be used in restricted quantity only.





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Salty Taste (Lavana Rasa)

The salty taste imparts a relish for the food and provides softness to the body parts. Like the sour taste, it enhances the enzyme secretions in the digestive tract and helps in digestion. It is digestive, lubricating, appetizer, enhances salivation, expectorant, laxative, removes stiffness, cleanses channels and softens all the body parts[11]. Though having so many qualities, excessive intake of the salty taste leads to increase in the body heat, burning sensation in the body, untimely greying and loss of hair, wrinkles, excessive thirst, impotency and various skin and gastric disorders. Therefore, must be taken in limited amount only[12].

Pungent Taste (KatuRasa)

It is very hot taste as in Chilli, green pepper, black pepper, mustard, ginger, garlic and onion. Pungent taste improves digestion and stimulates the digestive fire (*Agni*) in the body. It improves circulations and clears the channels. It has an anti-spasmodic action. It causes instant watering of eyes and nose if consumed directly. It increases absorption of digested food, helps in healing of wounds, checks the coagulation of blood and opens the channels. Though having so many properties if used singly and excessively damages sexual potency, causes mental confusion, malaise, depression, fainting, feeling of giddiness, burning in throat, loss of strength, thirst, tremors etc[13].

Bitter Taste (TiktaRasa)

It is the taste present in bitter gourd, *Methi* etc. and produces a very unpleasant taste in mouth. In spite of its unpleasant taste, it is important to incorporate this taste in our meal as it is anti-infectious and also detoxifies the body^[14]. It is also, anthelmintic, alleviates burning sensation and itching, provides firmness to skin and muscles, antipyretic, appetiser etc., it helps in toning of tissue and also cleanse the blood and therefore helps to alleviate any kind of skin disorder. Bitter food consumed in excess can produce adverse effects on the body like loss of strength and energy and produces emaciation by tissue depletion, malaise, mental confusion, giddiness, dryness of mouth etc.

Astringent Taste (KashayaRasa)

It is like the taste as present in salads and unripe fruits like bananas and guavas. Nutmeg is another example of this taste. It gives an immediate drying sensation in mouth on consumption. It purifies blood by its anti-inflammatory effects and tones the tissues due to astringent effect. It also helps in healing. Excess use of astringent food causes choking sensation and difficulty in speaking. It causes constipation along with distension of abdomen^[15]. It can produce flatulence, choking in voice, slowing of movement of fluids in channels, blackish hue (due to loss of complexion), impotency, gas formation during digestion and malaise etc. Prolonged consumption may lead to emaciation of the body, so must be consumed in limited quantity only.

Regimen According to Different Season

Of the six rasas, *Madura* Rasa is produced by the predominance of *water element*, *Amla* by the earth and fire. *Lavana* that of water and fire, *Katu* that of air and fire element, *Tikta* that of air and ether, and *Kashaya* by that of air and earth^[16]. Thus, the six forms of manifestations of *Rasa* takes place according to the quantum of *Mahabhutas* like various complexion and shapes in plants and animals. The dominance and depletion of *Mahabhutas* is possible due to time factor having six seasons. So, *Rasa* intake should be according to different seasons. According to Ayurveda a year consists of six seasons i.e. *Shishir* (winter), *Basant* (spring), *Grishama* (summer), *Varsha* (rainy), *Sharad* (autumn), *Hemant* (late autumn).

Shishir Ritu (Winter Season)

In the month of December and January, when the cold winds are blowing and the sun rays are also not too hot, *Agni* inside the body is high so as to overcome the cold. Body needs good amount of caloric food so as to keep the body warm and *Agni* up. So, *Madhura* and *Amla* *Rasa* are indicated so as to keep the *Doshas* in order^[17]. That's why the season is called healthy season as what we eat is digested immediately and thus most of the tissue nourishing food can





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be taken at this time. Nuts, jaggery, panjiri, laddoos and other sweets are recommended in addition to the normal diet so as to keep the metabolism up. Also, enough ghee must be taken to nullify the drying effect of cold winds. *AmlaRasa* in the form of *Amla* in *Chyavanprash* is beneficial. *Kanji* is another *amla rasa* preparation to keep the *Agni* up and to nourish the tissues.

Basant Ritu(Spring Season)

During Basant Ritu, the accumulated *Kapha* in mid-January to mid-march in winters irritated by the strong rays of the sun, flows into body channels and disturbs the body heat and thus causes many diseases[18]. Excess of accumulated *Kapha* in channels is mobilised and cold, cough, chest congestion, post nasal discharge and other *Kapha* related problems starts. Moreover, due to blossoming of different kinds of flowers allergic reactions in the form of allergic rhinitis, bronchitis, sinusitis etc. are commonly seen. So, the main aim is to cleanse the channels of accumulated *Kapha* and also to keep the *Agni* up so as to fight against superimposed infections etc. So, the advised *Rasa* are *Katu*, *Tikta* and *Kashaya*. *Madhura* and *lavanaRasa* must be avoided as these favours the accumulation of *Kapha*. *KatuRasa* food like ginger, black pepper is highly beneficial to cleanse the channels. *TiktaRasa* like *Methi* is also good to dry up the excess *Kapha*. Turmeric is also effective. Hence, during spring evacuative measures like vomiting etc. should be followed and heavy, sour, fatty and sweet diet as well as day sleep should be avoided.

Grisham Ritu(Summer Season)

During summer one has to consume foods which are sweet in taste, oily, warm and light to digest in the form of liquids. *Rasala*[19] (a drink prepared with milk and curd), sugars, milk, lassi and other dairy products, rice, vegetables soup etc. are recommended. Addition of sugar to all varieties of food is advised. Pungent, alkaline and sour foods should be avoided.

Varsha Ritu(Rainy Season)

During rainy season, *agni* is vitiated and *Vata* is in surge[20] and to pacify it, *Madhura*(sweet), *Amla*(sour) and *lavana*(salt) foods are to be consumed. In this season, curds, hot foods, meat from animals, wheat, rice, black gram should be consumed. Rice gruel or *Kheer* is effective in pacifying *Vata* and therefore is a tradition to consume *Kheer* during all the fasts in *VarshaRitu*. Eating dry foods should be prohibited. *Amla* and *lavanRasas* must be used in restricted quantity in this season.

Sharad Ritu(Autumn Season)

During post monsoon period, it is advised to consume ghee, food substances having sweet, bitter and astringent taste, easily digestible foods, milk, sugarcane juice, salts, less quantity of flesh from wild animals, wheat, barley, green gram, rice etc. [21] Curds, sour, pungent and spicy food should be prohibited during this season. Sugarcane juice, green gram and boiled milk are the things one must adopt for his better health during post monsoon period.

Hemant Ritu(Late Autumn Season)

In this season person should consume food in early hours of the day[22]. Food items during this season should include sour, sweet and saltish taste like wheat, sugarcane products, rice, black gram, freshly cultivated cereal food, sesame seeds, musk, saffron, oily and fatty foods etc.

DISCUSSION

According to *Ayurveda* a person can be healthy if all the *Doshai*. *Vata*, *Pitta* and *Kapha* remains in *Samyavastha* (homeostatic condition) and disharmony in the doshas may result in *Roga*(disease). Because *Dosha* keeps changing according to the various seasons, so accordingly person should follow a diet and lifestyle according to the different seasons to keep the *Doshas* in equilibrium. Depending on this analytical reasoning, ancient sages set up regimen according to the various seasons to remain healthy by preventing the disease to occur. In modern medicine doctors advise a strict diet and regular exercises along with other disease controlling drugs. But with the knowledge of





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Shadras as and their judicious use according to various seasons one can surely avoid various diseases and maintain the harmony of *Tridoshas* so as to stay healthy ever.

CONCLUSION

Different *Rasas* or tastes in the food have their individual importance in terms of health and nutrition and thereby nurturing all the body tissues in an optimum way so as to attain the longevity is the aim. All the *Rasas* i.e. sweet, sour, salty, bitter, pungent and astringent have specific effect on different doshas and also on different body functions. One must learn about their body type according to *Ayurveda* means the *Doshik* dominance in their body and then must follow dietary recommendations according to *Shadras* so as to maintain the optimum balance of doshas in the body. A *Vata* body type person needs more of the tissue forming *Rasa* like sweet, sour, salty to combat dryness in their body. A *Pitta* person must avoid sour, salty and pungent taste as these *Rasa* can provoke *Pitta* and cause inflammation in the body. Sweet, bitter and astringent taste are good for them to keep the *Pitta* in balance. *Kapha* type people have tendency to put on the weight due to slow metabolism and hence bitter, pungent and astringent are good for them to keep the metabolism up. Similarly, the dominance of *Doshas* changes with seasons as discussed, and thus diet must be changed accordingly. In summer and rainy season there is more of *Vata* in the system and hence the *Vata* pacifying *Rasas* like sweet, sour and salty are beneficial. In winter and spring season the *Kapha* is more in the system and thus bitter, pungent and astringent works well. Autumn season favours the increase of *Pitta* in the system and thus *Pitta* pacifying *Rasas* sweet, bitter and astringent are suggested. So, one must follow the principle of *Shadras* in day to day life as mentioned in *Ayurveda* according to various *Ritus* (season) as well as according to one's own body type to stay healthy.

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RESEARCH ARTICLE

gb - Chromatic Number of Some Standard Product Graphs

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ABSTRACT

The gb -chromatic number for a graph is defined as a proper colouring of a graph G , which combines the smallest cardinality of geodetic set and b -chromatic set of graph G whereas the combination of this is defined as gb -chromatic number and it is denoted as $\varphi_{gb}(G)$. In this paper, the gb -chromatic number of product graphs are obtained and we extend few results of gb -chromatic number for product graph of certain existing graphs as path graph and cycle graph.

Keywords: Geodetic, gb -Chromatic, Cartesian product, Corona product, Tensor product, Co-normal product, Lexicographic product

INTRODUCTION

All the graphs used in this study are undirected, simple, and finite. The order and size of G are n and m for any graph G with edge set $E(G)$ and vertex set $V(G)$ [2, 3]. The shortest distance between two vertices in $V(G)$, x_1 , and x_2 , determines the minimum size of $x_1 - x_2$ pathways in G . The term "geodesic of G " refers to an $x_1 - x_2$ path of size $d_G(x_1, x_2)$. We define $I_G(x_1 - x_2)$ as the collection of geodesics of G 's $x_1 - x_2$ vertices. The vertex is said to reside on the $x_1 - x_2$ geodesic if c is an inner vertex of $\mathcal{P}$. The vertices of the limited interval $I(x_1, x_2)$ are all situated on a geodesic of G between x_1 and x_2 . Consider a non - empty set $I(S) = \bigcup_{x_1 x_2 \in S} I(x_1 x_2)$. If G is connected graph, thus S is a geodetic set $g(S)$ such that $I(S) = V(G)$ [1,7]. The geodetic number $g(G)$ defines the least cardinality S of G [4,5,6]. A k - coloring of a G is a division of V into independent sets of G with $\mathcal{P} = \{v_1, v_2, v_3, \dots, v_k\}$. The chromatic number $\chi(G)$ of G is the minimum cardinality of k for which G has a k - coloring. The largest positive integer k such that G allows a proper k -





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coloring in which every color class has a representation adjacent to at least one vertex in each of the other color classes is the graph's b – chromatic number $\phi_b(G)$ of G [8]. In general, gb-chromatic number is both geodetic set and b-chromatic set. Here the gb-chromatic number for some standard product graphs such as Cartesian product, Corona product, Tensor product, Co-normal product, Lexicographic product as path graph and cycle graph has been covered [9,10].

gb Chromatic Number on Cartesian product graph on path graph with path graph

Let us consider $\mathcal{P}_2 = \{v_1, v_2\}$ and $\mathcal{P}_3 = \{u_1, u_2, u_3\}$. The Cartesian product of $\mathcal{P}_2 \otimes \mathcal{P}_3$ is defined as $\{(v_1u_1), (v_1u_2), (v_1u_3), (v_2u_1), (v_2u_2), (v_2u_3)\}$ which is 2 chromatic of b-colourable . (i.e.) We colour the vertices as C_1 for $\{(v_1u_1), (v_1u_3), (v_2u_2)\}$ and colour C_2 for $\{(v_1u_2), (v_2u_1), (v_2u_3)\}$.

The geodetic set of the Cartesian product of $\mathcal{P}_2 \otimes \mathcal{P}_3$ is $g(S) = \{(v_1u_1), (v_2u_3)\}$ which is the minimum gb chromatic number. (i.e.) The set $g(S)$ satisfies both geodetic set and b-chromatic set.

Hence $\phi_{gb}(\mathcal{P}_2 \otimes \mathcal{P}_3) = 2$.

Theorem

For the Cartesian product of path graph $\mathcal{P}_2$ with the path graph $\mathcal{P}_n$ when $n > 2$ the gb- chromatic number is given by

$$\phi_{gb}(\mathcal{P}_2 \otimes \mathcal{P}_n) = \begin{cases} 2, & \text{for } n = 3 \\ 3, & \text{for } n > 3 \end{cases}$$

Proof

Let G be the path graph of $\mathcal{P}_2 \otimes \mathcal{P}_n$, $n > 3$ where $\mathcal{P}_2 = \{v_1, v_2\}$ and $\mathcal{P}_n = \{u_1, u_2, u_3, \dots, u_n\}$.

The Cartesian product $\mathcal{P}_2 \otimes \mathcal{P}_n$ is given by

$$\mathcal{P}_2 \otimes \mathcal{P}_n = \{(v_1u_1), (v_1u_2), (v_1u_3), \dots, (v_1u_n), (v_2u_1), (v_2u_2), (v_2u_3), \dots, (v_2u_n)\}$$

Now, $g(S) = \{(v_1u_1), (v_2u_n)\}$ is the minimum geodetic set of $\mathcal{P}_2 \otimes \mathcal{P}_n$ and also $\mathcal{P}_2 \otimes \mathcal{P}_n$ is 3 chromatic of b-colouring.

That is we colour the vertices in such way that if n is even (v_1u_1) receive colour C_1 , (v_1u_n) receive colour C_2 and the neighbourhood vertex (v_1u_2) is coloured by C_3 and the remaining vertices are coloured by using proper colouring.

Similarly, when n is odd (v_1u_1) receive colour C_2 , (v_1u_n) receive colour C_1 and the neighbourhood vertex (v_1u_2) is coloured by C_3 and the remaining vertices are coloured by using proper colouring.

The b-colouring is given by $\phi_b = \{(v_1u_1), (v_1u_2), (v_1u_n)\}$.

Therefore, $g(S) \cup \phi_b = \{(v_1u_1), (v_1u_2), (v_1u_n)\}$ be the minimum colour gb-colouring of the graph $\mathcal{P}_2 \otimes \mathcal{P}_n$

Therefore $\phi_{gb}(\mathcal{P}_2 \otimes \mathcal{P}_n) = 3$.

gb- Chromatic Number on Lexicographic Product on path graph with path graph

Let us consider $\mathcal{P}_2 = \{v_1, v_2\}$ and $\mathcal{P}_3 = \{u_1, u_2, u_3\}$. Then the Lexicographic product of $\mathcal{P}_2 \bullet \mathcal{P}_3$ is defined as $\{(v_1u_1), (v_1u_2), (v_1u_3), (v_2u_1), (v_2u_2), (v_2u_3)\}$, which is 6 chromatic of b-colouring.

We colour the vertex (v_1u_1) by C_1 , (v_1u_2) by C_2 , (v_1u_3) by C_3 , (v_2u_1) by C_4 , (v_2u_2) by C_5 , (v_2u_3) by C_6 .

The geodetic set of the Lexicographic product is $\mathcal{P}_2 \bullet \mathcal{P}_n$ is given by

$g(S) = \{(v_1u_1), (v_1u_2), (v_1u_3), (v_2u_1), (v_2u_2), (v_2u_3)\}$, which is minimum gb-chromatic.

Hence $\phi_{gb}(\mathcal{P}_2 \bullet \mathcal{P}_n) = 6$.

Theorem

For the Lexicographic product of two paths graphs $\mathcal{P}_2$ and $\mathcal{P}_n$, the gb chromatic number is given by

$$\phi_{gb}(\mathcal{P}_2 \bullet \mathcal{P}_n) = \begin{cases} \frac{n}{2} + 3, & \text{if } n \text{ is odd} \\ \frac{(n+1)}{2} + 2, & \text{if } n \text{ is even} \end{cases}$$

Proof

Let us consider the vertices of $\mathcal{P}_2 = \{v_1, v_2\}$ and the vertices of $\mathcal{P}_n = \{u_1, u_2, u_3, \dots, u_n\}$.

Let G be Lexicographic product path graph for $\mathcal{P}_2$ and $\mathcal{P}_n$ denoted by $\mathcal{P}_2 \bullet \mathcal{P}_n$, for $n > 3$.

The lexicographic product is given by

$\mathcal{P}_2 \bullet \mathcal{P}_n = \{(v_1u_1), (v_1u_2), (v_1u_3), \dots, (v_1u_n), (v_2u_1), (v_2u_2), (v_2u_3), \dots, (v_2u_n)\}$.





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The graph $\mathcal{P}_2 \bullet \mathcal{P}_n$ is 4 chromatic of b-colouring.

Now $g(S) = \{(v_1u_1), (v_1u_3), (v_1u_n)\}$

When n is even the geodetic set S is given by $S = \{(v_1u_1), (v_1u_3), (v_1u_n)\}$ which is minimum. i.e. The set S receives only 2 colours C_1 and C_2 .

By adding 2 vertices of different colours C_3 and C_4 to the set S , it becomes a geo chromatic set.

That is $S_c = S \cup \{2 \text{ vertices with different colours}\}$ will be a minimum gb -chromatic set, which is given by

$$\varphi_{gb}(\mathcal{P}_2 \bullet \mathcal{P}_n) = \frac{(n+1)}{2} + 2.$$

When n is odd the geodetic set S receives same colour C_1 , so adding the remaining colours C_2, C_3, C_4 to $g(S)$. Therefore

$$\varphi_{gb}(\mathcal{P}_2 \bullet \mathcal{P}_n) = \{S \cup (v_1u_2), (v_2u_1), (v_2u_{n-1})\}.$$

That is vertex v_1u_2 is coloured by C_2 , v_2u_1 by C_3 and v_2u_{n-1} by C_4 .

Therefore it becomes a gb -chromatic set given by $\varphi_{gb}(\mathcal{P}_2 \bullet \mathcal{P}_n) = \frac{n}{2} + 3$

gb-Chromatic Number on Tensor Product graph on path graph with path graph

The gb -chromatic number for the Tensor product graph $\mathcal{P}_2 \times \mathcal{P}_n$ does not exist.

In the graph $\mathcal{P}_2 \times \mathcal{P}_n$ we find the Tensor product for the given $G_1 = \mathcal{P}_2$ and $G_2 = \mathcal{P}_n$ for $G_2 \times G_n$. Whereas the graph $G_2 \times G_n$ form a disconnected graph

Thereby we cannot find a u - v path in the graph $G_2 \times G_n$. Therefore the graph $G_2 \times G_n$ does not exist for Tensor product

Let us consider the cycle graph C_3 where $V(C_3) = \{v_1, v_2, v_3\}$ and the path graph $V(\mathcal{P}_2) = \{u_1, u_2\}$. The Corona product of $C_3 \circ \mathcal{P}_2$ defined as

$$V(C_3 \circ \mathcal{P}_2) = \{v_1, v_2, v_3\} \cup \{u_1, u_2\} \cup \{u'_1, u'_2\} \cup \{u''_1, u''_2\} \text{ which is 3 chromatic of b-colourable.}$$

The geodetic set of the Corona product of $C_3 \circ \mathcal{P}_2$ is

$$g(S) = \{u_1, u_2, u'_1, u'_2, u''_1, u''_2\} \text{ which is the minimum } gb \text{ chromatic number.}$$

(i.e.) The set $g(S)$ satisfies both geodetic set and b-chromatic set.

$$\text{Hence } \varphi_{gb}(C_3 \circ \mathcal{P}) = 6.$$

Theorem:

For the corona product of gb -chromatic number for path graph $\mathcal{P}_n$ and cycle graph C_3 is given by

$$\varphi_{gb}(C_3 \circ \mathcal{P}_n) = \begin{cases} \frac{3n+6}{2}, & \text{if } n \text{ is even} \\ \frac{3n+3}{2}, & \text{if } n \text{ is odd} \end{cases}.$$

Proof

Consider the cycle graph C_3 where $V(C_3) = \{v_1, v_2, v_3\}$ and the path graph $\mathcal{P}_n$ where $V(\mathcal{P}_n) = \{u_1, u_2, u_3, \dots, u_n\}$.

$$\text{Let } V(C_3 \circ \mathcal{P}_n) = \{v_1, v_2, v_3\} \cup \{u_1, u_2, u_3, \dots, u_n\} \cup \{u'_1, u'_2, u'_3, \dots, u'_n\} \cup \{u''_1, u''_2, u''_3, \dots, u''_n\}.$$

By definition of corona graph every vertex of C_3 is adjacent to every vertex of path $\mathcal{P}_n$, i.e. every vertex of u_i is adjacent with v_1 , u'_i is adjacent to v_2 and u''_i is adjacent with v_3 for $i=1, 2, 3, \dots, n$.

Let us assign the 4 colouring for $C_3 \circ \mathcal{P}_n$ as b-chromatic, i.e. for u_1 the colour is C_3 , for u_3 color C_2 , for u_2 colour C_4 and u'_1 colour C_1 . The remaining vertices are coloured by proper colouring.

Thus the geodetic set $g(S)$ of $C_3 \circ \mathcal{P}_n$ is $\{u_{2i-1}, u'_{2i-1}, u''_{2i-1}\}$ for odd and $\{u_{2i-1}, u_n, u'_{2i-1}, u'_n, u''_{2i-1}, u''_n\}$ for even which is the minimum geodetic set and b-chromatic set.

Therefore, when n is even the gb -chromatic number of $\varphi_{gb}(C_3 \circ \mathcal{P}_n)$ is $\frac{3n+6}{2}$ and for odd is given by $\frac{3n+3}{2}$.

gb Chromatic Number on Co-normal product graph on path graph with path graph

Let us consider $\mathcal{P}_4 = \{v_1, v_2, v_3, v_4\}$ and $\mathcal{P}_2 = \{u_1, u_2\}$. The Co-normal product of $\mathcal{P}_2 * \mathcal{P}_3$ is defined as $\{(v_1u_1), (v_1u_2), (v_2u_1), (v_2u_2), (v_3u_1), (v_3u_2), (v_4u_1), (v_4u_2)\}$

$$\text{Now } g(S) = \{(v_1u_1), (v_3u_1), (v_4u_1)\}.$$

Now, $g(S)$ is the minimum geodetic set of $\mathcal{P}_4 * \mathcal{P}_2$ and also $\mathcal{P}_4 * \mathcal{P}_2$ is 4 chromatic of b-colouring.

(i.e.) We colour the vertices as C_1 for (v_1u_1) , (v_3u_1) and colour C_3 for (v_4u_1) . The set S receives only 2 colours C_1 and C_3





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The geodetic set of the Cartesian product of $\mathcal{P}_4 * \mathcal{P}_2$ is $g(S) = \{(v_1u_1), (v_2u_3)\}$ which is the minimum gb chromatic number. The b-chromatic is given by

$$\phi_b(\mathcal{P}_4 * \mathcal{P}_2) = \{(v_1u_1), (v_3u_1), (v_4u_1), (v_1u_2), (v_4u_2)\}.$$

By adding 2 vertices of different colours C_2 and C_4 to the set S , it becomes a geo chromatic set.

$$\text{Therefore } \phi_{gb}(\mathcal{P}_4 * \mathcal{P}_2) = S \cup \phi_b = \{(v_1u_1), (v_3u_1), (v_4u_1), (v_1u_2), (v_4u_2)\}.$$

$$\text{Hence } \phi_{gb}(\mathcal{P}_4 * \mathcal{P}_2) = 5$$

Theorem:

For the Co-normal product of two paths graphs $\mathcal{P}_4$ and $\mathcal{P}_n$, the gb chromatic number is given by $\phi_{gb}(\mathcal{P}_4 * \mathcal{P}_n) = 7$ for $n > 2$.

Proof

Consider the cycle graph $\mathcal{P}_4$ where $\mathcal{P}_4 = \{v_1, v_2, v_3, v_4\}$ and the path graph $\mathcal{P}_n$ where

$$V(\mathcal{P}_n) = \{u_1, u_2, u_3, \dots, u_n\}.$$

Let G be Co-normal product path graph for $\mathcal{P}_4$ and $\mathcal{P}_n$ denoted by $\mathcal{P}_4 * \mathcal{P}_n$, for $n > 2$.

The co-normal product is given by

$$\mathcal{P}_4 * \mathcal{P}_n = \{(v_1u_1), (v_1u_2), (v_1u_3), \dots, (v_1u_n), (v_2u_1), (v_2u_2), (v_2u_3), \dots, (v_2u_n), \\ (v_3u_1), (v_3u_2), (v_3u_3), \dots, (v_3u_n), (v_4u_1), (v_4u_2), (v_4u_3), \dots, (v_4u_n)\}$$

The graph $\mathcal{P}_4 * \mathcal{P}_n$ is 5 chromatic of b-colouring.

$$\text{Now } g(S) = \{(v_1u_1), (v_3u_1), (v_1u_n), (v_3u_n)\}.$$

Now, $g(S)$ is the minimum geodetic set of $\mathcal{P}_4 * \mathcal{P}_n$ and also $\mathcal{P}_4 * \mathcal{P}_n$ is 5 chromatic of b-colouring. That is we colour the vertices in such way that,

If n is odd $(v_1u_3), (v_3u_1)$ receive colour C_1 , $(v_1u_n), (v_3u_n)$ receive colour C_3 and the neighbourhood vertex (v_1u_2) is coloured by C_2 , (v_2u_2) by C_4 , (v_3u_2) by C_5 and the remaining vertices are coloured by proper colouring.

Similarly, when n is even $(v_1u_3), (v_3u_1)$ receive colour C_1 , $(v_1u_n), (v_3u_n)$ receive colour C_2 and the neighbourhood vertex (v_1u_2) is coloured by C_2 , (v_2u_2) by C_4 , (v_3u_2) by C_5 and the remaining vertices are coloured by proper colouring.

The b-colouring is given by $\phi_b = \{(v_1u_1), (v_3u_1), (v_1u_2), (v_2u_2), (v_3u_2), (v_1u_n), (v_3u_n)\}$.

Therefore, $g(S) \cup \phi_b = \{(v_1u_1), (v_3u_1), (v_1u_2), (v_2u_2), (v_3u_2), (v_1u_n), (v_3u_n)\}$ be the minimum gb-colouring of the graph $\mathcal{P}_4 * \mathcal{P}_n$

$$\text{Therefore } \phi_{gb}(\mathcal{P}_4 * \mathcal{P}_n) = 7.$$

CONCLUSION

In this work, we have found few results about the gb-chromatic number for some standard product graphs like Cartesian product, Corona product, Tensor product, Co-normal product, and Lexicographic product for path graph with path and cycle graphs with path. This concept can further be extended to other product graphs and general graph classes.

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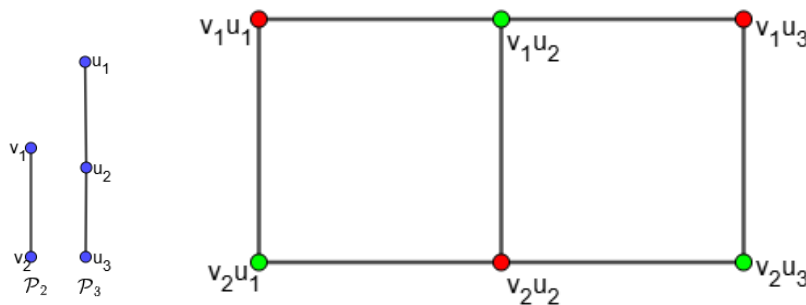
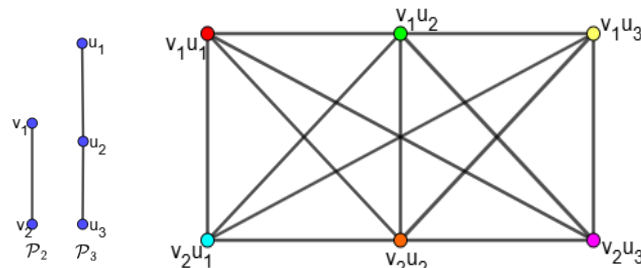
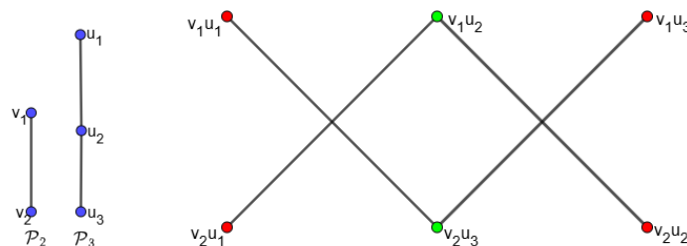
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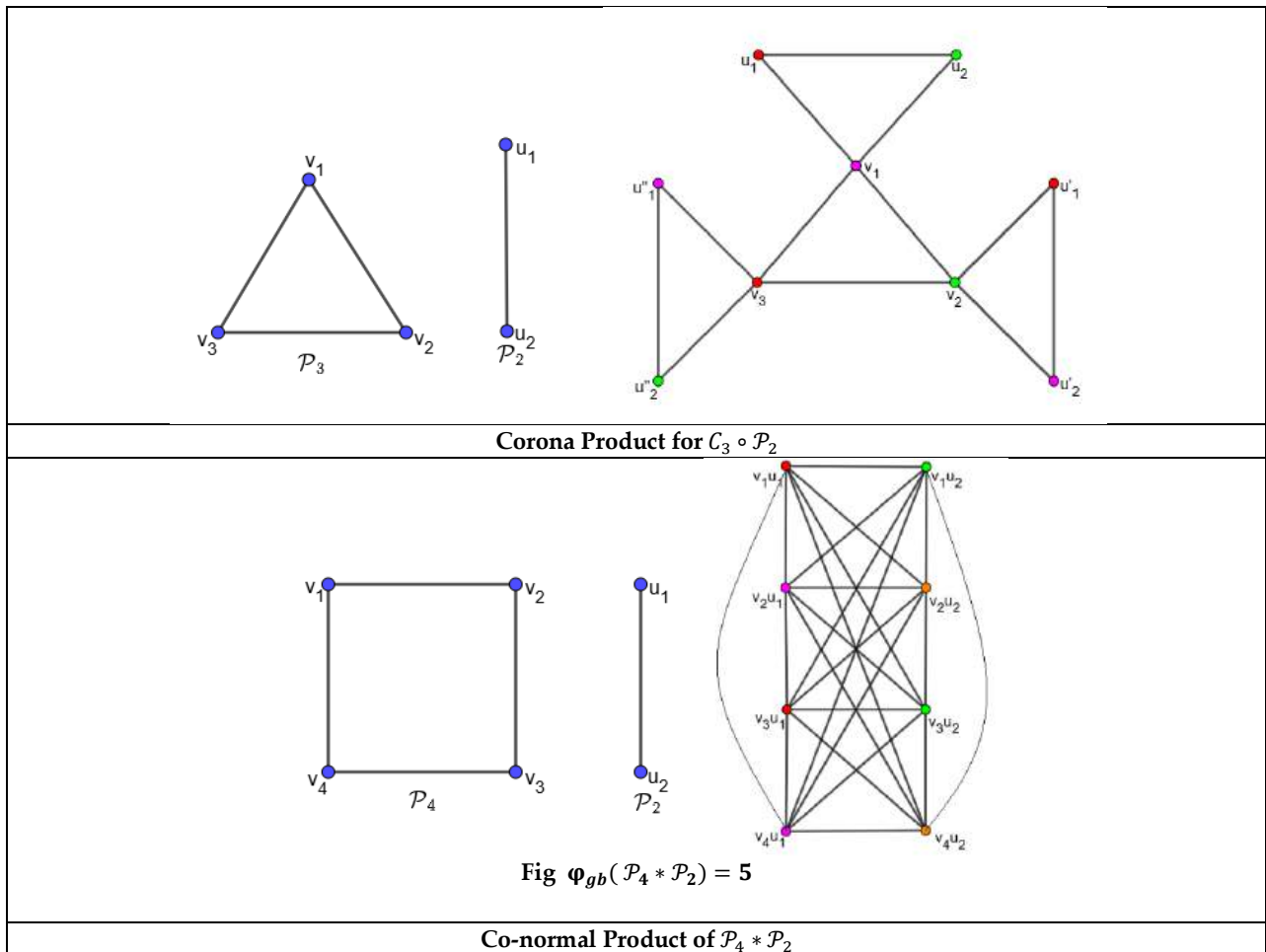
Fig $\phi_{gb}(P_2 \otimes P_3) = 2$ Cartesian Product for $P_2 \otimes P_3$ Fig $\phi_{gb}(P_2 \bullet P_n) = 6$.Lexicographic Product for $P_2 \bullet P_n$ Fig $P_2 \times P_n$

Corollary





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RESEARCH ARTICLE

Exploring Near Difference Cordial Labeling In Cycle-Related Graph

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ABSTRACT

Graphs are widely used in computer science, engineering, and social sciences to model complex systems and networks. This paper discusses the NDCL (near difference cordial labeling) of a few cycle-related graphs. We explore the concept in detail, examining several types of graphs. Specifically, we demonstrate that the snail graph(S_n), tortoise graph(T_n), Herschel graph, and fish graph are examples of NDCL (near difference cordial graph). Overall, this paper provides a comprehensive discussion of the NDCL of cycle-related graphs, with specific examples and theorems to illustrate the concept.

AMS Subject Classification: 05C78, 05C15, 05C38, and 05C75.

Keywords: Near Difference Cordial Labeling, Graph Labeling, Cycle related Graph and Cordial graphs.

INTRODUCTION

A variety of both graceful and harmonious labels were introduced in 1987 by I. Cahit [1]. An interactive summary of graph labeling was provided by Gallian, J.A. (2013) [2]. R. Ponraj, S. Sathis Narayanan, and R. Kala presented graphs with DCL (difference cordial labeling) [4]. Many kinds of graphs are examined. First introduced in 2017, the NDCL of various graphs was done by M. Abirami and S. Shanbaga Devi [5]. In 2019, M. Abirami and S. Shinbaga Devi [6]





presented NDCL for graphs connected to paths. This work aims to show that the Tortoise graph T_n , Snail graph S_n , Herschal graph, and fish graph are NDCG.

Preliminaries

Definition 2.1. Assume that the function f maps G 's vertices to $\{0, 1\}$. then, f can be thought of as a **Cordial labeling** of G , since the difference modulus between the number of nodes with the label "zero" and the number of nodes with the label "one" has at least one, as does the difference modulus between the number of lines with the label "zero" and the number of lines with the label "one." thus, we might write the modulus of the difference between two nodes on each line xy . [1]

Definition 2.2. Assume that $f: V(G) \rightarrow \{1, 2, \dots, P\}$ and that G is a (V, E) graph. Assign the label modulus of the difference between the two nodes that are assigned to each bridge uv . f is referred to as a **Difference Cordial labeling (DCL)**. If f is into and the difference modulus between bridges not labeled with one and those with a label of one is at least one, then should it be into. [4]

Definition 2.3. By joining two parallel edges between v_j and v_{n-j+1} for $j = 1, 2, \dots, \left\lfloor \frac{n}{2} \right\rfloor$, one can create a **snail** S_n ($n \geq 4$) from the path $P_n = v_1, v_2, \dots, v_n$. [7]

Definition 2.4. When one edge is attached between v_i and v_{n-i+1} for $i = 1, 2, \dots, \left\lfloor \frac{n-1}{2} \right\rfloor$, one obtains a **tortoise** T_n ($n \geq 4$) from route $P_n = v_1, v_2, \dots, v_n$. [7]

Definition 2.5. Slightly smaller than a Hamiltonian polyhedral graph, the **Herschel graph** is a bipartite graph with eleven nodes and eighteen bridges. [8]

Definition 2.6. A unique kind of graph is the **fish graph**. It consists of seven lines and six nodes. [9]

MAIN RESULTS

Definition 3.1. Assume with $f: v(g) \rightarrow \{1, 2, \dots, p-1, p+1\}$ and that G is a (p, q) graph. Each line must have the label modulus of the difference between two nodes assigned to it. When f is into, and the modulus of the difference between lines that are not labeled with a value of one and those that have a label of one is at least one, we refer to it as near difference cordial labeling (NDCL). A graph is referred to as a Near difference cordial labeling graph (NDCG) if it has a Near difference cordial labeling (NDCL). [5]

Theorem 3.2. Snail graph (S_n) admits NDCG.

Proof.

Suppose $V(S_n) = \{u_t: 1 \leq t \leq n\}$ &

$E(S_n) = \{(u_t u_{t+1}): 1 \leq t \leq n-1\} \cup \{2(u_t u_{t+1}): 1 \leq t \leq \frac{n}{2}\}$

Assume that $\omega: V(S_n) \rightarrow \{1, 2, \dots, p-1, p+1\}$.

The labels assigned to the vertices are,

$$\omega(u_t) = t, \quad 1 \leq t \leq n-2$$

$$\omega(u_{n-1}) = n+1$$

$$\omega(u_n) = n-1$$

These are the induced edge labelings:

$$\omega^*(u_t u_{t+1}) = 1, \quad 1 \leq t \leq n-3$$

$$\omega^*(u_t u_{n-t+1}) = n-2 \text{ if } t = 1$$

$$\omega^*(u_t u_{n-t+1}) = n-1 \text{ if } t = 2$$

$$\omega^*(u_t u_{n-t+1}) = n-2t+1 \text{ if } 3 \leq t \leq n$$

Consequently, the conditions that $|e_\omega(0) - e_\omega(1)| \leq 1$ are also satisfied by $e_\omega(0) = n$ and





$$e_{\omega}(1) = n - 1.$$

Hence, S_n admits NDCG.

Example: NDCL of S_6 is shown in Fig.3.2.1.

Theorem 3.3. The Tortoise graph or T_n admits NDCG.

Proof:

Let $V(T_n) = \{u_z : 1 \leq z \leq n\}$ &

$$E(T_n) = \{(u_z u_{z+1}) : 1 \leq z \leq n-1\} \cup \left\{2(u_z u_{z+1}) : 1 \leq z \leq \frac{n-1}{2}\right\}$$

Establish $\phi: V(T_n) \rightarrow \{1, 2, \dots, p-1, p+1\}$ by

$$\phi(u_z) = z, \quad 1 \leq z \leq n-1$$

$$\phi(u_n) = n+1$$

The labelings at the induced edges are,

$$\phi^*(u_z u_{z+1}) = 1, \quad 1 \leq l \leq n-2$$

$$\phi^*(u_z u_{n-z+1}) = n \quad \text{if } z = 1$$

$$\phi^*(u_z u_{n-z+1}) = n - 2z + 1 \quad \text{if } 2 \leq z \leq \frac{n-1}{2}$$

As shown here, $e_{\phi}(1) = n - 2$ and $e_{\phi}(0) = n - 3$. Because it ensures the requirement $|e_{\phi}(0) - e_{\phi}(1)| \leq 1$ In every case, T_n is a NDCG.

Example: Fig 3.3.1 displays the accurate labeling of T_7 with NDCG

Theorem 3.4. The Herschel graph (with eleven vertices and eighteen edges) is a NDCG.

Proof:

Assume G to be a Herschel graph.

$$V = \{u_r : 1 \leq r \leq 5, v_s : 1 \leq s \leq 6\} \&$$

$$E = \{v_s u_r, v_s u_{r+2}, u_r v_{s+3} : 1 \leq r, s \leq 3\} \cup \{u_r v_{s+1} : 3 \leq r, s \leq 5\} \cup$$

$$\{u_1 u_2, u_4 u_5, v_4 v_5, v_5 v_6\} \cup \{v_s v_{s+1} : 1 \leq s \leq 2\}.$$

Consider, $\eta: V(G) \rightarrow \{1, 2, \dots, p-1, p+1\}$ by

Because of this, $e_{\eta}(0) = e_{\eta}(1) = n - 2$ and it is also satisfied by $|e_{\eta}(0) - e_{\eta}(1)| \leq 1$.

As such, an NDCG is a Herschel graph.

Example: As seen in fig.3.4.1, the Herschel graph is an NDCG

Theorem 3.5. Fish graph admits NDCG (it has six vertices and seven edges).

Proof:

Consider G be a fish graph

$$\text{Suppose } V(G) = \{u_w : 1 \leq w \leq 6\} \text{ and } E(G) = \{u_w u_{w+1} : 1 \leq w \leq 5\} \cup \{u_6 u_3\} \cup \{u_3 u_1\}$$

$$\text{Define } \psi: V(G) \rightarrow \{1, 2, 3, 4, 5, 7\}$$

The vertex labels are,

Thus, it fulfills the requirement $|e_{\psi}(0) - e_{\psi}(1)| \leq 1$.

Fish graph is an NDCG as a result.

Example: The NDCL of fish graph is shown in fig.3.5.1.

CONCLUSION

In the field of graph theory, we believe that this work will be a helpful resource for scholars and practitioners. Our goal is to stimulate more study and innovation in this field by providing a thorough analysis of the NDCL of graphs connected to cycles.





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Table 1:

$\eta(v_1) = 12$	$\eta(v_2) = 3$	$\eta(v_3) = 10$
$\eta(v_4) = 8$	$\eta(v_5) = 7$	$\eta(v_6) = 6$
$\eta(u_1) = 1$	$\eta(u_2) = 2$	$\eta(u_3) = 9$
$\eta(u_4) = 4$	$\eta(u_5) = 5$	

The edge labels that are generalized are,

$\eta^*(u_1u_2) = 1$	$\eta^*(u_4u_5) = 1$	$\eta^*(u_2v_2) = 1$
$\eta^*(u_5v_6) = 1$	$\eta^*(v_2v_4) = 1$	$\eta^*(v_6v_5) = 1$
$\eta^*(v_4v_5) = 1$	$\eta^*(v_4u_3) = 1$	$\eta^*(u_3v_3) = 1$
$\eta^*(v_1v_2) = 9$	$\eta^*(v_2v_3) = 7$	$\eta^*(v_1u_1) = 11$
$\eta^*(v_1u_3) = 3$	$\eta^*(v_3u_5) = 5$	$\eta^*(u_1v_4) = 7$
$\eta^*(u_2v_5) = 5$	$\eta^*(u_3v_6) = 3$	$\eta^*(u_4v_5) = 3$

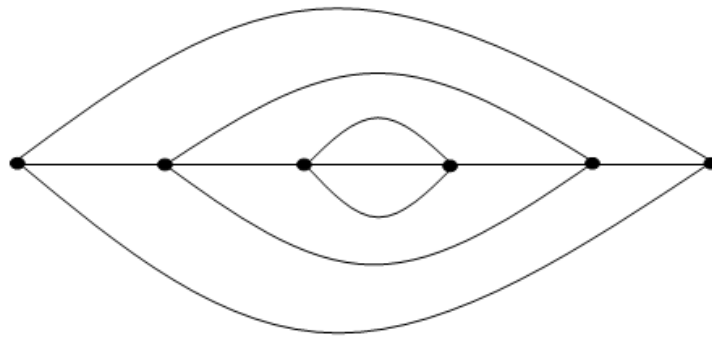
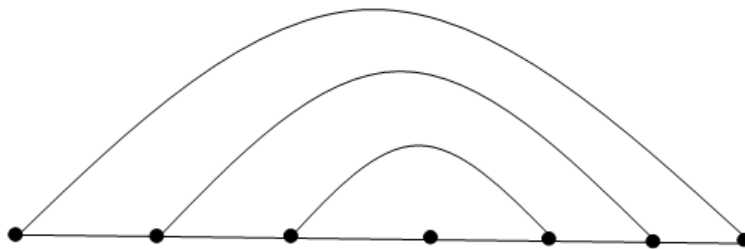
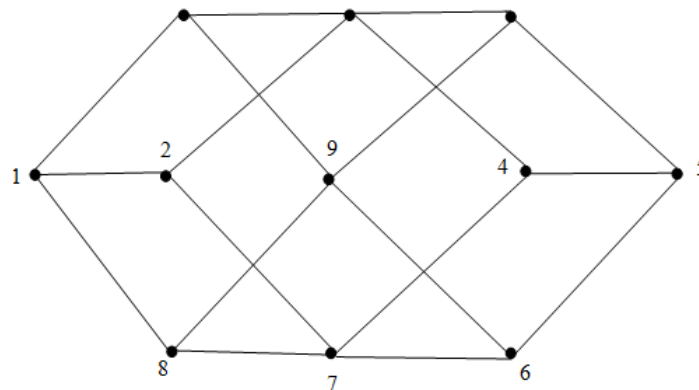
Table 2:

$\psi(u_1) = 1$	$\psi(u_2) = 2$	$\psi(u_3) = 3$
$\psi(u_4) = 4$	$\psi(u_5) = 5$	$\psi(u_6) = 7$

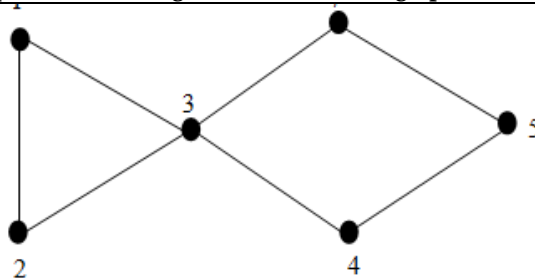
The induced edge labels are,

$\psi^*(u_1u_2) = 1$	$\psi^*(u_2u_3) = 1$	$\psi^*(u_3u_4) = 1$	$\psi^*(u_4u_5) = 1$
$\psi^*(u_5u_6) = 2$	$\psi^*(u_6u_3) = 4$	$\psi^*(u_3u_1) = 2$	



Jackson *et al.*,Example: NDCL of S_6 is shown in Fig.3.2.1.Example: Fig 3.3.1 displays the accurate labeling of T_7 with NDCG.

Example: As seen in fig.3.4.1, the Herschel graph is an NDCG



Example: The NDCL of fish graph is shown in fig.3.5.1.

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RESEARCH ARTICLE

Geometric Mean and Root Mean Square Based Fuzzy Delay Fourth Order Runge - Kutta Methods for Solving Fuzzy Delay Differential Equations

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ABSTRACT

In this paper, a numerical algorithm for solving fuzzy delay differential equations using the fuzzy delay fourth order Runge-Kutta methods based on Geometric Mean and the fuzzy delay fourth order Runge-Kutta method based on Root mean square are proposed in detail. The convergence of the methods are presented. Numerical examples are given to validate the effectiveness of the proposed numerical algorithm

Keywords: Triangular fuzzy number, Fuzzy Delay Differential Equations, Fuzzy Delay fourth order Runge-Kutta method, Fuzzy Delay fourth order Runge-Kutta method based on Geometric Mean, Fuzzy Delay fourth order Runge-Kutta method based on Root Mean Square.

INTRODUCTION

Fuzzy Delay Differential Equations (FDDEs) arise in many real world problems where the rate of change of variable depends not only on its present value but also on its past state and incorporates fuzziness. The fuzzy set theory was first introduced by Zadeh[1]. Gethsi Sharmila[21] proposed fourth order Runge-Kutta method based on Geometric





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mean to solve hybrid fuzzy initial value problems. Jansirani et.al [3] given Intuitionistic fuzzy differential equations using composite Runge-Kutta method using variety of means. Indrakumar et.al [4] given FDDE using Euler's method under generalised differentiability. A.F. Jameel et.al [5] presented paper to find an approximate analytical solution for first order fuzzy delay differential equations. Yookesh et.al [6] applied the variational iteration method which provides approximate solution for time delay differential equations under uncertainty conditions. Hamza et.al [7] presented an approximation technique for solving linear fuzzy delay differential equation. Muthukumar et.al [8] presented paper on solving fuzzy neutral delay differential equation using RK method of order five. Prasantha Bharathi et.al [9,10] presented approximate solution using Runge-Kutta method for fuzzy neutral and fuzzy mixed delay differential equation. Nguyen [11] studied fuzzy delay differential equations under granular differentiability, which provides both theoretical and practical applications. In this work, The Fuzzy Delay fourth order Runge-Kutta method based on Geometric Mean (FDRK4GM) and the Fuzzy Delay fourth order Runge-Kutta method based on Root Mean Square (FDRK4RMS) are developed and using the numerical algorithm, numerical examples are given. The comparison of solutions are done with Fuzzy Delay fourth order Runge-Kutta method (FDRK4).

The structure of the paper is organized as follows: Section 2 gives preliminaries. Section 3 explains the numerical algorithm to solve a fuzzy delay differential equations using the fuzzy delay fourth order Runge-Kutta method based on Geometric Mean and the convergence of the method. Section 4 explains the numerical algorithm to solve a fuzzy delay differential equations using the fourth order Runge-Kutta method based on Root Mean Square and the convergence of the method. In Section 5 numerical examples are given using the proposed algorithms and section 6 gives the conclusion.

Preliminaries

Triangular Fuzzy Number

The triangular fuzzy number is fuzzy interval represented as $A = (a_1, a_2, a_3)$ where a_1 and a_2 are two endpoints and a_2 is a peak point. The α cut interval for a fuzzy number A as A_α , the obtained interval A_α is defined as then

$$\mu_A(x) = \begin{cases} 0, & x < a_1 \\ \frac{x - a_1}{a_2 - a_1}, & a_1 \leq x \leq a_2 \\ \frac{a_3 - x}{a_3 - a_2}, & a_2 \leq x \leq a_3 \\ 0, & x > a_3 \end{cases}$$

The crisp interval is obtained as follows, $\forall \alpha \in [0, 1]$ by α cut operations. Then

$$A_\alpha = [(a_2 - a_1)\alpha + a_1, -(a_3 - a_2)\alpha + a_3]$$

Fuzzy Delay Differential Equation

A delay differential equation is of the form,

$$\begin{aligned} y'(\mathcal{X}) &= f(\mathcal{X}, y(\mathcal{X}), y(\mathcal{X} - \tau_1), y(\mathcal{X} - \tau_2), \dots, y(\mathcal{X} - \tau_i)), \mathcal{X} \geq \mathcal{X}_0 \\ y(\mathcal{X}) &= \phi(\mathcal{X}), \mathcal{X} \leq \mathcal{X}_0 \end{aligned} \quad (1)$$

where τ_i is a constant for each $i = 1, 2, 3, \dots, n$. In a Delay Differential Equation, a fuzzy parameter could be a coefficient, an initial condition, or both. It is known as a fuzzy delay differential equation (FDDE). The function $y(\mathcal{X})$ is a fuzzy derivative of $y(\mathcal{X})$ at $\mathcal{X} \in [-\tau, T]$ and $\phi(\mathcal{X})$ is a fuzzy number corresponding to the given initial function when $\mathcal{X} < 0$. It is represented in the following form





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$$\begin{aligned} \underline{y}'(\kappa) &= f(\kappa, \underline{y}(\kappa), \underline{y}(\kappa - \tau_1), \dots, \underline{y}(\kappa - \tau_i)), \kappa \geq \kappa_0 \\ \underline{y}(\kappa) &= \underline{\phi}(\kappa) \\ \overline{y}'(\kappa) &= f(\kappa, \overline{y}(\kappa), \overline{y}(\kappa - \tau_1), \dots, \overline{y}(\kappa - \tau_i)), \kappa \geq \kappa_0, \\ \overline{y}(\kappa) &= \overline{\phi}(\kappa) \end{aligned} \quad (2)$$

where τ_i is constant for each

The Fuzzy Delay Fuzzy delay fourth order Runge-Kutta method based on Geometric Mean(FDRK4GM)

Considering the fuzzy delay fourth order Runge-Kutta method based on Geometric Mean proposed by Gethsi Sharmila[1] for fuzzy differential equation, and it is further developed for FDEs as follows:

$$k_i(\kappa_{n+1}, y(\kappa_n), y_\kappa) = h_{n+1}$$

$$k_i(\kappa_{n+1}, y(\kappa_n), y_\kappa) = h_{n+1} f((\kappa_n + c_i h_{n+1}, y(\kappa_n) + \sum_{j=1}^r a_{ij} k_j(\kappa_{n+1}, y(\kappa_n), y_\kappa), y_\kappa), y(\kappa_{n+1}) = y(\kappa_n) + i=1r \text{ wi } k_i(\kappa_{n+1}, y(\kappa_n), y_\kappa). \quad (3)$$

where $y_\kappa = y(\kappa_n + c_i h - \tau)$ is a delay term. Let $\delta = \{\kappa_0, \kappa_1, \dots, \kappa_N = X\}$ be the given grid points and Here $h_{n+1} = \kappa_{n+1} - \kappa_n, n = 0, 1, 2, 3, \dots, N$ denote the corresponding stepsizes at which the exact solution $[Y]^r = [\underline{Y}(\kappa; r), \overline{Y}(\kappa; r)]$ is approximated by some $[Y]^r = [\underline{Y}(\kappa; r), \overline{Y}(\kappa; r)]$.

$$\begin{aligned} \underline{k}_i(\kappa_{n+1}, y(\kappa), y_\kappa; r) &= h_{n+1} F\{(\kappa_n + c_i h_{n+1}), y + \sum_{j=1}^r a_{ij} \underline{k}_j(\kappa_{n+1}, y(\kappa_n), y_\kappa), y_\kappa; r\}, \quad y_\kappa \in [\underline{y}(\kappa_n; r), \overline{y}(\kappa_n; r)], \\ &\quad y_\kappa \in [\underline{y}(\kappa_n + c_i h - \tau; r), (\kappa_n + c_i h - \tau; r)] \\ \overline{k}_i(\kappa_{n+1}, y(\kappa), y_\kappa; r) &= h_{n+1} G\{(\kappa_n + c_i h_{n+1}), y + \sum_{j=1}^r a_{ij} \overline{k}_j(\kappa_{n+1}, y(\kappa_n), y_\kappa), y_\kappa; r\}, \quad y \in [\overline{y}(\kappa_n; r), \overline{y}(\kappa_n; r)], \\ &\quad y_\kappa \in [\underline{y}(\kappa_n + c_i h - \tau; r), \overline{y}(\kappa_n + c_i h - \tau; r)] \\ \underline{k}_1(\kappa; y(\kappa; r)) &= \min \{h f(\kappa, y(\kappa), y_\kappa) \mid y(\kappa) \in [\underline{y}(\kappa; r), \overline{y}(\kappa; r)], \\ &\quad y(\kappa - \tau) \in [\underline{y}(\kappa - \tau; r), \overline{y}(\kappa - \tau; r)]\} \\ \overline{k}_1(\kappa; y(\kappa; r)) &= \max \{h f(\kappa, y(\kappa), y(\kappa - \tau)) \mid y(\kappa) \in [\underline{y}(\kappa; r), \overline{y}(\kappa; r)], \\ &\quad y(\kappa - \tau) \in [\underline{y}(\kappa - \tau; r), \overline{y}(\kappa - \tau; r)]\} \\ \underline{k}_2(\kappa; y(\kappa; r)) &= \min \{h f(\kappa + \frac{h}{2}, y(\kappa), y(\kappa - \tau), y(\kappa) \in [\underline{z}_1(\kappa, \underline{y}(\kappa; r)), \overline{z}_1(\kappa, \overline{y}(\kappa; r))], \\ &\quad y(\kappa - \tau) \in [\underline{z}_1(\kappa - \tau) \underline{y}(\kappa - \tau; r), \overline{z}_1(\kappa - \tau, \overline{y}(\kappa - \tau; r))]\} \\ \overline{k}_2(\kappa; y(\kappa; r)) &= \max \{h f(\kappa + \frac{h}{2}, y(\kappa), y(\kappa - \tau)) \mid y(\kappa) \in [\underline{z}_1(\kappa, \underline{y}(\kappa; r)), \overline{z}_1(\kappa, \overline{y}(\kappa; r))], \\ &\quad y(\kappa - \tau) \in [\underline{z}_1(\kappa - \tau) \underline{y}(\kappa - \tau; r), \overline{z}_1(\kappa - \tau, \overline{y}(\kappa - \tau; r))]\} \\ \underline{k}_3(\kappa; y(\kappa; r)) &= \min \{h f(\kappa + \frac{h}{2}, y(\kappa), y(\kappa - \tau)) \mid y(\kappa) \in [\underline{z}_2(\kappa, \underline{y}(\kappa; r)), \overline{z}_2(\kappa, \overline{y}(\kappa; r))], \\ &\quad y(\kappa - \tau) \in [\underline{z}_2(\kappa - \tau_1, \underline{y}(\kappa - \tau; r)), \overline{z}_2(\kappa - \tau, \overline{y}(\kappa - \tau; r))]\} \\ \overline{k}_3(\kappa; y(\kappa; r)) &= \max \{h f(\kappa + \frac{h}{2}, y(\kappa), y(\kappa - \tau)) \mid y(\kappa) \in [\underline{z}_2(\kappa, \underline{y}(\kappa; r)), \overline{z}_2(\kappa, \overline{y}(\kappa; r))], \\ &\quad y(\kappa - \tau) \in [\underline{z}_2(\kappa - \tau_1, \underline{y}(\kappa - \tau; r)), \overline{z}_2(\kappa - \tau, \overline{y}(\kappa - \tau; r))]\} \\ \underline{k}_4(\kappa; y(\kappa; r)) &= \min \{h f(\kappa + h, y(\kappa), y(\kappa - \tau)) \mid y(\kappa) \in [\underline{z}_3(\kappa, \underline{y}(\kappa; r)), \overline{z}_3(\kappa, \overline{y}(\kappa; r))], \\ &\quad y(\kappa - \tau) \in [\underline{z}_3(\kappa - \tau_1, \underline{y}(\kappa - \tau; r)), \overline{z}_3(\kappa - \tau, \overline{y}(\kappa - \tau; r))]\} \end{aligned}$$





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$$y(\kappa - \tau) \in [\underline{z}_3(\kappa - \tau_1, \underline{y}(\kappa - \tau_1; r)), \overline{z}_3(\kappa - \tau_1, \overline{y}(\kappa - \tau_1; r))]$$

$$\underline{k}_4(\kappa; y(\kappa; r)) = \max \{h f(\kappa + h, y(\kappa), y(\kappa - \tau_1)),$$

$$y(\kappa) \in [\underline{z}_3(\kappa, \underline{y}(\kappa; r)), \overline{z}_3(\kappa, \overline{y}(\kappa; r))]$$

$$y(\kappa - \tau) \in [\underline{z}_3(\kappa - \tau, \underline{y}(\kappa - \tau_1; r)), \overline{z}_3(\kappa - \tau, \overline{y}(\kappa - \tau_1; r))]$$

where,

$$\underline{z}_1(\kappa, \underline{y}(\kappa; r)) = \underline{y}(\kappa; r) + \frac{h}{2} \underline{k}_1(\kappa, \underline{y}(\kappa; r)),$$

$$\overline{z}_1(\kappa, \overline{y}(\kappa; r)) = \overline{y}(\kappa; r) + \frac{h}{2} \overline{k}_1(\kappa, \overline{y}(\kappa; r)),$$

$$\underline{z}_2(\kappa, \underline{y}(\kappa; r)) = \underline{y}(\kappa; r) + \frac{-1}{16} h \underline{k}_1(\kappa, \underline{y}(\kappa; r)) + \frac{9}{16} \underline{k}_2(\kappa, \underline{y}(\kappa; r))$$

$$\overline{z}_2(\kappa, \overline{y}(\kappa; r)) = \overline{y}(\kappa; r) + \frac{-1}{16} h \overline{k}_1(\kappa, \overline{y}(\kappa; r)) + \frac{9}{16} \overline{k}_2(\kappa, \overline{y}(\kappa; r)),$$

$$\underline{z}_3(\kappa, \underline{y}(\kappa; r)) = \underline{y}(\kappa; r) + \left(\frac{-1}{8}\right) h \underline{k}_1(\kappa, \underline{y}(\kappa; r)) + \frac{5}{24} \underline{k}_2(\kappa, \underline{y}(\kappa; r)) + \frac{11}{12} \underline{k}_3(\kappa, \underline{y}(\kappa; r)),$$

$$\overline{z}_3(\kappa, \overline{y}(\kappa; r)) = \overline{y}(\kappa; r) + \left(\frac{-1}{8}\right) h \overline{k}_1(\kappa, \overline{y}(\kappa; r)) + \frac{5}{24} \overline{k}_2(\kappa, \overline{y}(\kappa; r)) + \frac{11}{12} \overline{k}_3(\kappa, \overline{y}(\kappa; r)),$$

$$S[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

$$= \sqrt{|\underline{k}_1(\kappa; y(\kappa; r)) \underline{k}_2(\kappa; y(\kappa; r))|} + \sqrt{|\underline{k}_2(\kappa; y(\kappa; r)) \underline{k}_3(\kappa; y(\kappa; r))|} \\ + \sqrt{|\underline{k}_3(\kappa; y(\kappa; r)) \underline{k}_4(\kappa; y(\kappa; r))|}$$

$$T[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

$$= \sqrt{|\overline{k}_1(\kappa; y(\kappa; r)) \overline{k}_2(\kappa; y(\kappa; r))|} + \sqrt{|\overline{k}_2(\kappa; y(\kappa; r)) \overline{k}_3(\kappa; y(\kappa; r))|} \\ + \sqrt{|\overline{k}_3(\kappa; y(\kappa; r)) \overline{k}_4(\kappa; y(\kappa; r))|}$$

Then the approximate solution is given by

$$\begin{cases} \underline{y}(\kappa_{n+1}; r) = \underline{y}(\kappa_{n+1}; r) + \underline{y}(\kappa_n - \tau; r) \\ \overline{y}(\kappa_{n+1}; r) = \overline{y}(\kappa_{n+1}; r) + \overline{y}(\kappa_n - \tau; r) \end{cases} \quad (4)$$

Where,

$$\underline{y}(\kappa_{n+1}; r) = \underline{y}(\kappa_n; r) + \frac{1}{3} h S[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

$$\overline{y}(\kappa_{n+1}; r) = \overline{y}(\kappa_n; r) + \frac{1}{3} h T[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

The Convergence result for Fourth order Runge-Kutta based on Geometric Mean

The following lemmas will be applied to show convergence of these approximates in Theorem 2.1. and Theorem 3.1

Lemma:3.1

Let the sequence of numbers $\{W_n\}_{n=0}^{\{N\}}$ satisfy

$$|W_{n+1}| \leq (1 + A h) |W_n| + B h^2, \quad n = 0, 1, \dots, N-1$$

for some given positive constants A and B. Then

$$|W_n| \leq e^{\{A t_n\} \left(|W_0| + \frac{B h}{A} \right)}, \quad 0 \leq n \leq N.$$





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Lemma:3.2

Let the sequences of numbers $\{W_n\}_{n=0}^{\{N\}}$ and $\{V_n\}_{n=0}^{\{N\}}$ satisfy

$$|W_{n+1} - V_{n+1}| \leq (1 + Ah)|W_n - V_n| + Bh^2, \quad n = 0, 1, \dots, N-1$$

for some given positive constants A and B. Then, denoting

$$En = |W_n - V_n|,$$

we have

$$E_n \leq e^{\{A t_n\}} \left(E_0 + \frac{Bh}{A} \right),$$

Where $B = 2B$.

Let $S(\kappa, \beta, \alpha)$ and $T(\kappa, \beta, \alpha)$ be obtained by substituting $[y(t)]_r = [u, v]$

$$I = \{(\kappa, \beta, \alpha) | 0 \leq \kappa \leq X - \infty < \alpha < \infty, -\infty < \beta \leq \alpha\}.$$

The domain where S and T are defined and is given by

$$I = \{(\kappa, \beta, \alpha) | \kappa_0 \leq \kappa \leq X, -\infty < \beta \leq \gamma\}$$

Theorem: 3.1

Let S and T belong to $C^4(I)$ and let the partial derivatives of S and T be bounded over I. Then for arbitrary fixed $r : r \in [0, 1]$, the numerical approximate of Equation(4) converge uniformly to the exact solutions $\underline{Y}(\kappa; r), \bar{Y}(\kappa; r)$ uniformly in κ .

Proof

$$\underline{Y}(\kappa_{n+1}; r) = \underline{Y}(\kappa_n; r) + \frac{1}{3} S[\kappa_n, y(\kappa_n; r)] + \frac{2429}{184320} h^5 ML^4 + O(h^6)$$

$$\bar{Y}(\kappa; r) = \bar{Y}(\kappa_n; r) + \frac{1}{3} T[\kappa_n, \{y\}(\kappa_n; r)] + \frac{2429}{184320} h^5 ML^4 + O(h^6)$$

where M, L are positive constants. Then if

$$W_n = \underline{Y}(\kappa_n; r) - \underline{y}(\kappa_n; r)$$

$$V_n = \bar{Y}(\kappa_n; r) - \bar{y}(\kappa_n; r)$$

$$W_{n+1} = W_n + \frac{1}{3} \left\{ S[\kappa_n, \underline{Y}(\kappa_n; r), \bar{Y}(\kappa_n; r), \underline{Y}(\kappa_n - \tau; r), \bar{Y}(\kappa_n - \tau; r)] \right. \\ \left. - S[\kappa_n, \underline{y}(\kappa_n; r), \bar{y}(\kappa_n; r), \underline{y}(\kappa_n - \tau; r), \bar{y}(\kappa_n - \tau; r)] \right\} + \frac{2429}{184320} h^5 ML^4 + O(h^6)$$

$$V_{n+1} = V_n + \frac{1}{3} \left\{ T[\kappa_n, \underline{Y}(\kappa_n; r), \bar{Y}(\kappa_n; r), \underline{Y}(\kappa_n - \tau; r), \bar{Y}(\kappa_n - \tau; r)] \right. \\ \left. - T[\kappa_n, \underline{y}(\kappa_n; r), \bar{y}(\kappa_n; r), \underline{y}(\kappa_n - \tau; r), \bar{y}(\kappa_n - \tau; r)] \right\} + \frac{2429}{184320} h^5 ML^4 + O(h^6)$$

$$\|W_{n+1}\| \leq \|W_n\| + \frac{2}{3} Ph \max \|W_{n+1}\|_{[\tau, \kappa_n]}, \|W_n\|_{[\tau, \kappa_n]} + \frac{2429}{184320} h^5 ML^4 + O(h^6)$$

$$\|V_{n+1}\| \leq \|V_n\| + \frac{2}{3} Ph \max \|V_{n+1}\|_{[\tau, \kappa_n]}, \|V_n\|_{[\tau, \kappa_n]} + \frac{2429}{184320} h^5 ML^4 + O(h^6)$$

for $\kappa \in [0, X]$ and $P > 0$ is a bound for the partial derivatives of S and T. Then

$$\|W_n\| \leq \left(1 + \frac{2}{3} Ph\right)^n \|\zeta_0\|_{[\tau, \kappa_n]} + \frac{2429}{92160} h^5 ML^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} Ph\right)^n - 1}{\frac{4}{3} Ph} \right)$$

$$\|V_n\| \leq \left(1 + \frac{2}{3} Ph\right)^n \|\zeta_0\|_{[\tau, \kappa_n]} + \frac{2429}{92160} h^5 ML^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} Ph\right)^n - 1}{\frac{4}{3} Ph} \right)$$

where $\|\zeta_0\| = \|W_0\| + \|V_0\|$.





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In particular

$$\|W_n\| \leq \left(1 + \frac{2}{3} P h\right)^N \|\zeta_0\|_{[\tau, \mathcal{X}_n]} + \frac{2429}{122880} h^5 M L^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} P h\right)^{\frac{x}{h}} - 1}{P} \right)$$

$$\|V_n\| \leq \left(1 + \frac{2}{3} P h\right)^N \|\zeta_0\|_{[\tau, \mathcal{X}_n]} + \frac{2429}{122880} h^5 M L^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} P h\right)^{\frac{x}{h}} - 1}{P} \right)$$

since $W_0 = V_0 = 0$,

$$\|W_n\| \leq \frac{2429}{122880} h^4 M L^4 + \left(\frac{(e^{\frac{4}{3} P h}) - 1}{P} \right) O(h^5)$$

$$\|V_n\| \leq \frac{2429}{122880} h^4 M L^4 + \left(\frac{(e^{\frac{4}{3} P h}) - 1}{P} \right) O(h^5)$$

and if

$$h \rightarrow 0 \quad \|W_n\| \rightarrow 0, \|V_n\| \rightarrow 0$$

which completes the proof.

The Fourth Order Runge-Kutta method based on Root Mean Square(FDRK4RMS)

Considering the fuzzy delay fourth order Runge-Kutta method based on Root Mean Square to solve fuzzy delay differential equation,

$$\underline{k}_i(\mathcal{X}_{n+1}, y(\mathcal{X}), y_{\mathcal{X}}; r) = h_{n+1} F \mathcal{X}_n + c_i h_{n+1}, y + \sum_{j=1}^r a_{ij} k_j(\mathcal{X}_{n+1}, y(\mathcal{X}_n), y_{\mathcal{X}}, y_{\mathcal{X}}; r), \quad y_{\mathcal{X}} | y[\underline{y}(\mathcal{X}_n; r), \bar{y}(\mathcal{X}_n; r)],$$

$$y_{\mathcal{X}} \in [\underline{y}(\mathcal{X}_n + c_i h - \tau; r), (\mathcal{X}_n + c_i h - \tau; r)]$$

$$\bar{k}_i(\mathcal{X}_{n+1}, y(\mathcal{X}), y_{\mathcal{X}}; r) = h_{n+1} G[\mathcal{X}_n + c_i h_{n+1}, y + \sum_{j=1}^r a_{ij} k_j(\mathcal{X}_{n+1}, y(\mathcal{X}_n), y_{\mathcal{X}}, y_{\mathcal{X}}; r), y_{\mathcal{X}} | y \in [\bar{y}(\mathcal{X}_n; r), \bar{y}(\mathcal{X}_n; r)],$$

$$y_{\mathcal{X}} \in [\underline{y}(\mathcal{X}_n + c_i h - \tau; r), \bar{y}(\mathcal{X}_n + c_i h - \tau; r)]$$

$$\underline{k}_1(\mathcal{X}; y(\mathcal{X}; r)) = \min \{h f(\mathcal{X}, y(\mathcal{X}), y_{\mathcal{X}}) | y(\mathcal{X}) \in [\underline{y}(\mathcal{X}; r), \bar{y}(\mathcal{X}; r)],$$

$$y(\mathcal{X} - \tau) \in [\underline{y}(\mathcal{X} - \tau; r), \bar{y}(\mathcal{X} - \tau; r)]\}$$

$$\bar{k}_1(\mathcal{X}; y(\mathcal{X}; r)) = \max \{h f(\mathcal{X}, y(\mathcal{X}), y_{\mathcal{X}}) | y(\mathcal{X}) \in [\underline{y}(\mathcal{X}; r), \bar{y}(\mathcal{X}; r)],$$

$$y(\mathcal{X} - \tau) \in [\underline{y}(\mathcal{X} - \tau; r), \bar{y}(\mathcal{X} - \tau; r)]\}$$

$$\underline{k}_2(\mathcal{X}; y(\mathcal{X}; r)) = \min \{h f(\mathcal{X} + \frac{h}{2}, y(\mathcal{X}), y(\mathcal{X} - \tau), | y(\mathcal{X}) \in [\underline{z}_1(\mathcal{X}, \underline{y}(\mathcal{X}; r)), \bar{z}_1(\mathcal{X}, \bar{y}(\mathcal{X}; r))],$$

$$y(\mathcal{X} - \tau) \in [\underline{z}_1(\mathcal{X} - \tau) \underline{y}(\mathcal{X} - \tau; r), \bar{z}_1(\mathcal{X} - \tau, \bar{y}(\mathcal{X} - \tau; r))]\}$$

$$\bar{k}_2(\mathcal{X}; y(\mathcal{X}; r)) = \max \{h f(\mathcal{X} + \frac{h}{2}, y(\mathcal{X}), y(\mathcal{X} - \tau)) | y(\mathcal{X}) \in [\underline{z}_1(\mathcal{X}, \underline{y}(\mathcal{X}; r)), \bar{z}_1(\mathcal{X}, \bar{y}(\mathcal{X}; r))],$$

$$y(\mathcal{X} - \tau) \in [\underline{z}_1(\mathcal{X} - \tau) \underline{y}(\mathcal{X} - \tau; r), \bar{z}_1(\mathcal{X} - \tau, \bar{y}(\mathcal{X} - \tau; r))]\}$$

$$\underline{k}_3(\mathcal{X}; y(\mathcal{X}; r)) = \min \{h f\left(\mathcal{X} + \frac{h}{2}, y(\mathcal{X}), y(\mathcal{X} - \tau)\right) | y(\mathcal{X}) \in [\underline{z}_2(\mathcal{X}, \underline{y}(\mathcal{X}; r)), \bar{z}_2(\mathcal{X}, \bar{y}(\mathcal{X}; r))],$$

$$y(\mathcal{X} - \tau) \in [\underline{z}_2(\mathcal{X} - \tau_1, \underline{y}(\mathcal{X} - \tau; r)), \bar{z}_2(\mathcal{X} - \tau, \bar{y}(\mathcal{X} - \tau; r))]\}$$

$$\bar{k}_3(\mathcal{X}; y(\mathcal{X}; r)) = \max \{h f\left(\mathcal{X} + \frac{h}{2}, y(\mathcal{X}), y(\mathcal{X} - \tau)\right) | y(\mathcal{X}) \in [\underline{z}_2(\mathcal{X}, \underline{y}(\mathcal{X}; r)), \bar{z}_2(\mathcal{X}, \bar{y}(\mathcal{X}; r))],$$

$$y(\mathcal{X} - \tau) \in [\underline{z}_2(\mathcal{X} - \tau_1, \underline{y}(\mathcal{X} - \tau; r)), \bar{z}_2(\mathcal{X} - \tau, \bar{y}(\mathcal{X} - \tau; r))]\}$$

$$\underline{k}_4(\mathcal{X}; y(\mathcal{X}; r)) = h \{f(\mathcal{X} + h, y(\mathcal{X}), y(\mathcal{X} - \tau)) | y(\mathcal{X}) \in [\underline{z}_3(\mathcal{X}, \underline{y}(\mathcal{X}; r)), \bar{z}_3(\mathcal{X}, \bar{y}(\mathcal{X}; r))],$$

$$y(\mathcal{X} - \tau) \in [\underline{z}_3(\mathcal{X} - \tau_1, \underline{y}(\mathcal{X} - \tau_1; r)), \bar{z}_3(\mathcal{X} - \tau_1, \bar{y}(\mathcal{X} - \tau_1; r))]\}$$

$$\bar{k}_4(\mathcal{X}; y(\mathcal{X}; r)) = h \{f(\mathcal{X} + h, y(\mathcal{X}), y(\mathcal{X} - \tau_1)), |$$





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$$y(\kappa) \in [\underline{z}_3(\kappa, \underline{y}(\kappa; r)), \overline{z}_3(\kappa, \overline{y}(\kappa; r))],$$

$$y(\kappa - \tau) \in [\underline{z}_3(\kappa - \tau, \underline{y}(\kappa - \tau; r)), \overline{z}_3(\kappa - \tau, \overline{y}(\kappa - \tau; r))] \}$$

where,

$$\underline{z}_1(\kappa, \underline{y}(\kappa; r)) = \underline{y}(\kappa; r) + \frac{h}{2} \underline{k}_1(\kappa, \underline{y}(\kappa; r)),$$

$$\overline{z}_1(\kappa, \overline{y}(\kappa; r)) = \overline{y}(\kappa; r) + \frac{h}{2} \overline{k}_1(\kappa, \overline{y}(\kappa; r)),$$

$$\underline{z}_2(\kappa, \underline{y}(\kappa; r)) = \underline{y}(\kappa; r) + \frac{1}{16} h \underline{k}_1(\kappa, \underline{y}(\kappa; r)) + \frac{7}{16} \underline{k}_2(\kappa, \underline{y}(\kappa; r))$$

$$\overline{z}_2(\kappa, \overline{y}(\kappa; r)) = \overline{y}(\kappa; r) + \frac{1}{16} h \overline{k}_1(\kappa, \overline{y}(\kappa; r)) + \frac{7}{16} \overline{k}_2(\kappa, \overline{y}(\kappa; r)),$$

$$\underline{z}_3(\kappa, \underline{y}(\kappa; r)) = \underline{y}(\kappa; r) + \left(\frac{1}{8}\right) h \underline{k}_1(\kappa, \underline{y}(\kappa; r)) + \frac{-17}{56} \underline{k}_2(\kappa, \underline{y}(\kappa; r)) + \frac{33}{28} \underline{k}_3(\kappa, \underline{y}(\kappa; r)),$$

$$\overline{z}_3(\kappa, \overline{y}(\kappa; r)) = \overline{y}(\kappa; r) + \left(\frac{1}{8}\right) h \overline{k}_1(\kappa, \overline{y}(\kappa; r)) + \frac{-17}{56} \overline{k}_2(\kappa, \overline{y}(\kappa; r)) + \frac{33}{28} \overline{k}_3(\kappa, \overline{y}(\kappa; r))$$

$$S[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

$$= \sqrt{\frac{|\underline{k}_1^2(\kappa; \underline{y}(\kappa; r)) \underline{k}_2^2(\kappa; \underline{y}(\kappa; r))|}{2}} + \sqrt{\frac{|\underline{k}_2^2(\kappa; \underline{y}(\kappa; r)) + \underline{k}_3^2(\kappa; \underline{y}(\kappa; r))|}{2}}$$

$$+ \sqrt{\frac{|\underline{k}_3^2(\kappa; \underline{y}(\kappa; r)) \underline{k}_4^2(\kappa; \underline{y}(\kappa; r))|}{2}}$$

$$T[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

$$= \sqrt{\frac{|\overline{k}_1^2(\kappa; \overline{y}(\kappa; r)) + \overline{k}_2^2(\kappa; \overline{y}(\kappa; r))|}{2}} + \sqrt{\frac{|\overline{k}_2^2(\kappa; \overline{y}(\kappa; r)) + \overline{k}_3^2(\kappa; \overline{y}(\kappa; r))|}{2}}$$

$$+ \sqrt{\frac{|\overline{k}_3^2(\kappa; \overline{y}(\kappa; r)) + \overline{k}_4^2(\kappa; \overline{y}(\kappa; r))|}{2}}$$

Then the approximate solution is given by

$$\begin{cases} \underline{y}(\kappa_{n+1}; r) = \underline{y}(\kappa_{n+1}; r) + \underline{y}(\kappa_n - \tau; r) \\ \overline{y}(\kappa_{n+1}; r) = \overline{y}(\kappa_{n+1}; r) + \overline{y}(\kappa_n - \tau; r) \end{cases} \quad (5)$$

Where

$$\underline{y}(\kappa_{n+1}; r) = \underline{y}(\kappa_n; r) + \frac{1}{3} h S[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

$$\overline{y}(\kappa_{n+1}; r) = \overline{y}(\kappa_n; r) + \frac{1}{3} h T[\kappa, \underline{y}(\kappa; r), \overline{y}(\kappa; r)]$$

Convergence for Fourth Order Runge-Kutta based on Root Mean Square(FDRK4RMS)

Let $S(\kappa, \beta, \alpha)$ and $T(\kappa, \beta, \alpha)$ be obtained by substituting $ytr = [u, v]$.

The domain where S and T are defined is therefore

$$I = \{(\kappa, \beta, \alpha) \mid 0 \leq \kappa \leq X, -\infty < \alpha < \infty, -\infty < \beta \leq \alpha\}.$$

The domain where S and T are defined and is given by

$$I = \{(\kappa, \beta, \alpha) \mid \kappa_0 \leq \kappa \leq X, -\infty < \beta \leq \gamma\}$$

Theorem:4.1

Let S and T belong to $C^4(I)$ and let the partial derivatives of S and T be bounded over I . Then for arbitrary fixed $r : r \in [0, 1]$, (the numerical approximate of equation(5) converge uniformly to the exact solutions $\underline{y}(\kappa; r), \overline{y}(\kappa; r)$ uniformly in κ





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Proof:

$$\underline{Y}(\kappa_{n+1}; r) = \underline{Y}(\kappa_n; r) + \frac{1}{3} S [\kappa_n, \underline{y}(\kappa_n; r)] + \frac{15363}{1290240} h^5 ML^4 + O(h^6)$$

$$\overline{Y}(\kappa; r) = \overline{Y}(\kappa_n; r) + \frac{1}{3} T [\kappa_n, \overline{y}(\kappa_n; r)] + \frac{15363}{1290240} h^5 ML^4 + O(h^6)$$

where M, L are positive constants. Then if

$$W_n = \underline{Y}(\kappa_n; r) - \underline{y}(\kappa_n; r)$$

$$V_n = \overline{Y}(\kappa_n; r) - \overline{y}(\kappa_n; r)$$

$$W_{n+1} = W_n + \frac{1}{3} \left\{ S [\kappa_n, \underline{Y}(\kappa_n; r), \overline{Y}(\kappa_n; r), \underline{Y}(\kappa_n - \tau; r), \overline{Y}(\kappa_n - \tau; r)] \right. \\ \left. - S [\kappa_n, \underline{y}(\kappa_n; r), \overline{y}(\kappa_n; r), \underline{y}(\kappa_n - \tau; r), \overline{y}(\kappa_n - \tau; r)] \right\} + \frac{15363}{1290240} h^5 ML^4 + O(h^6)$$

$$V_{n+1} = V_n + \frac{1}{3} T [\kappa_n, \underline{Y}(\kappa_n; r), \overline{Y}(\kappa_n; r), \underline{Y}(\kappa_n - \tau; r), \overline{Y}(\kappa_n - \tau; r)] - T [\kappa_n, \underline{y}(\kappa_n; r), \overline{y}(\kappa_n; r), \underline{y}(\kappa_n - \tau; r), \overline{y}(\kappa_n - \tau; r)] + \frac{15363}{1290240} h^5 ML^4 + O(h^6)$$

$$\|W_{n+1}\| \leq \|W_n\| + \frac{2}{3} P h \max \|W_{n+1}\|_{[\tau, \kappa_n]}, \|W_n\|_{[\tau, \kappa_n]} + \frac{15363}{1290240} h^5 ML^4 + O(h^6)$$

$$\|V_{n+1}\| \leq \|V_n\| + \frac{2}{3} P h \max \|V_{n+1}\|_{[\tau, \kappa_n]}, \|V_n\|_{[\tau, \kappa_n]} + \frac{15363}{1290240} h^5 ML^4 + O(h^6)$$

for $\kappa \in [0, X]$ and $P > 0$ is a bound for the partial derivatives of S and T. Then

$$\|W_n\| \leq \left(1 + \frac{2}{3} P h\right)^n \|\zeta_0\|_{[\tau, \kappa_n]} + \frac{15363}{645120} h^5 ML^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} P h\right)^n - 1}{\frac{4}{3} P h} \right)$$

$$\|V_n\| \leq \left(1 + \frac{2}{3} P h\right)^n \|\zeta_0\|_{[\tau, \kappa_n]} + \frac{15363}{645120} h^5 ML^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} P h\right)^n - 1}{\frac{4}{3} P h} \right)$$

where $\|\zeta_0\| = \|W_0\| + \|V_0\|$.

In particular

$$\|W_n\| \leq \left(1 + \frac{2}{3} P h\right)^N \|\zeta_0\|_{[\tau, \kappa_n]} + \frac{15363}{860160} h^5 ML^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} P h\right)^{\frac{x}{h}} - 1}{P} \right)$$

$$\|V_n\| \leq \left(1 + \frac{2}{3} P h\right)^N \|\zeta_0\|_{[\tau, \kappa_n]} + \frac{15363}{860160} h^5 ML^4 + O(h^6) \left(\frac{\left(1 + \frac{4}{3} P h\right)^{\frac{x}{h}} - 1}{P} \right)$$

since $W_0 = V_0 = 0$,

$$\|W_n\| \leq \frac{15363}{860160} h^4 ML^4 + \left(\frac{(e^{\frac{4}{3} P h}) - 1}{P} \right) O(h^5)$$

$$\|V_n\| \leq \frac{15363}{860160} h^4 ML^4 + \left(\frac{(e^{\frac{4}{3} P h}) - 1}{P} \right) O(h^5)$$

and if $h \rightarrow 0$ $\|W_n\| \rightarrow 0$, $\|V_n\| \rightarrow 0$

which completes the proof.





Numerical Example

Example:5.1

Consider the FDDE

$$y'(\kappa) = y(\kappa) + y(\kappa - 1), \quad \kappa \geq 0,$$

$$y(\kappa) = \phi(\kappa), -1 \leq \kappa \leq 0$$

The initial value is given by

$$[y_0]^r(\kappa) = [(0.75 + 0.25r), (1.125 - 0.125r)] \quad r \in [0,1]$$

The approximate solutions obtained using the methods FDRK4GM and FDRK4RMS are presented graphically in the figure 5.1 and the numerical solutions obtained by FDRK4GM and FDRK4RMS are compared with FDRK4 in table 5.1. The table and figure show the numerical result for $h=0.1$ and $h=0.01$ respectively. The numerical result of the proposed methods FDRK4GM and FDRK4RMS coincide with numerical result obtained by FDRK4

Example:5.2

Consider the FDDE

$$y'(\kappa) = \lambda y(\kappa - 1) \quad \kappa \geq 0,$$

$$y(\kappa) = \phi(\kappa), \quad -1 \leq \kappa \leq 0$$

The initial value is given by $[y_0]^r(\kappa) = [(0.75 + 0.25r), (1.125 - 0.125r)] \quad r \in [0,1]$

The approximate solution for the values of $\lambda=0.5$ and $r \in [0,1]$. Figure 5.2 illustrates the comparison of numerical solutions obtained using FDRK4GM and FDRK4RMS when $\kappa=2$ and $h=0.01$. Table 5.2 presents the numerical values of solution obtained by FDRK4RMS and FDRK4GM when $\kappa=2$ and $h=0.1$. The numerical result of the proposed methods FDRK4GM and FDRK4RMS coincide with numerical result obtained by FDRK4.

CONCLUSION

In this chapter, the Fourth Order Runge Kutta method based on Geometric Mean and Root Mean Square are proposed to solve FDDE. The numerical algorithm are developed and the Convergence of the methods proposed. From the comparative study of the numerical solutions obtained using FDRK4, FDRK4GM, and FDRK4RMS methods, it is observed that all three schemes successfully approximate the solution of the given problems. The FDRK4GM produces numerical results that are very close to those obtained by the FDRK4, indicating higher accuracy and better stability when compared to the FDRK4 and FDRK4RMS approaches. This closeness suggests that FDRK4GM effectively captures the dynamics of the system with reduced truncation error. Hence FDRK4GM can be an efficient alternative FDRK4 for solving fuzzy delay differential equations.

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Table 1 Comparison between the solutions of example 1 obtained by FDRK4RMS and FDRK4GM with FDRK4 when $x=2$ and $h=0.1$

r	FDRK4GM		FDRK4RMS		FDRK4	
	$y(x; r)$	$\bar{y}(x; r)$	$y(x; r)$	$\bar{y}(x; r)$	$y(x; r)$	$\bar{y}(x; r)$
0.0	11.8379958	17.7569937	11.8359101	17.7538652	11.8369598	17.7554398
0.1	12.23259568	17.5596938	12.2304405	17.5566001	12.2315251	17.5581571
0.2	12.6271955	17.3623938	12.6249708	17.3593349	12.6260905	17.3608744
0.3	13.0217954	17.165093	13.019501	17.1620697	13.0206558	17.1635918
0.4	13.4163952	16.96779402	13.4140315	16.9648045	13.4152211	16.9663091
0.5	13.81099513	16.77049408	13.80856187	16.7675394	13.8097865	16.7690264
0.6	14.20559499	16.57319415	14.20309221	16.5702742	14.2043518	16.5717438
0.7	14.60019485	16.37589422	14.59762255	16.3730090	14.5989171	16.3744611
0.8	14.99479471	16.17859429	14.99215289	16.1757439	14.9934825	16.1771784
0.9	15.38939457	15.98129436	15.3866832	15.9784787	15.3880478	15.9798958
1.0	15.78399443	15.78399443	15.7812135	15.7812135	15.7826131	15.7826131

Table 2 Comparison between the solutions of example 2 obtained by FDRK4RMS and FDRK4GM with FDRK4 when $x=2$ and $h=0.1$

r	FDRK4GM		FDRK4RMS		FDRK4	
	$y(x; r)$	$\bar{y}(x; r)$	$y(x; r)$	$\bar{y}(x; r)$	$y(x; r)$	$\bar{y}(x; r)$
0.0	1.59373416	2.39060124	1.59376583	2.39064875	1.59375000	2.39062499
0.1	1.64685863	2.36403900	1.64689136	2.36408599	1.64687500	2.36406250
0.2	1.69998310	2.33747677	1.70001689	2.33752322	1.69999999	2.33749999
0.3	1.75310757	2.31091453	1.75314242	2.31096046	1.75312500	2.31093750
0.4	1.80623204	2.28435229	1.80626794	2.28439770	1.80624999	2.28437499
0.5	1.85935659	2.25779006	1.85939347	2.25783490	1.85937499	2.25781250





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0.6	1.91248099	2.23122782	1.91251900	2.23127217	1.91249999	2.23125000
0.7	1.96560546	2.20466559	1.96564453	.204709408	1.96562499	2.20468749
0.8	2.01872993	2.17810335	2.01877006	2.178146644	2.01875000	2.17812500
0.9	2.07185441	2.15154111	2.07189558	2.151583880	2.07187500	2.15156249
1.0	2.12497888	2.12497888	2.12502111	2.125021116	2.12500000	2.12500000

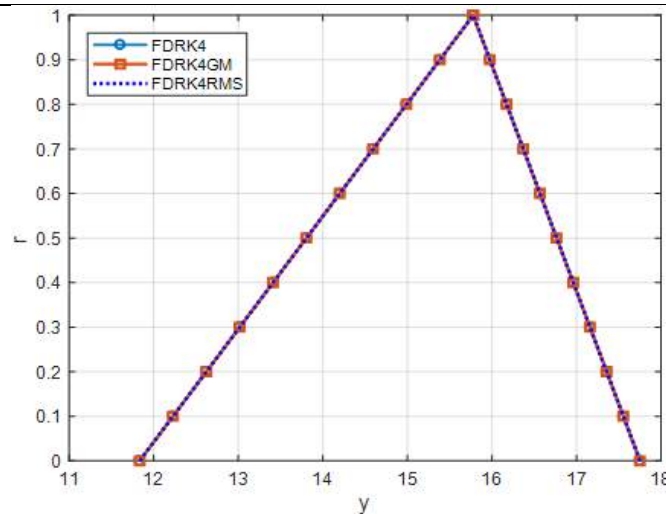


Fig.1 Comparison between the solutions of example 1 obtained by FDRK4RMS and FDRK4GM when $x=2$ and $h=0.01$

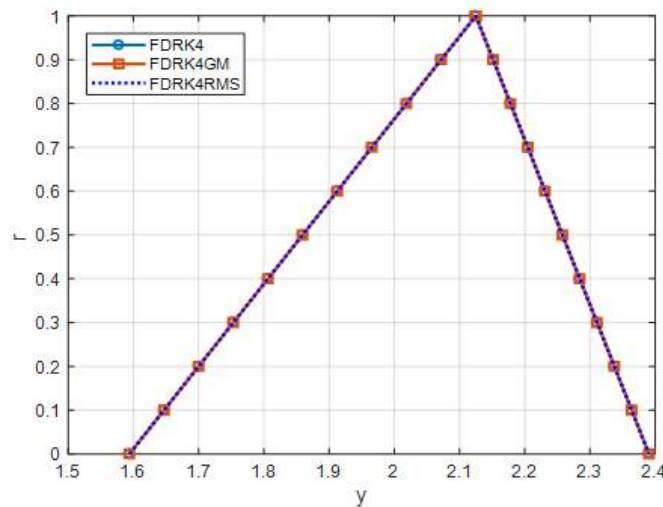


Fig. :2 Comparison between the solutions of example 2 obtained by FDRK4RMS and FDRK4GM when $x=2$ and $h=0.01$

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RESEARCH ARTICLE

A Controversial Analysis of *Bauhinia Variegata* L.[*Kanchanar*]: A Solution

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ABSTRACT

This article sets one's sight on the masked controversy of a medicine *Bauhinia variegata* [*Kanchanar*]. In ayurveda literature, disputes and differences are usually in identification, names and synonyms, species variations of certain substances. This medicinal plant is also part of that controversial theory with different names in different traditional texts. This difference might create a trouble in research, academics, medicinal use and identifying the drug. Therefore, the purpose of this study is to conduct and explore the controversy of *Bauhinia variegata* based on classical texts, traditional lexicons, and to clarify its actual form. Present study will help in authentication of *Bauhinia variegata* for identification and uniformity in clinical use as medicine.

Keywords: *Kanchanar*, Kovidara, Controversial Drug, *Bauhinia Variegata*, Medicinal Plants

INTRODUCTION

The identity of medicinal plants in ayurveda has historically been influenced by variations in nomenclature, synonymy and morphological interpretation. Such variations often lead to difference in understanding and using of drug, especially when one plant is described by multiple names in different texts. *Bauhinia variegata* (*Kanchanar*),



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commonly identified Ayurvedic drug uncertainly has confusion about its synonyms and correct identifications. In classical literature, the mentioned names are Kovidara, *Karbudara* or *Kanchanar* but with the same name for a single drug is questionable. In earlier classical medical compendia, the term Kovidara is mainly used, suggesting that it was the commonly accepted name during that early phase of Ayurvedic documentation. In later traditional Lexicons and Materia medica texts, the term *Kanchanar* becomes more prominently accepted and the plant is described in greater detail based on the observational features such as flower colour and structural characterization. The term *Karbudara* is uncommon and in specific contexts, which says it may not be a complete independent species but might be a condition-based choice of the same plant. These descriptive interpretations, the difference in naming and observational features, regional variations or practicing documentation among research scholars lead to inconsistency. This can affect pharmacological standardization, botanical identity and clinical applicability of the substance in modern era.

Additionally, complexity has been raised from the classification of *Bauhinia variegata* into different forms like red, white and yellow and the difference in there flowering patterns according to the observations and described in traditional sources. although present studies have scientifically validated *Bauhinia variegata* action potential with its identification points but the description couldn't be that successful in resolving the controversy of substance. Therefore, the present study aims to critically analyse traditional literature related to *Bauhinia variegata* L. Considering the names *Kanchanar*, *Karbudara*, and Kovidara to bring out the solution.

MATERIALS AND METHODOLOGY

The present work was carried out as a critical analysis of review of literature to solve the controversy of *Bauhinia variegata* as explained in traditional compendia sources. To fulfil this purpose, the information was collected from the range of classical medical texts along with later complications and modern scientific publications. The work was not only to gather the data but also to understand the interpretation for using the drug which is on focus because of its medicinal utility indication. Primarily references were taken from earlier compendia as well as later lexicons and texts, so that both the original as well as evolved developments could be considered together. In addition, the help was taken from commentarial works wherever required to justify the difference in naming and explaining multiple sources. Modern literature, which includes Review articles, related to *Bauhinia variegata* and its allied species, was also addressed to support correlation and botanical understanding. During analysis, emphasis was placed mainly on three aspects mainly related to synonyms of drug in different texts, the description in terms of features and therapeutic uses. Rather than treating these descriptions separately, they were together examined to understand whether they point towards multiple entities or a single plant.

A comparative approach was followed throughout the study. Descriptive tables were prepared and data was placed side by side from different sources to observe overlaps, similarities and differences in view. Special attention was given to features such as flower colour, types, plant form, flowering patterns as these appeared repeatedly in classics seems to play important role in differentiation. Interpretations provided by later scholars and commentators were taken in account, where context dependency occurred. This helped in identifying possible reasons behind variation in naming and classification. The collected data were then examined to see that different variations as mentioned in literature indicates distinct botanical species or simply variations within the same plant group. For botanical validation, available modern literature on *Bauhinia variegata* and related species was reviewed and classical descriptions were compared with contemporary scientific observations. The step taken was to understand the practical botanical basis of traditional classification. Since the study is based entirely on literature, the analysis remained qualitative in nature. No statistical methods were applied, as the study is about interpretation rather than experiment. Overall, the study approach to develop a more logical explanation for identity related confusion associated with *Bauhinia variegata* L. (*Kanchanar*) synonyms and integration of text for trials.



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RESULTS AND DISCUSSION

The observations obtained from classical and modern sources are summarized in Figure 1.1 and Figure 1.2.A Comparison of these sources reveals a clear understanding in a way *Kanchanar* and terms related to this have been described over time. One of the most noticeable findings is the difference in terminology across different periods of ayurvedic literature. Earlier texts consistently use the term *Kovidara*, suggesting that this was the commonly accepted name during the initial phase of documentation. In contrast, later works show a gradual shift toward the use of the term *Kanchanar* with detailed descriptions. This change reflects an evolution in classification practices from function-based identification process to morphology-based classification. A clear distinction is visible when classical textual interpretation is done with pharmacological and botanical study. Modern pharmacognostic studies provide further clarity on this variation. Comparative analysis has interpreted measurable differences between *Kanchanar* and *Kovidara* in terms of microscopic structure, physicochemical and phytochemical parameters. However, despite these differences, their therapeutic properties show considerable overlap, which explains why classical texts often treat them as functional equivalent.

The interpretation of *Karbudara* is significantly different from the above two terms. Some traditional demonstrations associated with specific morphology, particularly the white flowered variety, while the others relate it to clinical condition such as glandular swellings. This dual pattern says that the term may have been used either to denote a phenotypic variant or to emphasize therapeutic conditions. Further insight is gained when seasonal as well as environmental factors are focused. A consistent observation is that entity identified as *Kovidara* is associated with a distinct morphological feature of bilobed leaves with a deep cleft, along with the profuse purplish-pink flowering. The flowering tendency is seen in autumn season, indicating a specific phenological behaviour. In contrast, the entity correlated with *Kanchanar* including the form referred as *Karbudara*, demonstrates a different seasonal expression. This form has a flowering during spring season and is linked with *Bauhinia variegata*. The plant has broader leaves with less pronounced cleaving and show variation in flower colour, including lighter or white forms. This represents a variant expression of *Karbudara* associated with this group with same botanical entity rather than a separate species. When we observed together, a clear pattern emerges in which seasonal variation plays a defining role in differentiation. The spring Flowering form, corresponding to *Kanchanar*, includes multiple phenotypic variants, while the autumn flowering form identified as *Kovidara* shows relatively distinct morphological traits. Such differentiation contributes to assignment of different names. An additional information of cleft pattern in leaf shape, flower colour and flowering season supports modern era studies as species of *Bauhinia* show variations while their close relation explains similar medicinal use. Thus, *Bauhinia variegata* has multiple varieties and the properties are similar due to natural diversity variations and not due to incorrect identification.

CONCLUSION

The Present analysis indicated that there is variation among the terms *Kanchanar*, *Kovidara* and *Karbudara* due to morphology, seasonal expression and textual interpretation rather than true difference in identity. *Kanchanar* and *Kovidara* can be considered closely related and may be interchangeably in most contexts. In contrast, *Karbudara* shows variable usage across sources and is also synonym to different plants. Its use in relation to *Bauhinia variegata* [*Kanchanar*] appears to be context specific, therefore the careful interpretation is must on textual references rather than assumed as fixed botanical identity. *Kovidara* represents the original classical drug, *Kanchanar* denotes its later classified varieties based on morphology and flower colour, *Karbudara* is best understood as a closely related variant or subtype within the same *Bauhinia* group rather than a completely separate entity. This is the solution helps in resolving and support accurate identification, improved standardization, and consistent clinical application of the drug.





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Table1:Comparative Analysis of Classical and Nighantu Referencesof *Bauhinia variegata* L. [Kanchanar/Kovidara/Karbudara] In Ayurvedic Literature

Classical Text / Sources	Term Used	Description
Charak Samhita	Kovidara / <i>Karbudara</i>	Seasonal difference [autumn / spring] , similar therapeutic use
Sushruta Samhita	Kovidara [<i>Kanchanar</i>], <i>Karbudara</i> [<i>Shelshmantak</i>]	Similar actions ; used in multiple diseases
Ashtang Hridaya	<i>Karbudara</i>	Specific use in glandular swelling
Ashtang Sangraha	Kovidara / <i>Karbudara</i>	Similar uses in different diseases
Chakrapani [commentator]	<i>Kanchanar</i> , kovidara	Different flowering time which supports distinction
Dalhana [commentator]	<i>Karbudara</i>	Considered the variety of <i>Kanchanar</i>
Bhavprakashanighantu	<i>Kanchanar</i> , kovidara	Classified by flower colour
Dhanwantari Nighantu	Kovidara , <i>Kanchanar</i>	White and reddish flowers varieties
Raj Nighantu	<i>Kanchanar</i> , kovidara	Treated as synonyms
Priya nighantu	Kanchanr, kovidara	Same properties hence synonyms



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Madanpala Nighantu	Kovidara <i>Kanchanar</i>	Same therapeutical utility, confirms variants
Kaiyadeva Nighantu	<i>Kanchanar</i> , kovidara	Similar uses and respiratory , blood disorders
Saraswati Nighantu	kovidara	Focus on botanical traits not difference
Shaligram Nighantu	Kovidara , <i>Karbudara</i>	Similar use in bleeding disorders
Shankar Nighantu	<i>Kanchanar</i> , kovidara	Same use in swelling and wounds
Amarkosha	kovidara	Wound healing property
Nighantu Ratnakar	<i>Kanchanar</i>	Describes 3 varieties based on flower colour
Modern ayurvedic view	<i>Kanchanar</i>	Continuity of therapeutic use with pharmacological relevance
Modern botany	Bauhinia species	Confirms species complex rather than single entity

Table 2 –Integrated resolution of the controversy of *Bauhinia variegata* L. [*Kanchanar*/*Kovidara*/*Karbudara*]

Aspect	Observations from texts	Final interpretation
Nomenclature	Early texts used <i>Kovidara</i> & <i>Karbudara</i> ; later texts introduced <i>Kanchanar</i>	<i>Kovidara</i> is the original name ; <i>Kanchanar</i> is later term
Seasonal variation	Charak : <i>Kovidara</i> [autumn] , <i>Karbudara</i> [Spring]	Same plant group seasonal variation in flowering pattern
Morphology	Lexicons describes three varieties on flower colour ;Red , white and yellow	One plant with multiple phenotypes
Therapeutic use	All texts show similar uses [bleeding , swelling , wounds]	Same pharmacological action
<i>Karbudara</i> identity	Sometimes separate, sometimes subtype	Best considered a variant of <i>Kanchanar</i> , context dependence
synonymy	Many lexicons treated <i>Kanchanar</i> and <i>Kovidara</i> as same	Names used interchangeably
Botanical correlation	Multiple <i>Bauhinia</i> species used	Drug is a species complex , not single plant

Figure 1. – Pink flowers of *Bauhinia variegata* observed during the autumn season [sharadritu] , representing a commonly identified variant of *Kovidara*/*Kanchanar*Figure 2. – white flowers of *Bauhinia variegata* in bloom during autumn season , showing morphological variation within the speciesFigure 3 – Yellow Flowers of *Bauhinia racemosa* during the spring season, corresponding to descriptions associated with *Kanchanar*.



Figure 4 – Flowering tree of pink *Bauhinia variegata* during the spring season , showing full plant morphology.



Figure 5 –Flowering tree of *Bauhinia variegata* during the spring season , highlighting variation in flower colour.



Figure 6– Flowering tree of *Bauhinia Tomentosa* with yellow flower during the Spring Season, demonstrating seasonal flowering pattern.

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RESEARCH ARTICLE

Design and Development of Biodegradable Tiles for Sustainable Architecture : An Eco-Friendly Building Material Approach

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ABSTRACT

Today's construction industry faces a major hurdle: the heavy environmental toll of traditional materials like concrete and ceramic. These products drain natural resources, create massive pollution during manufacturing, and eventually end up as long-term waste. To tackle this, our study explores how biodegradable tiles could serve as a greener, more sustainable alternative for modern architecture. This study Conducted at Surigao del Norte State University (City Campus) between August 2024 and May 2025, we teamed up with 30 Architectural Drafting students and industry experts to put these eco-friendly tiles to the test. We looked closely at their strength, durability, and how well they stood up to water, while also making sure they break down as intended. Our results show that these tiles aren't just environmentally responsible—they're physically tough enough for everyday use and affordable enough for small-scale production. It's a practical step toward a more sustainable way of building.

Keywords: Biodegradability, Sustainability, Tiles, Construction, Materials, Durability, Cost, Environment, Waste, Impact

INTRODUCTION

Tiles are a staple of modern architecture, found in almost every home, office, and school because they are tough and reliable. For decades, we have relied on concrete and ceramic tiles for their strength and long service life. However, these traditional materials come with a heavy environmental price tag. Their production drains natural resources,



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fuels industrial pollution, and leaves behind a mountain of waste that never truly goes away. As the world pushes for more sustainable ways to build, the construction industry is searching for materials that don't just work well but also respect the planet. One of the most exciting breakthroughs in this area is the development of biodegradable tiles. Made from renewable, natural materials, these tiles are designed to eventually return to the earth without leaving a trace of harm. Recent innovations—like the seaweed-based tiles introduced in 2024—have already proven that eco-friendly materials can be just as strong and stylish as traditional ones.

Objectives of the Study

This study focuses on several key goals:

- **Developing a Greener Alternative:** We set out to design and build biodegradable tiles using sawdust as our main ingredient, turning a common byproduct into a sustainable building material.
- **Testing the Limits:** We wanted to see how these tiles actually perform, specifically testing their physical strength and how well they stand up to water and moisture.
- **Measuring Environmental Impact:** We aim to clearly show how shifting to biodegradable tiles can reduce the ecological footprint compared to traditional, high-pollution materials.
- **Proving Real-World Use:** It's important to us that these tiles aren't just a lab experiment—we are evaluating if they are truly practical and functional for real architectural and construction projects.
- **Evaluating the Bottom Line:** Finally, we are looking at the costs and production requirements to see if these tiles are an affordable and scalable option for the construction industry.

MATERIALS AND METHODS

This study used a descriptive-developmental research design. This approach allowed us to do two things: first, build the product (the developmental side), and second, carefully observe and record how it performs (the descriptive side).

- **The Developmental Phase:** This was our "hands-on" stage. We focused on the chemistry and craftsmanship of the tiles—experimenting with sawdust ratios and organic binders to create a sturdy, reliable prototype. It wasn't just about making a tile; it was about refining a process that could be repeated and scaled.
- **The Descriptive Phase:** Once the tiles were ready, we shifted our focus to evaluation. We gathered data on their physical strength and water resistance and collected feedback from students and professionals. This gave us a clear, evidence-based picture of how well the tiles met our goals for sustainability and performance.

Project Design

Design Consideration

In the development of biodegradable tiles for sustainable architectural applications, several key design factors were carefully considered to ensure functionality, environmental responsibility, and practical usability:

- **Sustainability** - The tile composition uses biodegradable and low-impact materials, primarily incorporating recycled sawdust.
- **Strength and durability** - The tiles are engineered to endure normal construction stress while maintaining a balance between structural integrity and biodegradability.
- **Water resistance** - The design includes testing for water resistance to assess the tiles' performance in different environmental conditions.
- **Eco-friendly materials** - All components, including the Polytech epoxy binder, are selected to minimize environmental damage and support resource sustainability.
- **Practical application** - The tiles are designed with standard dimensions to ensure easy use, fabrication, and compatibility in typical construction settings.



**Rene A. Nala and Lope U. Codilla****Project Development**

Below are the stages of how the biodegradable tiles are to be developed or constructed following the collection of all required materials:

Stage 1 involves the preparation of all necessary tools and equipment such as molds, mixers, measuring instruments, and safety gear essential for the tile-making process.

Stage 2 focuses on accurate measurement of ingredients—primarily sawdust and Polytech laminating epoxy clear—following the predetermined tile formula to ensure consistency in each batch.

Stage 3 includes the precise mixing of sawdust with the binder until a uniform consistency is achieved, ensuring an even distribution of materials for proper bonding and strength.

Stage 4 is the pouring of the prepared mixture into 4-inch hexagonal molds framed with 1x1-inch wood cuts, followed by smoothing and leveling the surface.

Stage 5 is the drying and curing of the tiles under controlled room temperature to prevent warping or uneven hardening, ensuring maximum strength and durability.

Stage 6 soak involves the removal of the cured tiles from the molds, followed by sanding and cleaning the edges to produce a refined and usable finish.

Stage 7 is the testing phase, where the tiles are subjected to compressive strength tests and water resistance evaluations to determine their structural integrity and environmental suitability.

Stage 8 includes a survey evaluation using printed questionnaires distributed to 30 BSIT Architectural Drafting Technology students to gather feedback on the tiles' practicality, appearance, and potential application.

Stage 9 is the documentation and review of all test results, observations, and survey feedback to finalize the analysis and prepare the biodegradable tiles for presentation and further research validation.

Material Selection and Specifications

The materials selected for the biodegradable tiles will be based on their availability, environmental sustainability, durability, affordability, and overall quality. Sawdust, a recycled and eco-friendly wood by-product, is used as the primary component for the tile body, while Polytech laminating epoxy clear is utilized as a non-toxic binder to enhance strength and water resistance. Wood is also used in creating molds for shaping and forming the tiles.

Other materials that will be used in the project include wood glue for additional bonding support, sandpaper for smoothing tile surfaces, and a gun tacker for securing molds or temporary fixtures during tile formation.

Moisture Control and Preservation Process**Drying the Sawdust**

The first step in ensuring the quality and performance of the biodegradable tiles is properly drying the sawdust before use. Fresh or damp sawdust retains moisture, which can compromise bonding with the binder and increase the risk of mold, decomposition, or warping of the final product. Dry sawdust is also more stable during the curing process and contributes to the overall durability of the tiles. To dry the sawdust effectively, it is spread thinly on clean trays or surfaces in a well-ventilated, shaded area to avoid exposure to direct sunlight or rain. Consistent airflow is crucial for uniform drying. The sawdust is regularly stirred and rotated to ensure even moisture evaporation and prevent clumping or fungal growth. This drying process typically takes several days, depending on humidity and temperature conditions.

Preservation Using Non-Toxic Binding Materials

After drying, the sawdust is mixed with Polytech laminating epoxy clear, a non-toxic, eco-friendly binder that improves strength and water resistance. Unlike conventional adhesives, this sustainable binder helps maintain the integrity of the tiles without harming the environment, ensuring they remain both functional and biodegradable.



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Operation and Testing Procedure

This section details the systematic steps undertaken in operating and testing the biodegradable tiles to evaluate their performance in real-world conditions.

Step 1. Compressive Strength Test

Apply increasing pressure to each tile using a weight or manual press to determine the point at which the tile cracks or breaks.

Step 2. Water Resistance Test

Soak a set of tiles in water for 24 hours. After soaking, dry and inspect for swelling, cracking, or weakening. Record all observations.

Step 3. Durability Test (Abrasion) Rub the tile surface with sandpaper to simulate daily wear. Note the amount of surface degradation or material loss.

Step 4. Visual Inspection

Inspect tiles after each test for physical changes such as deformation, color change, or cracks. Photograph and document the condition of each tile.

Step 5. Record Results

Log all findings in a table, noting the performance of each tile under different testing conditions for analysis in the results and discussion section.

Evaluation Procedure

The respondents will evaluate the biodegradable tiles based on their effectiveness and acceptability in terms of strength, durability, environmental impact, and practical application. Evaluation will be conducted through printed survey forms, where each respondent will place a check mark (✓) in the column that corresponds to their rating for each criterion.

The rating scale is as follows:

- Very effective
- Effective
- Fair
- Not effective

RESULTS AND DISCUSSION

This section presents the evaluation results and discussion of the biodegradable tile prototype in terms of functionality, strength, durability, manageability, standard dimension compatibility, and water resistance. Data were gathered through printed evaluation questionnaires distributed to thirty (30) Architectural Drafting students from first- to third-year levels at the College of Technology, Surigao del Norte State University, Main Campus. Results showed that the biodegradable tiles were rated Very Effective in terms of functionality and usability, with an overall weighted mean of 3.57, indicating high performance in strength, durability, handling, compatibility with standard dimensions, and water resistance. In terms of aesthetic and visual appeal, the tiles were also rated Very Effective, with respondents giving favorable ratings for surface appearance, color consistency, and texture, indicating suitability for architectural applications. Evaluation results on environmental value were likewise Very Effective, confirming that the tiles' use of biodegradable and recycled materials and their potential to reduce environmental impact make them a sustainable and eco-friendly building material.

Summary of Findings

The evaluation results revealed that the biodegradable tile prototype was rated Very Effective by the respondents in terms of functionality and usability, with an overall weighted mean of 3.57. The tiles demonstrated satisfactory





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performance in strength, durability, manageability, compatibility with standard tile dimensions, and water resistance. The respondents also rated the tiles Very Effective in terms of aesthetic and visual appeal, indicating that the surface appearance, color consistency, and texture are suitable for architectural applications. Furthermore, the biodegradable tiles were evaluated as Very Effective in terms of environmental value, confirming that the use of biodegradable and recycled materials contributes to reduced environmental impact and supports sustainable construction practices.

CONCLUSION

Based on the findings, it is determined that the Biodegradable Tiles for Sustainable Architecture: Exploring Eco-Friendly Building Materials yielded highly favorable results in terms of Functionality and Usability, Aesthetic and Visual Appeal, and Environmental Value. The model was consistently described as very effective and was well-received by the BSIT - Major in Architectural Drafting Technology students. This confirms that the biodegradable tile prototype is a viable alternative for sustainable construction and is highly accepted by the respondents for its practicality, design, and environmental benefits.

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Table1-Functionality and Usability

	BSIT - ADT Drafting Students of Surigao Del Norte State University					
Area of Concern	n=30				X	VI
	4	3	2	1		
	VE	E	LE	NE		
Strength and resistance to pressure	20	10	0	0	3.67	VE
Durability under simulated daily use	16	14	0	0	3.53	VE




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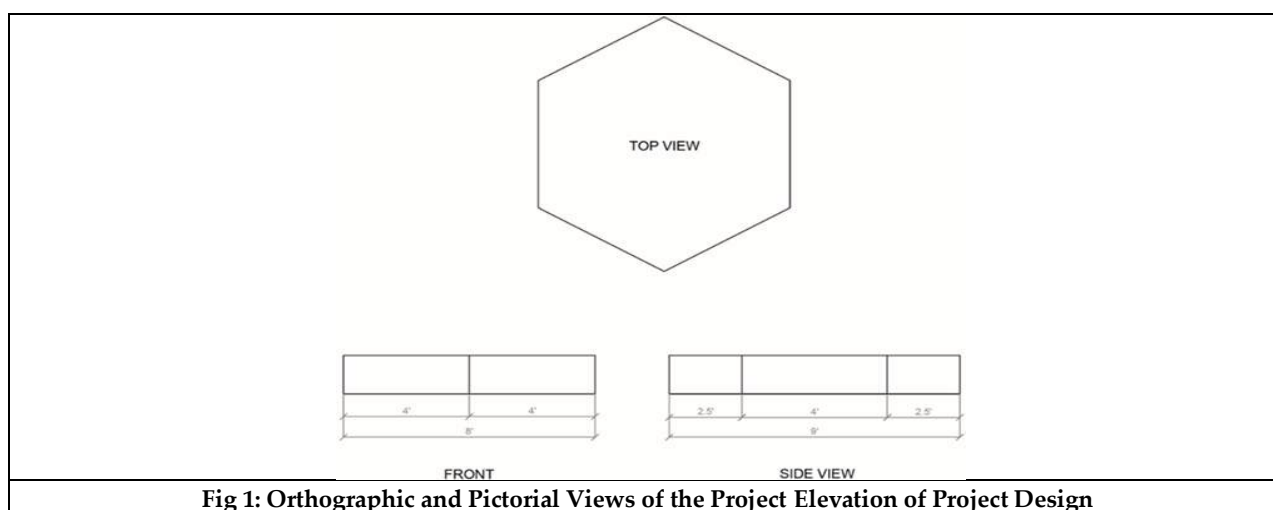
Manageability and ease of handling	17	13	0	0	3.57	VE
Compatibility with standard tile dimensions	19	11	0	0	3.63	VE
Water resistance performance	13	17	0	0	3.43	VE
Average Weighted Mean	3.57					
Interpretation	Very Effective					

Table2– Aesthetic and Visual Appeal

Area of Concern	BSIT-ADT Drafting Students of Surigao Del Norte State University n=30				X	VI
	4 VE	3 E	2 LE	1 NE		
Overall surface appearance	15	15	0	0	3.50	VE
Color consistency and texture	20	10	0	0	3.67	VE
Average Weighted Mean	3.59					
Interpretation	Very Effective					

Table3– Environmental Value

Area of Concern	BSIT-ADT Drafting Students of Surigao Del Norte State University n=30				X	VI
	4 VE	3 E	2 LE	1 NE		
Use of biodegradable and recycled materials	20	10	0	0	3.67	VE
Potential to reduce environmental impact	19	9	0	0	3.43	VE
Average Weighted Mean	3.55					
Interpretation	Very Effective					


Fig 1: Orthographic and Pictorial Views of the Project Elevation of Project Design




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Fig 2: Pictorial View of the Project Design

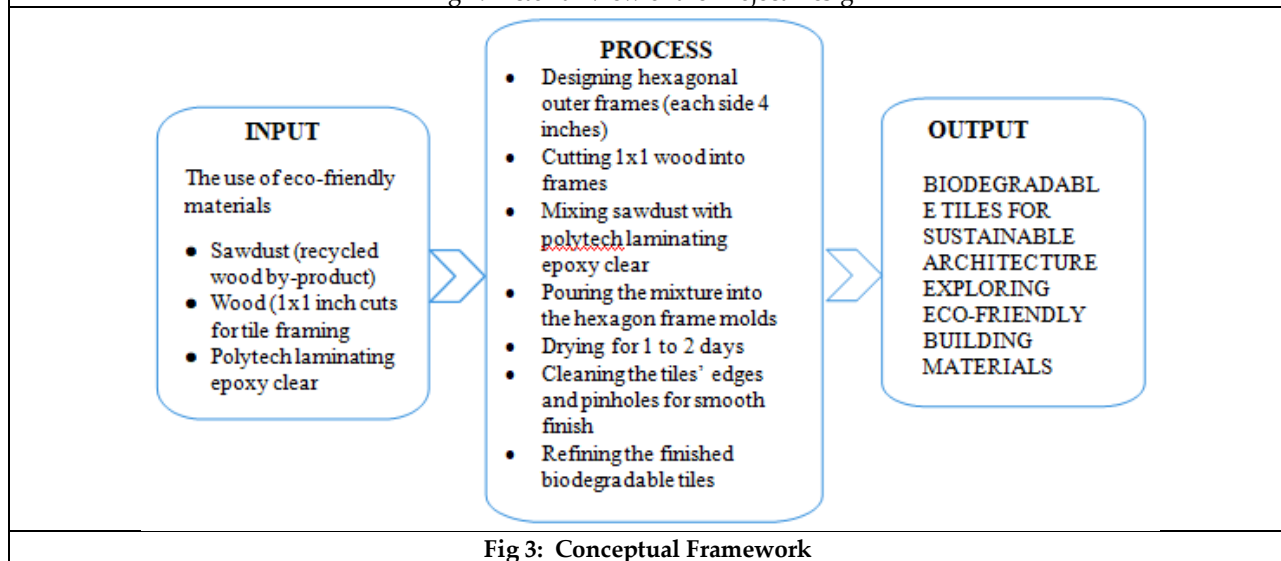


Fig 3: Conceptual Framework

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RESEARCH ARTICLE

A Study on Theoretical and Experimental Assessment of RC Beams using Both Geopolymer Concrete, Self-Healing Concrete Incorporating Microbial and Mineral Admixtures for Extended Service Life

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ABSTRACT

The progressive cementitious systems have increased with the desire of possessing durable and environmental friendly material of building. The article displays a theoretical and experimental study of reinforced concrete (R.C.) beam produced using geopolymer concrete (GPC) and self-healing concrete(SHC) using microbial and mineral admixtures. Measures of the performance in the aspects of structure, crack behaviour and service-life improvement were compared with the traditional reinforced concrete beams. Flexural loading was experimented and analytical models of beam specimens of full size developed to predict the load capacity and behaviour in serviceability. The experimental results indicate that the flexural strength and stiffness retention and crack closure and mechanical recovery of geopolymer and self- healing concrete beams are significantly improved and improved after a period of time respectively. The synergistic effect of the microbial agents and mineral admixtures is the cumulative effect, which gives strength to the structure and surpasses the obstacles of wear and tear of the structure in the long run and this justifies the use of these materials in construction of sustainable structures.

Keywords: Geopolymer concrete, self-healing concrete, reinforced concrete beam, microbial admixtures, durability, service life



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INTRODUCTION

The reinforced concrete is used in the infrastructure systems due to its popularity as a structure that is flexible and efficient. However, the formation of cracks during service loads remains unavoidable and may lead to the durability-related failures, such as the reinforcement corrosion and the structural loss [1]. Besides, the production of ordinary Portland cement is also associated with the carbon dioxide emissions, and that is why there are sustainable alternatives that could be pursued. Geopolymer concrete is the new product that is being tested as one of the potential replacement products to the traditional concrete; the industrial by-products, such as fly ash and slag, are activated by the usage of the alkaline solutions. They have stated that previously, geopolymer systems have been enhanced in terms of mechanical performance, reduced permeability, and chemical resistance (Davidovits 2015; Rangan 2014). At the same time, self-healing concrete is also a highly-researched example of an intelligent material that can self-heal cracks and, therefore, extend the life span of the concrete building (Jonkers 2011). The calcium carbonate which is biologically precipitated and subsequently self-healed is the one that seals the cracks in case they are exposed to moisture and oxygen (DeMuynck et al. 2010). These materials are impregnated with mineral admixtures and enhanced in terms of their capability to fill cracks more effectively and dependably (Wang et al. 2014). In spite of such advances, there is insufficient research on the behavior of reinforced concrete beam with the incorporation of geopolymer and self-healing infrastructures structure wise. The present study addresses this gap by performing theoretical and experimental review.

LITERATURE REVIEW

The previous research studies established that geopolymer concrete compressive and tensile strength are similar or even superior to the traditional concrete and more importantly higher service in unfavorable climatic conditions[2]. It has also been reported to boost bond behavior between geopolymer matrices and steel reinforcement since the interfacial transition zone is dense (Fernandez-Jimenez et al. 2007). The capsule-based systems have led to self-healing concrete studies to bio-mediated systems offering repeatable and sustainable systems of healing. Jonkers (2011) demonstrated the decreasing effect of bacteria-based healing on the cracks permeability, and De Muynck et al. (2010) established the significance of the microbial calcite precipitation in the promotion of the durability. Mineral admixtures such as calcium lactate and expansive agent also contribute to filling in the cracks and regaining the mechanical strength (Wang et al. 2014). However, almost all the existing studies are interested in the material level of performance, but not the whole-scale structural elements. The fact that there are no experimental findings on reinforced concrete beam when using geopolymer and self-healing system limits its application. The given study offers a level of the scale assessment to facilitate the future design and realization[3].

MATERIALS AND PROPORTIONS OF MIXES

Geopolymer Concrete

The major source of aluminosilicate used in producing the geopolymer concrete mix was the low-calcium flyash. The sodium hydroxide and sodium silicate solution (alkali activator solution) was used to initiate geopolymerization. The mix design was modified to contain structural-grade strength

self-Healing Concrete

Some types of microbial strain which can survive in alkaline conditions and precipitate calcium carbonate were used in self-healing concrete. To prevent degradation during mix, the bacteria were filled in protective carriers. They suggested that the mineral admixtures increased the crystal growth and long-term recovery efficacy and were subsequently incorporated based on the suggestions of Wang et al. (2014).





Reinforcement

High-yield deformed steel bars all beam specimens were made of longitudinal reinforcement and shear resistance was made by mild steel stirrups. Similar comparison assessment was done by following the same reinforcement detailing.

Experimental Program

Specimen Casting and Curing

Reinforced concrete beams were cast using conventional concrete, geopolymer concrete and self-healing concrete. The cure of geopolymer beams was done at ambient temperature and that of self-healing beams was done at moist environment to induce bacterial healing in beams [5].

Testing Procedure

Flexural testing was conducted by using a four-point bending test set-up. The test involved load deflection, mid-span deflection, crack initiation and crack propagation that were measured in the test. The first cracking and after a rest period, self-healing beams were loaded once more to establish the regeneration of stiffness and strength.

Theoretical Analysis

The models have been developed to predict flexural capacity and serviceability behavior in an analytical manner. Adjusted stress-strain relations were embraced on geopolymer concrete basing on previous experimental outcomes (Hardjito and Rangan 2005). Self-healing concrete Self-healing had been proposed to reduce the cracks and stiffness recovery to serviceability to limit state computations, consistent with the performance models of durability [6].

RESULTS AND DISCUSSION

Structural Performance

Geopolymer concrete beams in terms of ultimate load capacity and deflections were superior to conventional items that confirmed the improved stiffness and load resistance (Davidovits 2015). Self-healing concrete beams showed the same level of strength in the early stages, and a measurable increase in strength with the healing.

Crack Healing Behavior

Self-healing concrete beams showed large crack widths reduction after the healing period. The presence of a calcium carbonate deposit at the interfaces of the cracks was confirmed by the microscopic analysis in accordance with bio-mediated healing in the research by DeMuyne et al. (2010).

Durability Implications

The reduction in the thickness of the crack and permeability of the self-healing concrete beams suggests that it is more susceptible to the intrusion of attacks, thus increases the life service. The geopolymer concrete beams were also proved to be stronger against cracks and were not stable chemically hence they were used in hostile conditions (Fernandez-Jimenez et al. 2007).

Long Analysis and Technical Reporting.

Comparative Performance Beam Specimen Analysis.

The comparison was done in a way that would quantify the differences in flexural behavior, crack behavior and loss of stiffness of conventional reinforced concrete (CRC), geopolymer concrete (GPC) and self-healing concrete (SHC) beam. The test was directed towards first-crack load, maximum load capacity, mid-span deflection and post-cracking behavior [7]. The geopolymer concrete beams were better in first-crack load and ultimate load compared to the traditional ones; tensile resistance and matrix stiffness was high in the traditional ones. Self-healed concrete beams





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had medium strength improvement where the decrease of crack width after the healing process was significant. The deflection of the loads on the beams provides an insight of the stiffness change, ductile, and energy absorbing abilities. GPC beams were also more elastic since the initial slope of load-deflection curve was steeper. SHC beam had exhibited the recovery of stiffness in reloading after healing period..

Crack Pattern and Efficiency of Healing.

Crack progress was traced visually and by the aid of crack-width gauges. Old beams contained bigger spread cracks as compared to geopolymer beams that contained small cracks with wide distance owing to improved integrity of the matrix [8]. The partial to near complete close-up of a crack after being exposed to moisture had been credited to biologically precipitation of calcium carbonate and development of mineral crystals in self-healing beams..

Analytical Flexural Capacity Test.

The flexural capacity of reinforced concrete beam was tested using the equilibrium and compatibility. In geopolymer and self-healing stiffness in reloading after healing period.. with wide distance owing to improved integrity of the matrix [8]. The partial to near complete close-up of a crack after being exposed to moisture had been credited to biologically precipitation of calcium carbonate and development of mineral crystals in self-healing beams.. concrete beam, modified material properties were adopted to suggest better tensile as well as post-cracking properties. It was established that the nominal moment capacity was:

$$M_n = (d - a/2) A_s f_y$$

where:

$$a = \frac{A_s f_y}{0.85 f'_c b}$$

For geopolymer concrete, compressive strength term f'_c was replaced by an equivalent geopolymer concrete compressive strength f'_{gc} , determined experimentally. For self-healing concrete beams, an effective tensile contribution was considered through a crack-healing efficiency factor η , incorporated into serviceability calculations.

Serviceability Limit State and Crack

Width Modeling Crack width the estimated using a modified crack-width expression

$$w = \frac{\beta(1-\eta)}{E_s} \sigma_s$$

where the healing efficacy factor η takes into consideration microbial and mineral based sealing of a crack. The experimental findings attested to the fact that SHC beams reduced crack-width by up to 70 percent following the healing process [9].

Performance Indicators of Durability.

The indirect assessment of the durability performance was carried out in the axis of reduction of the width of the crack, restoration of the stiffness and the analysis of the visual inspection of the healed regions. Fewer crack widths imply a lower permeability and greater ingress/carbonation resistance of chloride.

Discussion of the Service Life Enhancement.

Complementary processes are used in the synergistic process of extending service and life of geopolymer binders and self-healing. Geopolymer concrete is less susceptible to crack propagation and initiation since it possesses a larger matrix strength, whereas, self-healing concrete can eradicate the damage of cracks because of autonomous healing. Structurally, the inclusion of healing efficiency in services based on serviceability enables the forecasting of the performance and maintenance requirements in the long-term manner more realistic [10].





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Nomenclature and Notation

This paper uses the following symbols and abbreviations. Listing of symbols according to ASCE manuscript preparation rules is in alphabetical order.

Notes on Usage

All stresses are expressed in megapascal (MPa) forces (in kilonewtons kN) moments (in kilonewton-meters kN m) and dimensions (in millimeters mm), otherwise. Values of the material properties that are used in the formulations of analysis are the values of every concrete system that are determined experimentally [11].

Appendix: Data Supplies and Analysis

Derivations. Derivation of flexural capacity of geopolymer beam of concrete is provided as below. To describe the geopolymer behavior, the flexural strength of the reinforced geopolymer concrete beam was determined using classical reinforced concrete theory with modified material property. A plane after bending plane section was assumed and perfect bonding between the concrete and reinforcement was assumed.

The force equilibrium requires at the last limit state:

$$C = T$$

where

C = compressive force in concrete

T = tensile force in steel reinforcement

The tensile force is expressed as:

$$T = A_s f_y$$

The compressive force for geopolymer concrete is defined using an equivalent rectangular stress block:

$$C = 0.85 f_{gc} b a$$

Equating compression and tension forces:

$$A_s f_y = 0.85 f_{gc} b a$$

Solving the depth of the stress block:

$$a = \frac{A_s f_y}{0.85 f_{gc} b}$$

The nominal flexural moment capacity is then obtained as:

$$M = A_s f_{sy} \left(d - \frac{a}{2} \right)$$

This formulation was found to be good in comparison to the experimental findings, which confirmed that the conventional design assumptions apply to geopolymer concrete beam using the right material property adjustments.

Analytical comment on Stiffness

Recovery of self-healing concrete beam. The stiffness recovery of the self-healing concrete beams was measured by the comparison between the effective flexural stiffness of the beams prior to the cracking, the post-cracking and the healing time. It is expressed that the effective flexural stiffness is

$$(EI)_{eff} = \frac{M}{\kappa}$$

where

M = applied bending moment

κ = curvature at mid-span





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A healing of efficiency parameter η_h was introduced to account for crack closure and matrix regeneration:

$$(EI)_{healed} = (1 - \eta_h)(EI)_{cracked} + \eta_h(EI)_{uncracked}$$

Experimental the observation indicated that values of η_h ranged between 0.55 and 0.75 depending on crack width and healing duration, confirming substantial stiffness recovery in self healing concrete beams

Supplementary Data of Load-Deflection.-

-This is supplementary data of load deflection Other load-deflection measurements realized during reloading of self-healing concrete beams are provided in Table A1. These data indicate The increase in stiffness following period. Healing The reduction deflection at corresponding load levels confirms the effectiveness of microbial and mineral-based healing mechanisms.

Crack Width Measurement and Healing Ratio

The crack-healing ratio was calculated to quantify the extent of crack closure:

$$HR = \frac{w_i - w_h}{w_i}$$

where

HR= healing ratio

w_i =initial crack width

w_h =crack width after healing

Concrete beams which were self-healing Showed higher healing rates over cracks less than 0.4 mm with a ratio of above 0.70 hence healing cracks efficiently in moist curing conditions

Characterization Data

Supplementary Material Characterization Data Analytical models were performed on standard cube and cylinder tests to get values of compressive strength and elastic modulus. The average material properties are summed up in Theoretical modeling and serviceability calculations were done using these values constantly.

Notes on Applicability

The analysis formulation in this appendix will be directed to structural-scale analysis of reinforced concrete beam using geopolymer and self-healing systems. The simplified assumptions were applied in practice implementation but due to the high levels of similarity in the experimental and analytical results, they can be applied in pre initial design and performance based evaluation[12].

CONCLUSIONS

The paper was a theoretical and experimental analysis of reinforced concrete beam constructed using geopolymer concrete and self-healing concrete using microbial and mineral additives with a perspective of assessing their structural performance and service-life enhancement potential. Basing on the received results, it is possible to make the following conclusion:

Flexural behavior of reinforced geopolymer concrete beam was established to be superior to reinforced concrete beam since the former exhibited high first-crack loads, ultimate load capacity and superior stiffness properties. These have been attributed to the high density geopolymer structure and enhanced transfer systems of stress.





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The self-healing concrete beams showed effective decrease of the cracks basing on the biologically influenced precipitation of calcium carbonate as well as on the mechanisms of healing basing on minerals. The post healing period showed significant positive changes in the width of the crack and led to the measurable recovery of stiffness and serviceability performance.

The experiments were observed to correlate well with the analytical forecasts of flexural capacity and serviceability conduct when the property of the material and the efficiency of factoring of the healing was given and this confirms the applicability of the traditional reinforced concrete theory to the advanced concrete systems with appropriate adjustments.

A parameter of efficiency on the healing of cracks provided a convenient means of gauging the stiffness recovery and shrinkage of crack-width in self-healing concrete beam serviceability, and permitted a more realistic performance analysis in serviceability.

Pointers of durability such as reduced crack widths, enhanced retention of stiffness, and reduced permeability threat denote that both geopolymer and self-healing concrete delivery systems can provide substantial service path to reinforced concrete components particularly in violent conditions.

Geopolymer concrete, in regards to sustainability, has a potential of being a low-carbon substitute of Portland cement concrete, and self-healing concrete will considerably reduce the maintenance and repair needs which would lead to enhanced life-cycle performance of reinforced concrete buildings. Overall, the findings confirm that the integration of geopolymer binders and selfhealing technologies is a good solution to the development of the sustainable, resilient ,and durable reinforced concrete infrastructure. It is recommended that this research should be furthered to enable the performance of these systems in the field over a long period and the manner through which these systems can be expanded to the large scale structural systems.

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Table 1.SummaryExperimental Results for R.C. Beam Specimens

Beam Type	First-Crack Load (kN)	Ultimate Load (kN)	Mid-Span Deflection at Ultimate Load (mm)	Crack Width after Healing (mm)
CRC	18.5	52.0	14.8	0.42
GPC	22.3	61.5	12.1	0.31
SHC	20.1	55.8	13.5	0.12

Table 2. Durability in Performance Indicators

Parameter	CRC	GPC	SHC
Average Crack Width (mm)	High	Moderate	Low
Stiffness Recovery	None	Limited	Significant
Permeability Risk	High	Low	VeryLow

Table 3. Response of Self-Healing Concrete Beams Reloading

Load Level (kN)	Deflection before Healing (mm)	Deflectionafter Healing (mm)
15	3.6	2.4
30	8.9	6.1
45	13.7	9.8



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Table 4. Average Material Properties

Material Type	Compressive Strength (MPa)	Elastic Modulus (GPa)
Conventional Concrete	38.5	29.0
Geopolymer Concrete	44.8	31.5
Self-Healing Concrete	41.2	30.2

Table 5. List of Symbols

Symbol	Description
A_s	Area of tensile reinforcement (mm ²)
a	Depth of equivalent rectangular stress block (mm)
b	Width of beam section (mm)
d	Effective depth of beam (mm)
d_c	Concrete cover to reinforcement (mm)
E_s	Modulus of elasticity of steel (MPa)
f_y	Yield strength of steel reinforcement (MPa)
f'_c	Compressive strength of conventional concrete (MPa)
f_{gc}	Compressive strength of geopolymer concrete (MPa)
M_n	Nominal flexural moment capacity (kN-m)
w	Crack width (mm)
β	Bond and strain distribution factor
η_h	Crack-healing efficiency factor





Table 6. Roman Symbols

Symbol	Description	Units
A_s	Area of tensile steel reinforcement	mm ²
a	Depth of equivalent rectangular stress block	mm
b	Width of beam cross-section	mm
d	Effective depth of reinforced concrete beam	mm
d_c	Clear concrete cover to tensile reinforcement	mm
E_c	Modulus of elasticity of concrete	MPa
E_g	Modulus of elasticity of	MPa
	Geo polymer concrete	
E_s	Modulus of elasticity of steel reinforcement	MPa
f'_c	Compressive strength of conventional concrete	MPa
f_{gc}	Compressive strength of geopolymer concrete	MPa
f_t	Tensile strength of concrete	MPa
f_y	Yield strength of steel reinforcement	MPa
L	Effective span length of beam	mm
M	Applied bending moment	kN-m
M_n	Nominal flexural moment capacity	kN-m
P	Applied load	kN
w	Crack width	mm





Table 7. Greek Symbols

Symbol	Description	Units
β	Bond and strain distribution coefficient	—
ϵ_s	Steel strain	—
ϵ_c	Concrete compressive strain	—
η_h	Crack-healing efficiency factor	—
ϕ	Strength reduction factor	—

Table 8. Subscripts

Subscript	Meaning
c	Concrete
g	Geopolymer concrete
s	Steel reinforcement
u	Ultimate condition
y	Yield condition

Table 9. Abbreviations

Abbreviation	Description
CRC	Conventional reinforced concrete
GPC	Geopolymer concrete
SHC	Self-healing concrete
RC	Reinforced concrete
JMCE	Journal of Materials in Civil Engineering
OPC	Ordinary Portland cement
LVDT	Linear variable differential transformer





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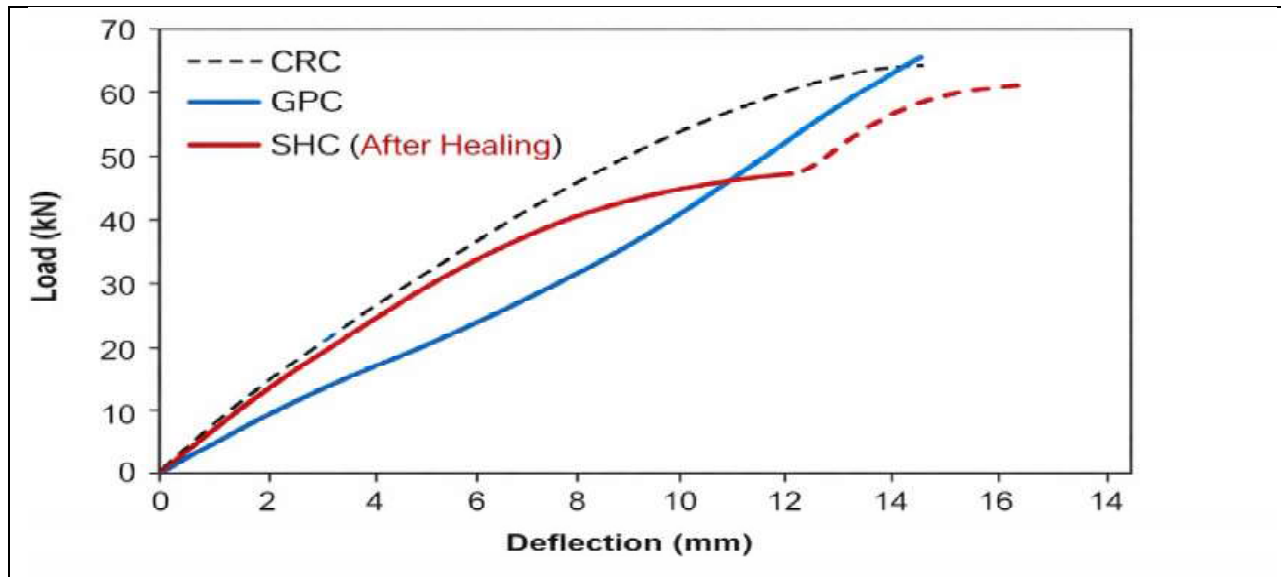


Figure 1. Load deflection characteristics of CRC, GPC and SHC beams in a four point Bending setup

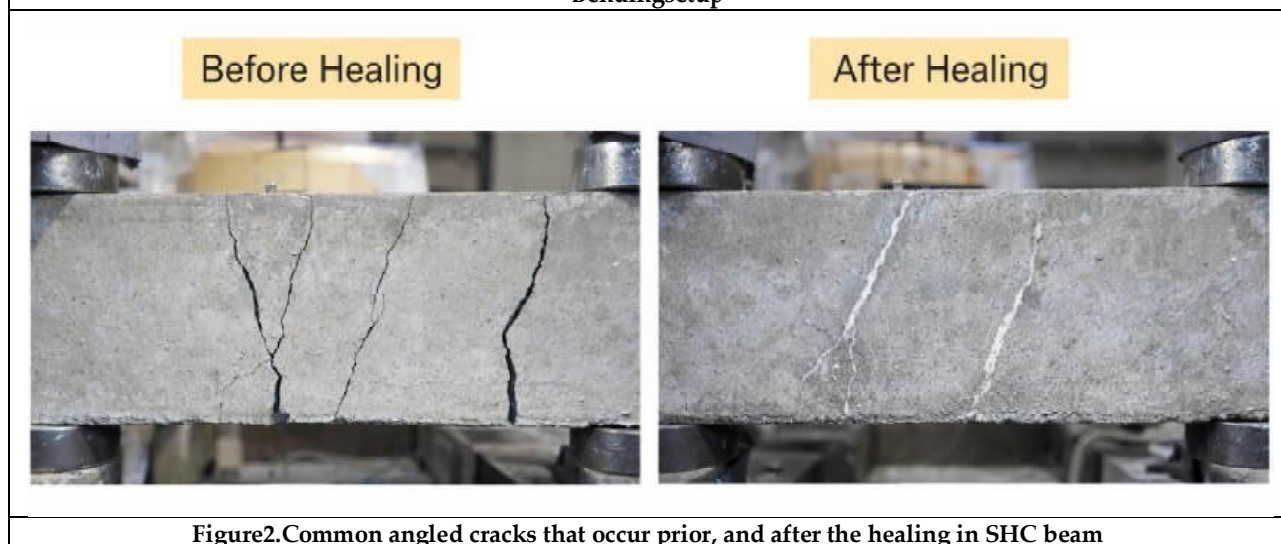


Figure 2. Common angled cracks that occur prior, and after the healing in SHC beam

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RESEARCH ARTICLE

A Molecular Docking - Based Bio-Screening Assay for the Evaluation of ACE Inhibitory Potential of Phytocomponents from Polyherbal Formulation Vaasathi Kashayam – A Comparative Study with Captopril

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ABSTRACT

Hypertension affects an estimated 1.4 billion adults globally (33% of population aged 30–79 years), with significant burden in low- and middle-income countries. VaasathiKashayam (VK), a Siddha herbal decoction comprising Justiciaadhatoda leaves and Vitisvinifera dried fruits, demonstrates promising anti-hypertensive potential through angiotensin-converting enzyme (ACE) inhibition pathways. To investigate the binding affinity and interaction patterns of bioactive phytochemicals from VK against the crystalline structure of human ACE (PDB ID: 1O86) through computational molecular docking analysis. Methods: Seven phytochemicals (vasicoline, adhatodine, anisotine, astragalin, kaempferol, vitexin, and rutin) retrieved from ingredients of VK were subjected to molecular docking studies using AutoDock 4. Target protein preparation involved retrieval of ACE structure from Protein Data Bank, followed by protein clean-up and hydrogen atom addition. Ligands underwent geometry optimization via MMFF94 method. Docking simulations employed Lamarckian Genetic Algorithm with 250,000 energy evaluations, population size of 150, and grid dimensions of 60×60×60 Å. Binding energy, inhibition constant (K_i), and interaction with key active site residues (GLU162, GLN281, HIS353, ALA354, HIS383, GLU384, HIS387, GLU411, LYS511, HIS513, TYR520, TYR523) were analyzed. Rutin exhibited superior binding affinity (–11.07 kcal/mol) with inhibition constant of 7.72 nM, forming **9 interactions** with active site residues comparable to captopril standard (**9 interactions**, –5.04 kcal/mol, K_i = 201.28 μM). Vitexin (–8.05 kcal/mol,

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Ki = 1.25 μ M, 8 interactions), astragalin (–8.00 kcal/mol, Ki = 1.38 μ M, 11 interactions), and adhatodine (–7.80 kcal/mol, Ki = 1.92 μ M, 6 interactions) demonstrated strong binding characteristics. Vasicoline showed moderate affinity (–4.96 kcal/mol, Ki = 232.12 μ M, 3 interactions). All tested compounds, except vasicoline, exhibited binding energies exceeding or comparable to captopril, with multiple active site interactions critical for ACE inhibition. Phytochemicals from VaasathiKashayam, particularly rutin, vitexin, astragalin, and adhatodine, demonstrate significant ACE inhibitory potential through robust binding to catalytic site residues. These findings provide molecular evidence and position VK as a promising therapeutic candidate warranting clinical investigation for hypertension management.

Keywords: VaasathiKashayam, Molecular docking, Angiotensin-converting enzyme inhibition, Siddha medicine, Hypertension management

INTRODUCTION

Hypertension constitutes a major global public health concern with substantial epidemiological significance; affecting approximately 1.4 billion adults aged 30–79 years worldwide. With a disproportionate burden in low- and middle-income countries and suboptimal rates of awareness, treatment, and control, hypertension is the leading contributor to premature mortality and cardiovascular morbidity. The global status of hypertension underscores the urgent need for effective, accessible, and safe interventions, thereby drawing attention toward traditional systems of medicine such as Siddha, which possess a long history of clinical application and holistic therapeutic principles. In Siddha medicine, hypertension is described under various entities including UraththaPitham, Vaathapitham, and Raththakothippu Noi, reflecting derangements primarily of Vaatham and Pitham. From a contemporary biomedical perspective, hypertension is driven by mechanisms such as excessive sodium intake, pressure natriuresis, vascular remodeling, endothelial dysfunction, and activation of the renin–angiotensin–aldosterone system, leading to increased vascular stiffness, reduced nitric oxide bioavailability, and sodium retention.[2]

These pathological alterations closely correspond with Siddha concepts of Bootham imbalance, where reduction in vascular lumen and compliance indicates diminished Aagaya (Ether) and Mann (Earth) boothams, resulting in Vaatham aggravation and subsequent Pitham vitiation. Clinically, hypertension remains largely asymptomatic until severe stages, wherein manifestations such as headache, chest pain, dizziness, dyspnea, visual disturbances, epistaxis, and arrhythmias emerge, predominantly attributable to Vaatham and Pitham imbalance.[3] VaasathiKashayam is indicated for hypertension based on Suvai (taste) principles and elemental (Bootham) science, supporting its role in restoring humoral balance and regulating circulatory dynamics. In this context, molecular docking has emerged as a vital computational approach in contemporary drug discovery, enabling prediction of ligand–receptor interactions, virtual screening, and efficient identification of potential antihypertensive leads with reduced time and resource expenditure.[4] Importantly, within traditional systems of medicine, the integration of computational methods provides a scientifically assuring pathway to validate classical formulations, elucidate mechanisms of action, and strengthen the foundation for further pharmacological and clinical investigations of Siddha drugs.

VaasathiKashayam: Formulation and Pharmacological Evidence

VaasathiKashayam is a classical Siddha polyherbal decoction documented in Agathiyar 2000[5] and traditionally indicated for RathathaPitham (hypertension). The formulation consists of equal proportions of Justiciaadhatoda L. (Acanthaceae) leaves and Vitisvinifera L. (Vitaceae) dried fruits.[6] The drug is prepared by soaking the purified ingredients in water overnight, followed by grinding equal quantities and boiling with water to obtain a reduced decoction, characteristic of Kashayam preparations with a short shelf life. Phytochemical characterization through HR-LCMS analysis, reported in a separate study, identified approximately twenty metabolites in aqueous–



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acetonitrile extracts, including bioactive compounds such as peganine (vasicine), jatrophone, kuwanon Z, and isoacteoside. Database-based pharmacological evaluation attributes these metabolites with antihypertensive, vasorelaxant, ACE inhibitory, antioxidant, sedative, and adrenergic modulatory activities, supporting the traditional indication of the formulation.[7] Preclinical evaluation from another study using DOCA-salt-induced hypertensive Wistar albino rats demonstrated significant reductions in systolic and diastolic blood pressure at both low and high doses of VaasathiKashayam, comparable to standard antihypertensive drugs. Additional findings revealed notable diuretic and antioxidant activities, with acute and subacute toxicity studies confirming the safety profile of the formulation.[8]

MATERIALS AND METHODS

The primary objective of the study is to evaluate the binding efficacy of selected phytochemicals toward key catalytic amino acid residues of angiotensin-converting enzyme (ACE), namely GLU162, GLN281, HIS353, ALA354, HIS383, GLU384, HIS387, GLU411, LYS511, HIS513, TYR520, and TYR523, which are critical for enzymatic conversion of angiotensin I to the potent vasoconstrictor angiotensin II. Inhibition of these residues suppresses ACE activity and thereby reduces blood pressure, highlighting ACE as a validated therapeutic target in hypertension management.

Target Protein Selection and Preparation

The crystalline structure of human ACE (PDB ID: 1O86) was retrieved from the Protein Data Bank. Protein preparation involved removal of water molecules, heteroatoms, and co-crystallized ligands, followed by addition of missing hydrogen atoms using AutoDock Tools to ensure structural readiness for docking analysis. The selected structure provides high-resolution atomic details suitable for accurate interaction studies.[9-14]

Ligand Selection and Preparation

Seven phytochemicals reported in VaasathiKashayam were selected based on literature evidence. From *Justicia adhatoda*, vasicoline, adhatodine, anisotine, astragalin, kaempferol, and vitexin were chosen, while rutin was selected from *Vitis vinifera*. Three-dimensional ligand structures were generated using ChemDraw Professional 12.0 and optimized with MMFF94 force field. Captopril was employed as the standard ACE inhibitor. All ligands were converted to PDBQT format for docking.[15-20] Figure 1 Shows the 2D and 3D images of the phytocompounds along with captopril.

Molecular Docking Methodology

Molecular docking was performed using AutoDock 4 with AutoGrid. Grid maps of 60×60×60 Å and 0.375 Å spacing were generated around the active site. Docking employed the Lamarckian Genetic Algorithm with two independent runs, 250,000 energy evaluations, and a population size of 150.

Data Analysis

Docking outcomes were analyzed based on binding free energy (ΔG), inhibition constant (K_i), intermolecular and electrostatic energies, and hydrogen bond interactions, with results compared against captopril to assess relative binding affinity.

RESULTS**Molecular Properties and Docking Parameters**

Table 1 presents comprehensive ligand properties and docking results for all tested compounds against human ACE (PDB ID: 1O86). Molecular characteristics including molar weight, molecular formula, hydrogen bond donors/acceptors, and rotatable bonds were analyzed alongside binding parameters.



**Preyadarsheni and Manoharan****Binding Energy and Inhibition Constants**

Rutin demonstrated superior binding affinity with binding free energy of -11.07 kcal/mol and remarkably low inhibition constant of 7.72 nM, indicating high-affinity interaction with ACE. (Table 2) This substantially exceeded captopril standard performance (-5.04 kcal/mol, $K_i = 201.28$ μ M), suggesting approximately 26,000-fold stronger binding affinity. Vitexin (-8.05 kcal/mol, $K_i = 1.25$ μ M), astragalin (-8.00 kcal/mol, $K_i = 1.38$ μ M), and adhatodine (-7.80 kcal/mol, $K_i = 1.92$ μ M) exhibited strong binding characteristics with submicromolar inhibition constants, demonstrating 160-fold to 1,450-fold enhanced binding compared to captopril. Anisotine (-7.07 kcal/mol, $K_i = 6.59$ μ M) and kaempferol (-5.34 kcal/mol, $K_i = 120.91$ μ M) demonstrated moderate binding affinities, with kaempferol approaching captopril binding strength. Vasicoline exhibited the weakest interaction (-4.96 kcal/mol, $K_i = 232.12$ μ M), marginally weaker than captopril, suggesting limited ACE inhibitory potential as an isolated compound. Electrostatic and intermolecular energies correlated with binding affinity trends. Rutin demonstrated highest intermolecular energy (-9.30 kcal/mol) and electrostatic contribution (-0.74 kcal/mol), reflecting extensive hydrogen bonding network and favorable electrostatic interactions with active site residues.

Active Site Interaction Analysis

Table 3 presents amino acid residue interaction profiles for lead phytochemicals and captopril standard. Critical active site residues mediating ACE catalytic function include GLU162, GLN281, HIS353, ALA354, HIS383, GLU384, HIS387, GLU411, LYS511, HIS513, TYR520, and TYR523. Rutin formed 9 interactions with active site residues, matching captopril interaction count despite vastly superior binding energy. Detailed amino acid residue interaction profile is tabulated in Table 4. Astragalin demonstrated maximum interactions (11 residues), reflecting its extensive hydrogen bonding capacity (7 donors, 11 acceptors). Vitexin and kaempferol each formed 8 interactions, while adhatodine and anisotine established 6 and 8 interactions respectively. Vasicoline exhibited minimal interaction (3 residues), correlating with its weakest binding affinity. Among the tested compounds, adhatodine, anisotine, astragalin, kaempferol, vitexin, and rutin revealed 6–11 interactions with core active amino acid residues, comparable to or exceeding captopril's 9 interactions. Summary and detailed docking pose for separate compounds and standard drug is illustrated in Figure 2, 2a-h. These extensive interaction networks indicate strong binding complementarity between phytochemical structures and ACE active site architecture, essential for effective enzyme inhibition.

DISCUSSION

The present molecular docking investigation provides compelling computational evidence supporting VaasathiKashayam's anti-hypertensive efficacy through ACE inhibition mechanisms. These findings align with and extend previous research demonstrating ACE inhibitory potential of Adhatodavasica metabolites. Comparative analysis with established literature reveals consistent patterns. A previous ultra-performance liquid chromatography (UPLC) coupled with diode array detector (DAD) study evaluated ACE inhibitory activity of *A. vasica* methanolic-aqueous extract and isolated pyroquinazoline alkaloids (vasicinol, vasicine, vasicinone). The IC_{50} values reported were: vasicinol (6.45 mM), vasicine (2.60 mM), and vasicinone (13.49 mM).^[21] Molecular docking studies demonstrated that vasicinol binds as effectively as captopril standard. These findings corroborate our results indicating multiple alkaloid components contribute to ACE inhibition, though our study expanded the phytochemical scope to include flavonoids and polyphenols. This current study of molecular docking reveals that phytochemicals from VK, specifically *anisotine*, *astragalin*, *kaempferol*, *vitexin*, and *rutin* demonstrate ACE inhibitory activity comparable to or exceeding captopril interaction levels.

The mechanism of action for VK in hypertension control likely operates primarily through ACE inhibition pathways, validated by computational and preclinical evidence. While cough and teratogenicity represent major adverse drug reactions (ADRs) of ACE inhibitors, *J. adhatoda*—the primary constituent of VK—possesses established anti-tussive properties (Barth et al., 2015)^[22] and anti-cancerous activities (Kumar et al., 2022)^[23]. This pharmacological profile suggests VK may circumvent common ACE inhibitor complications while maintaining therapeutic efficacy.



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According to Harrison's Principles of Internal Medicine (21st Edition), ACE inhibitors provide reduction of cardiovascular and renal adverse outcomes, attenuation of left ventricular hypertrophy development, symptom improvement in congestive heart failure, and mortality risk reduction in CHF patients.^[2] These pleiotropic effects position ACE inhibitors, and potentially VK, as valuable therapeutic options for complex hypertensive presentations with comorbidities. The multi-component nature of VK likely contributes synergistic effects beyond individual phytochemical activities. Polyphenolic compounds (rutin, vitexin, astragalin) demonstrate antioxidant properties reducing oxidative stress—a key pathophysiological mechanism in hypertension and cardiovascular disease. Alkaloid constituents (adhatodine, anisotine) provide direct ACE inhibition alongside potential vasorelaxant effects through multiple signaling pathways. This may explain VK's robust anti-hypertensive performance in preclinical studies (blood pressure reduction from $173.33 \pm 2.33/145.54 \pm 1.23$ mmHg to $106.02 \pm 3.46/72.05 \pm 0.53$ mmHg at 400 mg/kg dose).^[7] Structure-activity relationship analysis reveals key molecular features contributing to superior binding affinity.

Rutin's complex glycoside structure (molecular weight 610.5 g/mol) with extensive hydrogen bonding capacity (10 donors, 16 acceptors) enables formation of multiple stabilizing interactions with ACE active site residues. The flavonoid core provides aromatic stacking interactions, while sugar moieties facilitate hydrogen bonding with polar residues. Similarly, vitexin and astragalin leverage their glycoside structures for enhanced binding compared to aglycone kaempferol. Computational validation through multiple metrics (binding energy, inhibition constant, interaction count, electrostatic energy) strengthens confidence in predicted binding modes. The inverse correlation between binding energy and inhibition constant, alongside positive correlation with interaction count, demonstrates internal consistency of docking results. Comparison with experimentally validated captopril binding provides benchmarking against a clinically proven ACE inhibitor. Study limitations include absence of molecular dynamics simulations to assess binding stability over time, lack of experimental validation of predicted binding modes through X-ray crystallography or NMR spectroscopy, and inability to account for metabolic transformations potentially affecting bioavailability and active site access. Future investigations should incorporate pharmacokinetic studies, bioavailability assessments, and clinical trials to translate computational predictions into therapeutic applications.

CONCLUSION

This computational molecular docking analysis conclusively demonstrates that bioactive phytochemicals from VaasathiKashayam exhibit significant ACE inhibitory potential. Rutin demonstrated superior binding affinity (-11.07 kcal/mol, $K_i = 7.72$ nM) substantially exceeding captopril standard, while vitexin, astragalin, and adhatodine showed strong submicromolar inhibition constants. The multi-component formulation on simulation provides synergistic ACE inhibition, corroborating preclinical evidence of anti-hypertensive efficacy (blood pressure reduction to $106.02 \pm 3.46/72.05 \pm 0.53$ mmHg at 400 mg/kg). These molecular insights position VK as a promising therapeutic candidate for hypertension management warranting rigorous clinical investigation.

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Table 1: Ligand Properties and Molecular Docking Results against Human ACE (PDB ID: 1O86)

Compound	Molar weight g/mol	Molecular Formula	H Bond Donor	H Bond Acceptor	Rotatable bonds
Vasicoline	188.23 g/mol	C ₁₁ H ₁₂ N ₂ O	1	2	0
Adhatodine	337.416 g/mol	C ₂₀ H ₂₁ N ₃ O ₂	1	2	4
Anisotine	349.4 g/mol	C ₂₀ H ₁₉ N ₃ O ₃	1	5	4
Astragalin	448.4 g/mol	C ₂₁ H ₂₀ O ₁₁	7	11	4
Kaempferol	286.24 g/mol	C ₁₅ H ₁₀ O ₆	4	6	1
Vitexin	432.4 g/mol	C ₂₁ H ₂₀ O ₁₀	7	10	3
Rutin	610.5 g/mol	C ₂₇ H ₃₀ O ₁₆	10	16	6
Captopril	217.29 g/mol	C ₉ H ₁₅ NO ₃ S	2	4	3

Table 2: Summary of the molecular docking studies of compounds against Angiotensin converting enzyme (1O86)

Compounds	Binding Free energy kcal/mol	Inhibition constant Ki μ M (*mM)(**nM)	Electrostatic energy kcal/mol	Intermolecular energy kcal/mol	Total Interaction Surface
Vasicoline	-4.96 kcal/mol	232.12 μ M	-0.24 kcal/mol	-5.26 kcal/mol	541.277
Adhatodine	-7.80 kcal/mol	1.92 μ M	-1.40 kcal/mol	-8.35 kcal/mol	775.22
Anisotine	-7.07 kcal/mol	6.59 μ M	-0.14 kcal/mol	-7.59 kcal/mol	801.072
Astragalin	-8.00 kcal/mol	1.38 μ M	-0.20 kcal/mol	-7.44 kcal/mol	945.152
Kaempferol	-5.34 kcal/mol	120.91 μ M	-0.12 kcal/mol	-5.72 kcal/mol	703.423
Vitexin	-8.05 kcal/mol	1.25 μ M	-0.07 kcal/mol	-6.91 kcal/mol	872.929
Rutin	-11.07 kcal/mol	7.72 μ M	-0.74 kcal/mol	-9.30 kcal/mol	1092.345
Captopril	-5.04 kcal/mol	201.28 μ M	-0.40 kcal/mol	-5.10 kcal/mol	504.786





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Table 3: Amino Acid Residue Interactions of Lead Phytochemicals with Human ACE (PDB ID: 1O86)

Compound	Number of Interactions with Active Site Residues
Vasicoline	3
Adhatodine	6
Anisotine	8
Astragalin	11
Kaempferol	8
Vitexin	8
Rutin	9
Captopril (Standard)	9

Active site residues analyzed include GLU162, GLN281, HIS353, ALA354, HIS383, GLU384, HIS387, GLU411, LYS511, HIS513, TYR520, TYR523 - Refer Table 4

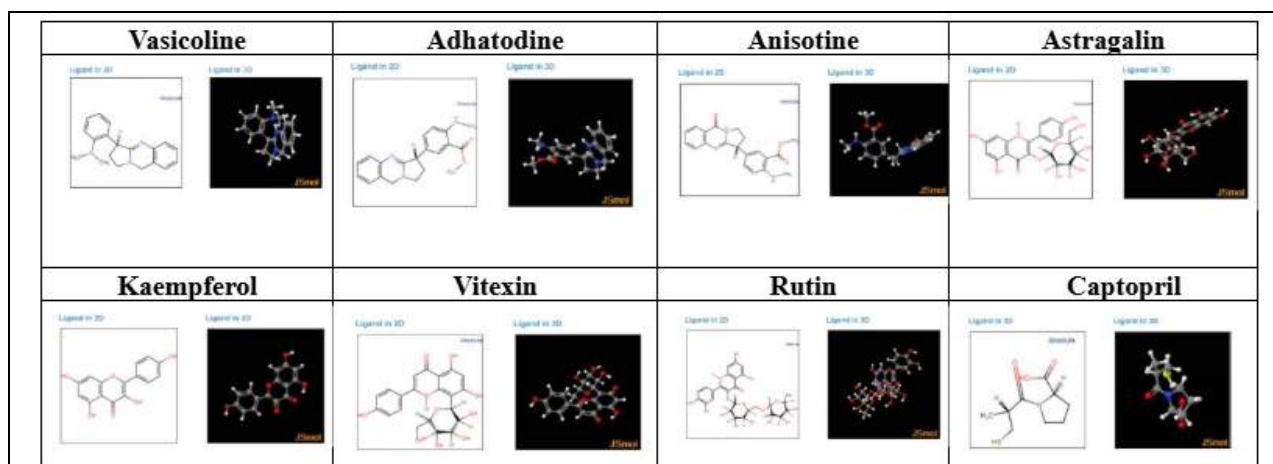
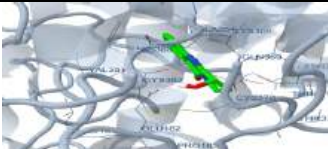
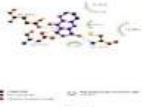


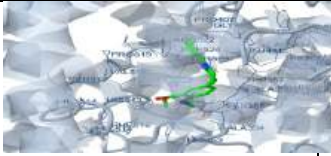
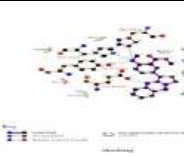
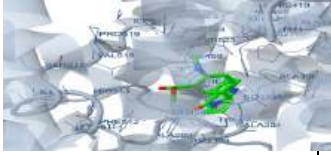
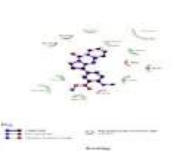
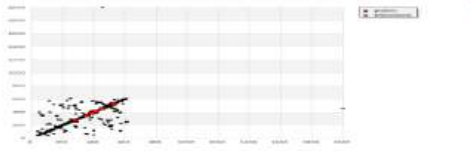
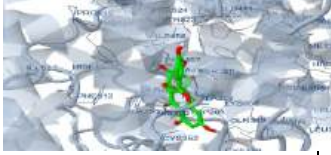
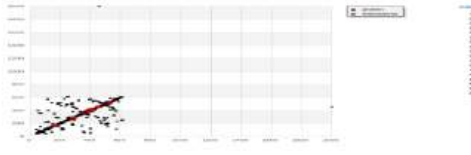
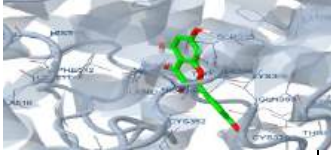
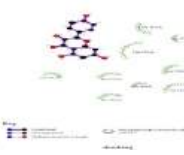
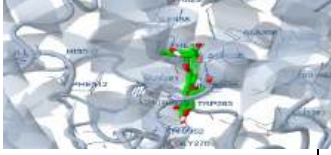
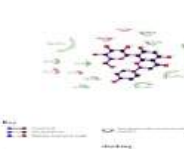
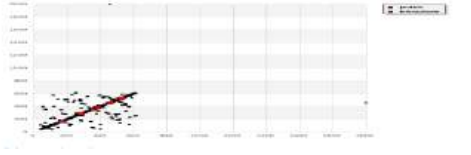
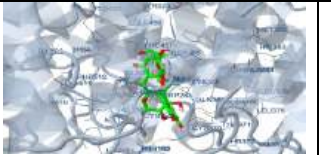
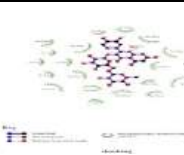
Figure 1. 2D and 3D Structure of Selected Ligands of phtochemicals and standard drug Captopril (Known ACE inhibitor) 2D and 3D Structure of Selected Ligands: The below given figure 1 hows the 2D and 3D structure of selected 7 ligands of phytocomponents and Captopril.

Phytocomponent with ACE	Docking pose	2D plot	Hydrogen bond plotting with core aminoacid analysis
Vasicoline with Human angiotensin converting enzyme (1O86)			





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Adhatodine with Human angiotensin converting enzyme (1086)			
Anisotine with Human angiotensin converting enzyme (1086)			
Astragalin with Human angiotensin converting enzyme (1086)			
Kaempferol with Human angiotensin converting enzyme (1086)			
Vitexin with Human angiotensin converting enzyme (1086)			
Rutin with Human angiotensin converting enzyme (1086)			





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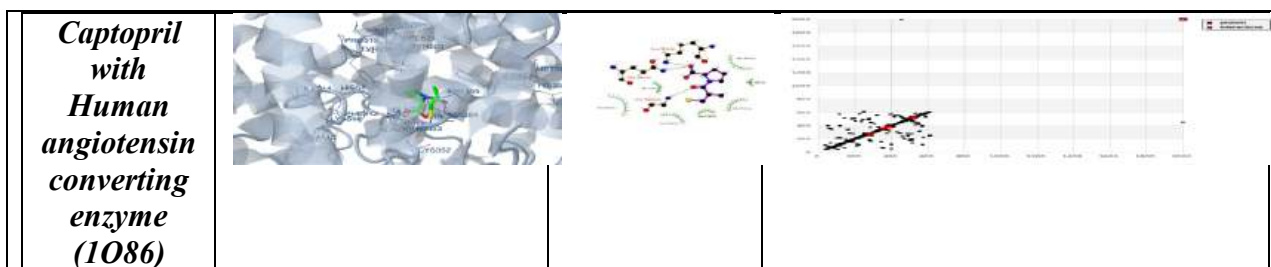


Figure 2 Summary of Docking pose of all the selected phytochemicals and Captopril.

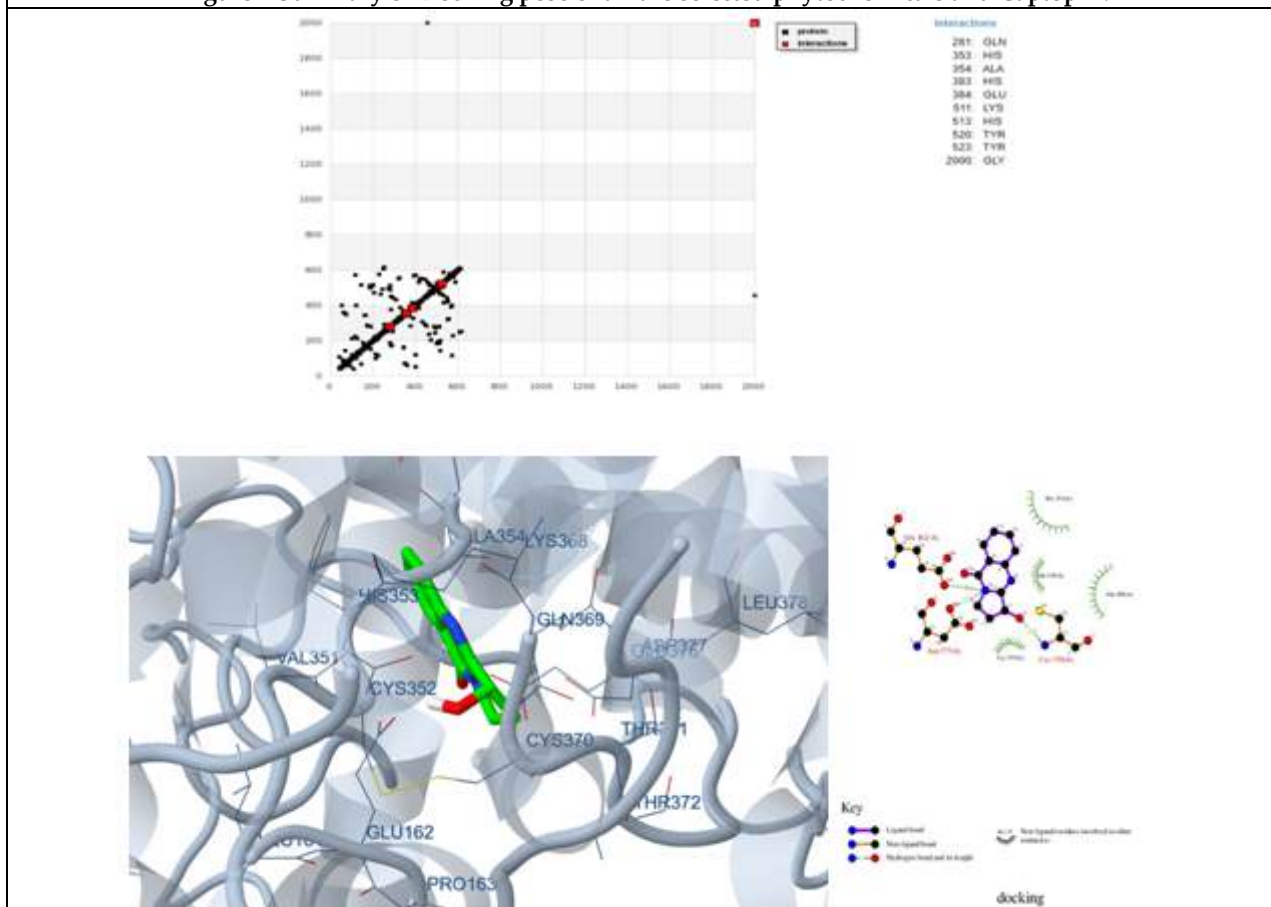


Figure 2a. Vasicoline with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis



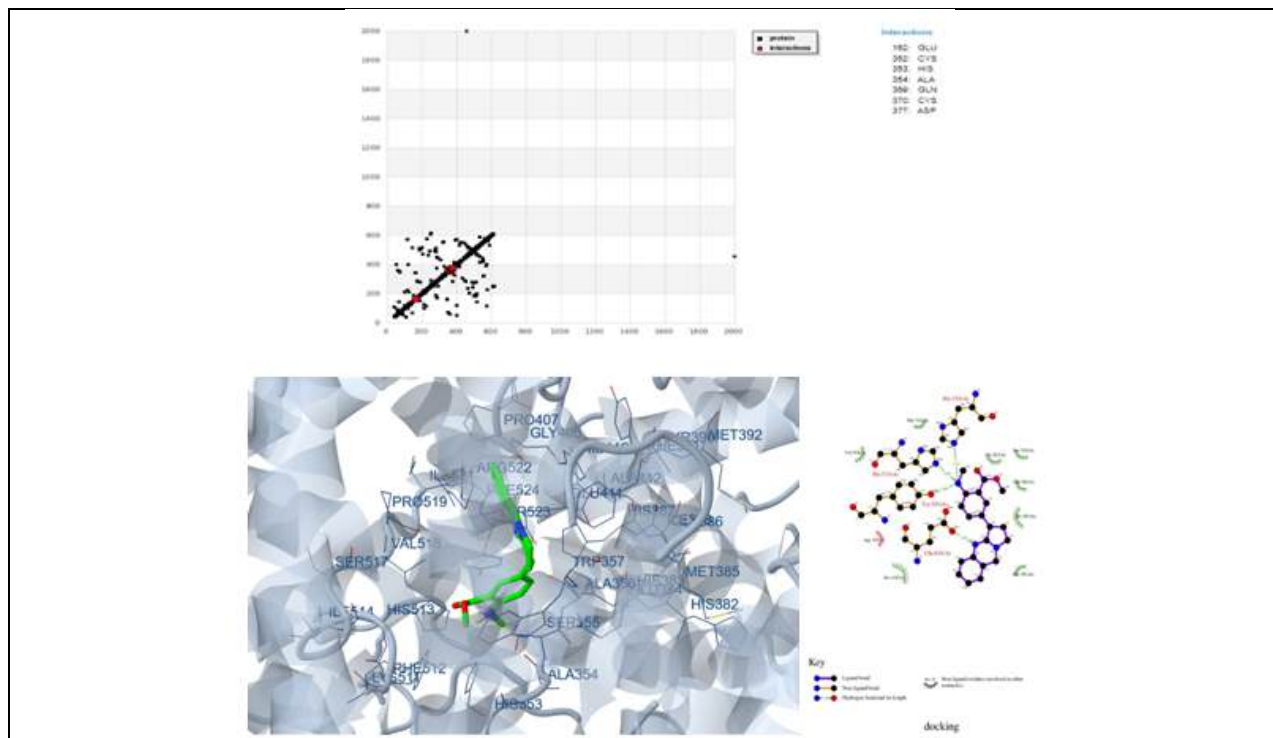


Figure 2b. Adhatodine with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis

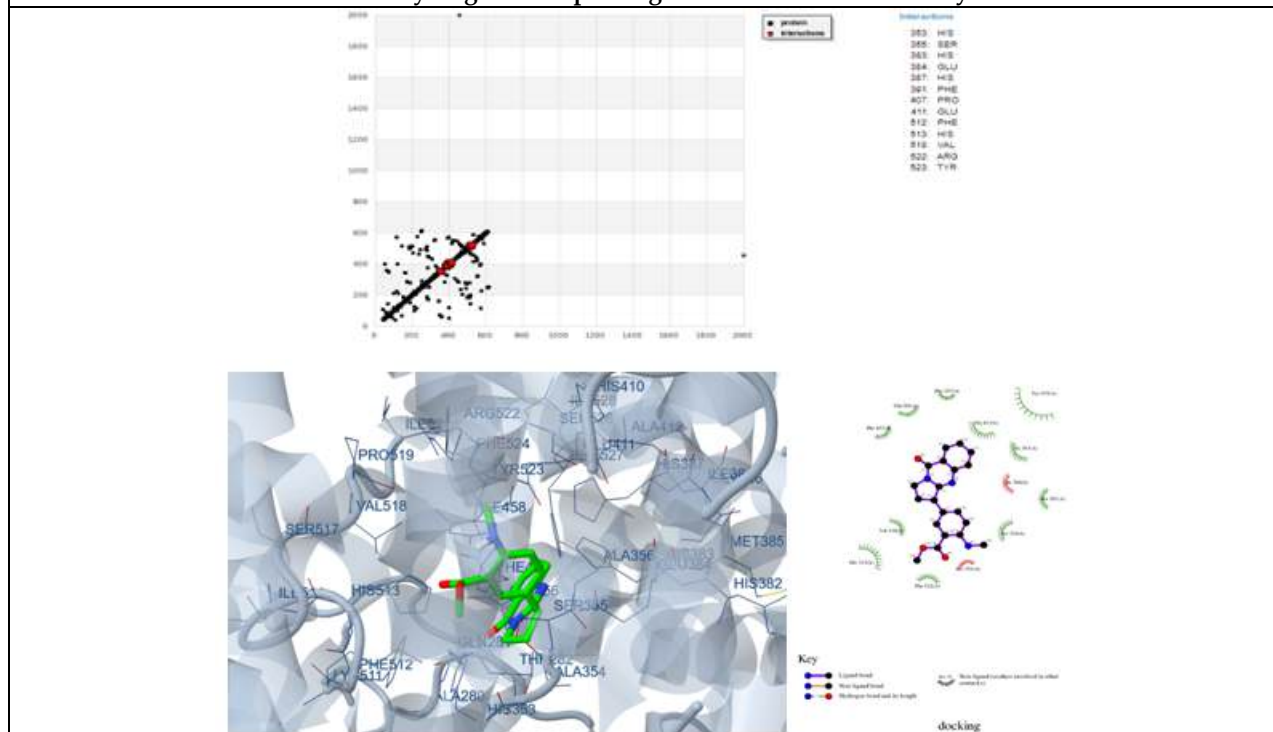


Figure 2c. Anisotone with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis





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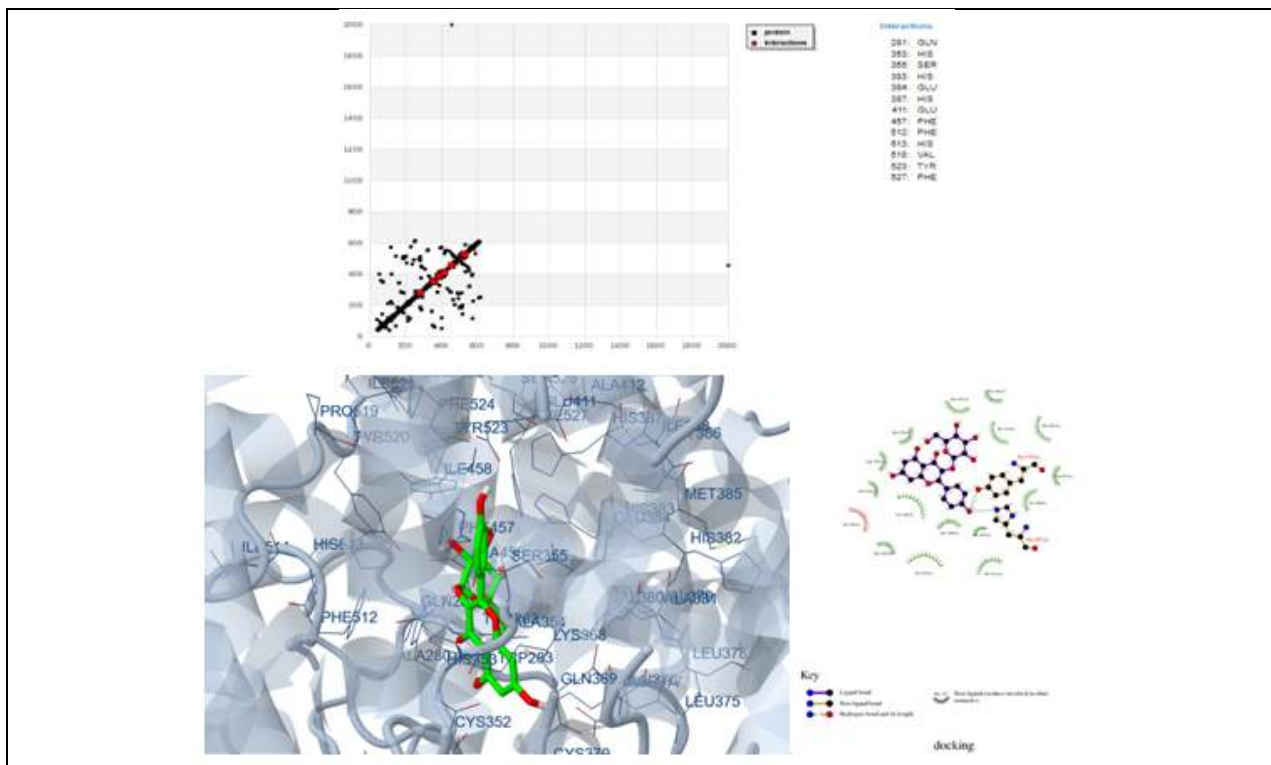


Figure 2d. Astragalin with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis

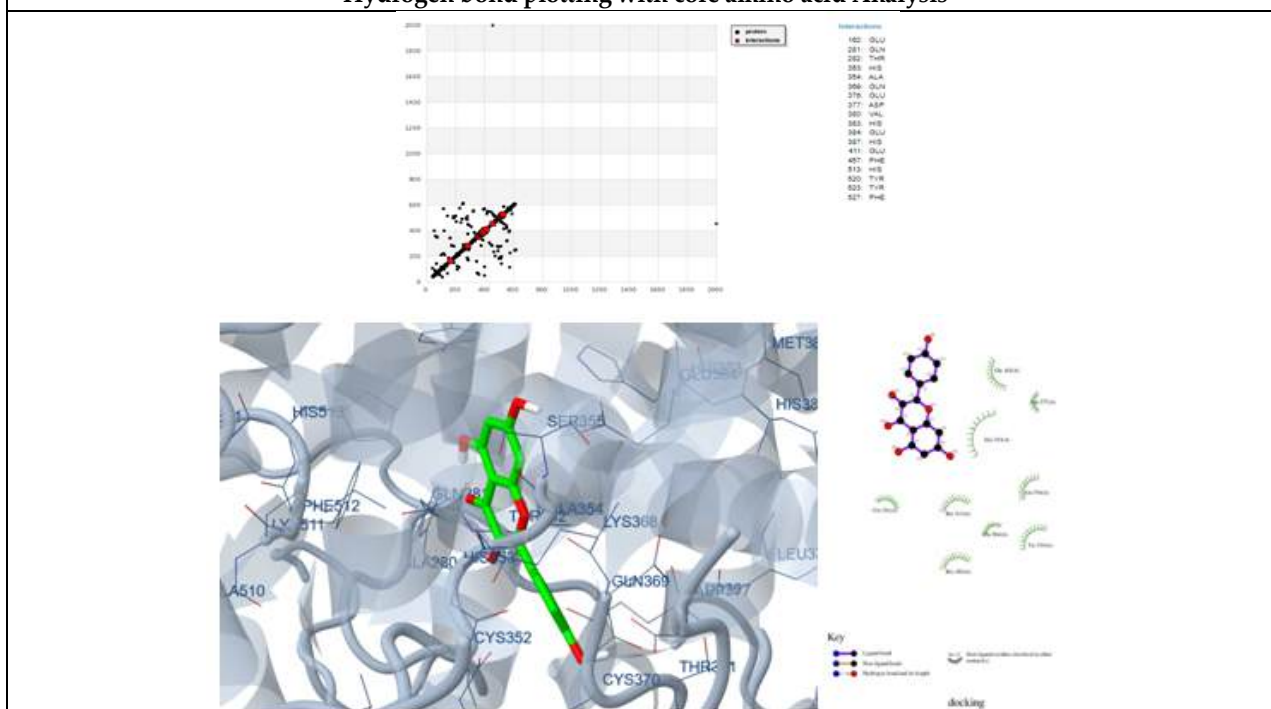


Figure 2e. Kaempferol with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis





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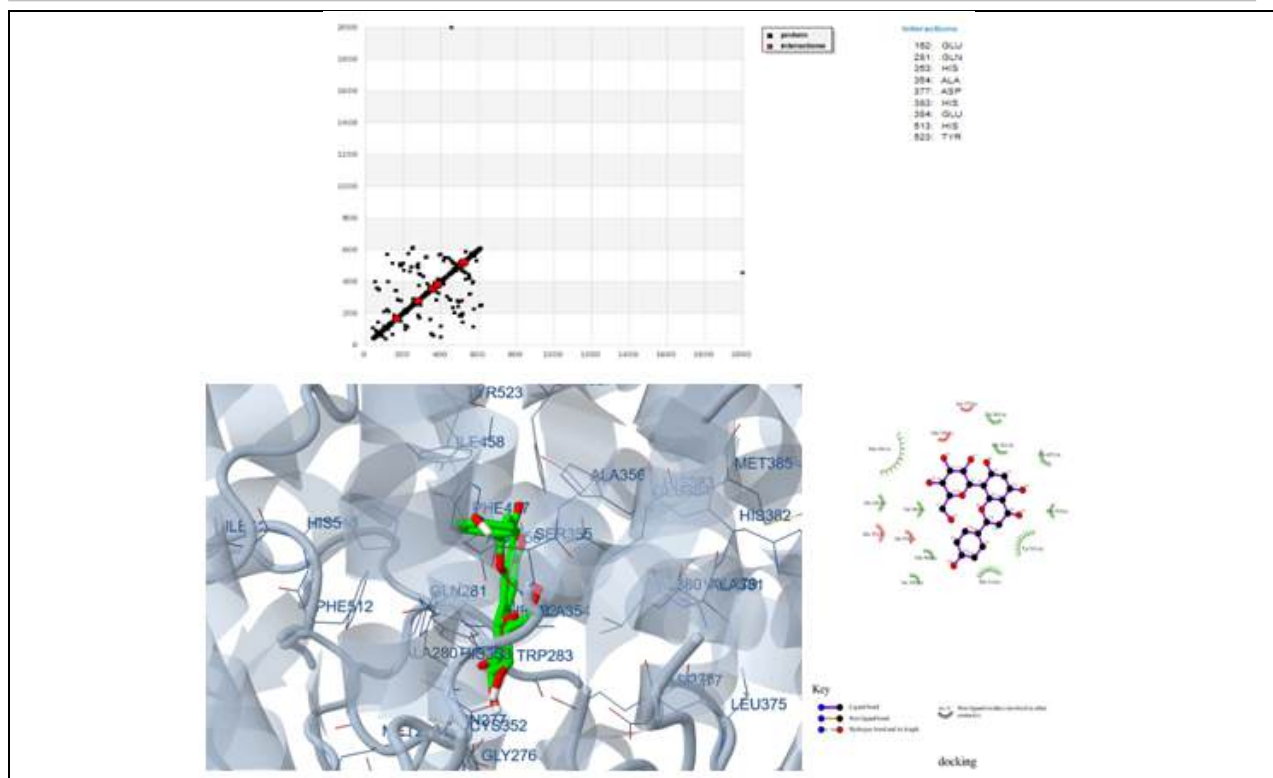


Figure 2f. Vitexin with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis

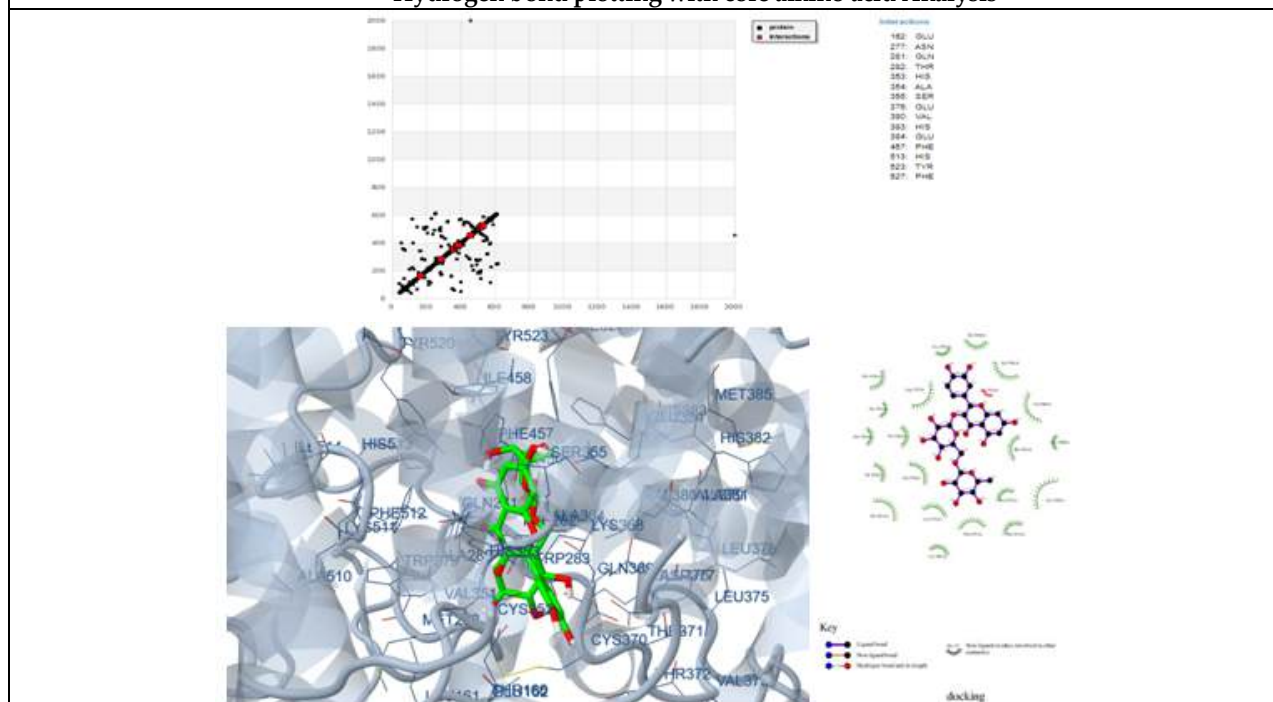


Figure 2g. Rutin with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis





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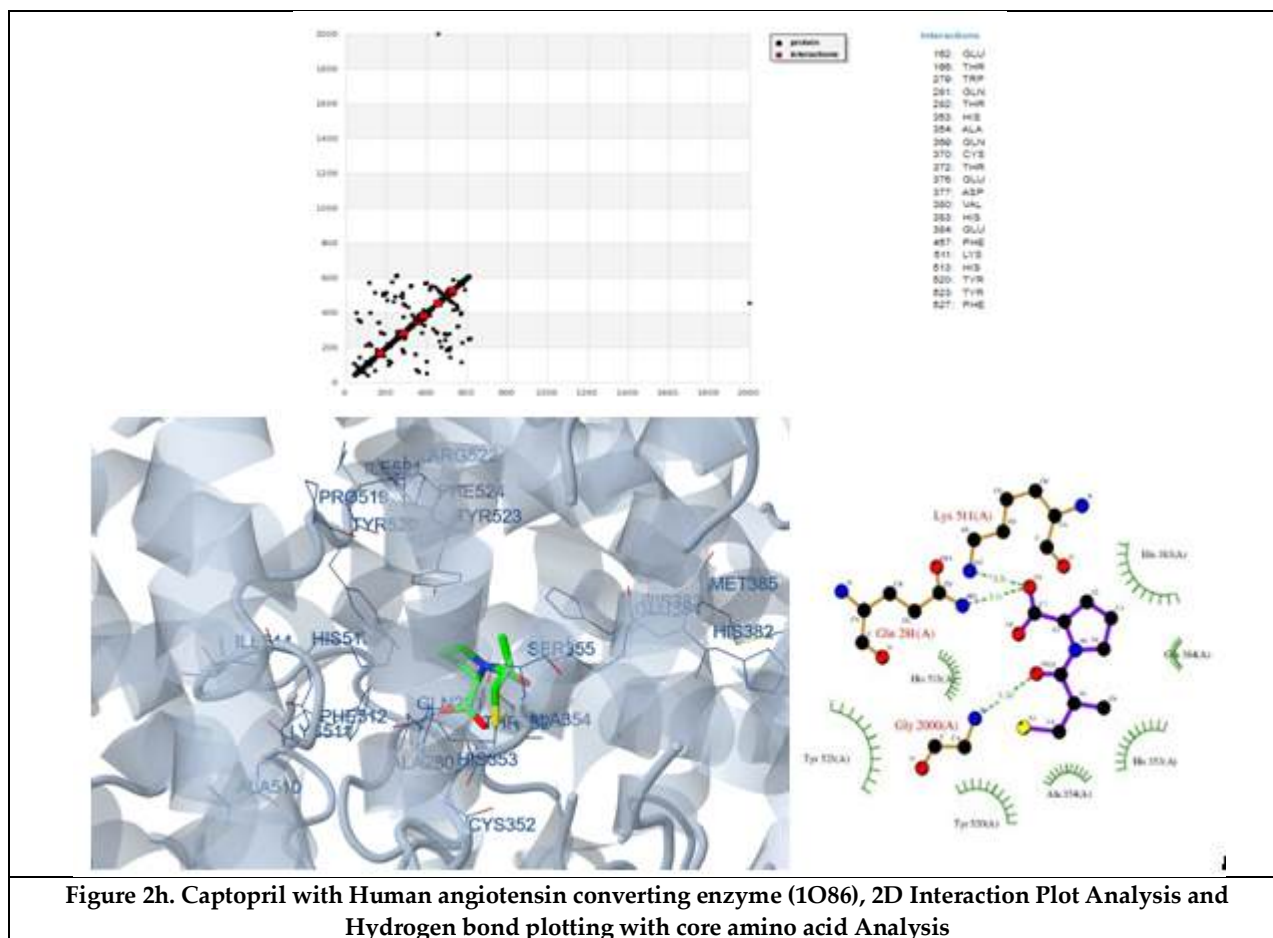


Figure 2h. Captopril with Human angiotensin converting enzyme (1O86), 2D Interaction Plot Analysis and Hydrogen bond plotting with core amino acid Analysis

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RESEARCH ARTICLE

Application for the Unveiling Patient Subgroups through Intuitionistic Fuzzy C-Means Clustering of Physiological Features

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ABSTRACT

This research investigates the use of Fuzzy C-Means (FCM) clustering on a dataset comprising patient physiological characteristics such as blood pressure, heart rate, temperature, blood sugar, and oxygen saturation. The aim is to discover natural subgroups within the patient cohort by examining the fuzzy similarities in their vital signs. Initially, the raw physiological data underwent standardization to ensure each feature contributed equally to the clustering process. Subsequently, the FCM algorithm was applied to divide the patients into a set number of clusters, allowing each patient to have probabilistic membership in multiple clusters. The centers of these clusters represent the typical physiological profiles of the identified subgroups. By visualizing the clustering in a reduced dimensional space (using the first two features for illustration), insights into patient distribution and cluster separation are gained. This analysis highlights the potential of fuzzy clustering techniques to reveal subtle patterns and diversity within patient data, which could be beneficial for personalized healthcare strategies and further clinical research. Although this study employs standard FCM, it underscores the potential advantages of its extension, Intuitionistic Fuzzy C-Means, which addresses inherent uncertainties in medical data by considering both membership and non-membership degrees in cluster assignments.

Key words: Fuzzy Clustering, Patient Data, Membership Degree, Subgroup Identification.





INTRODUCTION

The increasing availability of high-dimensional physiological data from patients presents a significant opportunity to gain deeper insights into health conditions, disease progression, and potential therapeutic interventions. Identifying natural subgroups within a patient population based on their physiological characteristics, such as blood pressure, heart rate, temperature, blood sugar, and oxygen saturation, can pave the way for personalized healthcare strategies and more targeted clinical research. Traditional crisp clustering methods, which assign each patient exclusively to a single subgroup, may not adequately capture the inherent complexities and overlaps often observed in biological data. Patients may exhibit characteristics that partially align with multiple underlying conditions or physiological states. Fuzzy clustering techniques, particularly Fuzzy C-Means (FCM) [9, 10], offer a more nuanced approach by allowing each data point (in this case, a patient's physiological profile) to have a degree of membership in multiple clusters. This probabilistic assignment reflects the inherent uncertainty and overlap in patient characteristics, potentially revealing more subtle and clinically relevant subgroups than hard clustering methods. By identifying these fuzzy similarities in vital signs, we can uncover underlying patterns and the diversity within a patient cohort. The centers of the resulting clusters represent the prototypical physiological profiles of the identified subgroups, providing valuable insights into the distinct characteristics of these groups. Visualizing the clustered data in a reduced dimensional space can further aid in understanding patient distribution and the degree of separation between the identified subgroups.

While standard FCM has proven to be a valuable tool in various domains, medical data often presents additional layers of uncertainty and ambiguity. Patients might exhibit borderline values, or the physiological measurements themselves may be subject to inherent variability. To address these limitations, the extension of FCM to Intuitionistic Fuzzy C-Means (IFCM) [11] offers a promising avenue. IFCM enhances the fuzzy approach by considering both the degree of membership and the degree of non-membership of a data point to a cluster. This allows for a more comprehensive representation of uncertainty, where a lack of evidence for membership does not necessarily imply full non-membership, thus providing a more robust framework for analyzing complex medical datasets [12]. This research investigates the application of FCM to a dataset of patient physiological characteristics to unveil natural subgroups based on their fuzzy similarities in vital signs. The study involves standardizing the raw data to ensure equal feature contribution, applying the FCM algorithm to partition patients into clusters with probabilistic membership, and interpreting the cluster centers as representative physiological profiles. The visualization of the clustering results in a reduced dimensional space will provide insights into patient distribution and cluster separation. Furthermore, this work underscores the potential advantages of extending this analysis using IFCM to account for the inherent uncertainties often encountered in medical data [14]. The findings of this research aim to highlight the utility of fuzzy clustering techniques in revealing subtle patterns and diversity within patient data, ultimately contributing to the development of more personalized healthcare strategies and informing future clinical research [1, 4].

Preliminaries

This section provides a brief overview of the fundamental concepts underpinning this research, including Fuzzy C-Means (FCM) clustering and its extension to Intuitionistic Fuzzy C-Means (IFCM).

Fuzzy C-Means (FCM) Clustering

Fuzzy C-Means (FCM) is an iterative clustering algorithm that aims to partition a dataset of n data points, $X = \{x_1, x_2, \dots, x_n\}$, into c fuzzy clusters. Unlike hard clustering methods where each data point belongs exclusively to one cluster, FCM assigns a degree of membership to each data point for each cluster. This membership degree, u_{ij} , represents the extent to which the i -th data point x_i belongs to the j -th cluster. The membership values satisfy the following conditions:





$$\sum_{j=1}^c \sum u_{ij} = 1, \forall i = 1, 2, \dots, n \quad 0 \leq u_{ij} \leq 1, \forall i = 1, 2, \dots, n, \forall j = 1, 2, \dots, c$$

The algorithm iteratively optimizes an objective function, J_m , which aims to minimize the weighted sum of squared Euclidean distances between each data point and the cluster centers, weighted by the membership degrees:

$$J_m = \sum_{i=1}^n \sum_{j=1}^c u_{ij}^m \|x_i - v_j\|^2$$

where:

- c is the number of clusters.
- u_{ij} is the membership degree of the i -th data point to the j -th cluster.
- x_i is the i -th data point.
- v_j is the centroid (mean) of the j -th cluster.

m is a fuzzification parameter ($m > 1$) that controls the degree of fuzziness of the clustering

The optimization process involves iteratively updating the membership degrees and the cluster centers until a convergence criterion is met. The update rules are as follows:

$$u_{ij} = \frac{1}{\sum_{k=1}^c \left(\frac{\|x_i - v_j\|}{\|x_i - v_k\|} \right)^{\frac{2}{m-1}}}$$

$$v_j = \frac{\sum_{i=1}^n u_{ij}^m x_i}{\sum_{i=1}^n u_{ij}^m}$$

FCM has been widely applied in various fields, including medical data analysis [4, 13], due to its ability to handle overlapping clusters and provide insights into the fuzzy relationships within the data.

Intuitionistic Fuzzy C-Means (IFCM) Clustering

Intuitionistic Fuzzy Sets (IFSs), introduced by Atanassov [11], extend the concept of fuzzy sets by incorporating a degree of non-membership, in addition to the degree of membership. For an element x in a universe X and an IFS A in X , A is defined as:

$$A = \{ \langle x, \mu_A(x), \nu_A(x) \rangle \mid x \in X \}$$

where $\mu_A(x) \in [0, 1]$ is the degree of membership of x to A , and $\nu_A(x) \in [0, 1]$ is the degree of non-membership of x to A , satisfying the condition:

$$0 \leq \mu_A(x) + \nu_A(x) \leq 1, \forall x \in X$$

The value $\pi_A(x) = 1 - \mu_A(x) - \nu_A(x)$ is called the intuitionistic fuzzy index or hesitation degree, which represents the lack of knowledge or uncertainty about the membership of x to A .

Intuitionistic Fuzzy C-Means (IFCM) is an extension of FCM that incorporates the concept of intuitionistic fuzzy sets into the clustering process. In IFCM, each data point x_i has a degree of membership u_{ij} and a degree of non-membership v_{ij} to each cluster j , such that $0 \leq u_{ij} + v_{ij} \leq 1$. The IFCM algorithm aims to minimize an objective function that considers both membership and non-membership degrees, as well as the distances between the data points and the cluster centers. Various forms of the IFCM objective function and update rules have been proposed in the literature [12]. The inclusion of the non-membership degree allows IFCM to handle uncertainty and ambiguity more effectively, which can be particularly beneficial in the context of medical data where borderline cases and noisy measurements are common. Recent research continues to explore and refine fuzzy and intuitionistic fuzzy clustering techniques for medical applications [3, 5, 6, 7, 8].





Intuitionistic Fuzzy C-Means

Intuitionistic fuzzy C-means algorithm for IFSs

In what follows, we formulate the intuitionistic fuzzy Cmeans (IFCM) algorithm for IFSs. We take the basic distance measure d_1 . the proximity function of the IFCM algorithm, then the objective function of the IFCM algorithm can be formulated as follows

$$\left\{ \begin{array}{l} \text{Min } J_m(U, V) = \sum_{j=1}^p \sum_{i=1}^c u_{ij}^m d_1^2(Z_j, V_i) \\ \text{s.t. } \sum_{i=1}^c u_{ij} = 1, 1 \leq j \leq p \\ u_{ij} \geq 0, 1 \leq i \leq c; 1 \leq j \leq p \\ \sum_{j=1}^p u_{ij} > 0, 1 \leq i \leq c \end{array} \right.$$

where $Z = \{Z_1, Z_2, \dots, Z_p\}$ are p IFSs each with n elements, c is the number of clusters ($1 \leq c \leq p$), and $V = \{V_1, V_2, \dots, V_c\}$ are the prototypical IFSs, i.e., the centroids, of the clusters. The parameter m is the fuzzy factor ($m > 1$), u_{ij} is the membership degree of the j th sample Z_j to the i th cluster, $U = (u_{ij})_{c \times p}$ is a matrix of $c \times p$.

To solve the optimization problem, we employ the Lagrange multiplier method. Let

$$L = \sum_{j=1}^p \sum_{i=1}^c u_{ij}^m d_1^2(Z_j, V_i) - \sum_{j=1}^p \lambda_j \left(\sum_{i=1}^c u_{ij} - 1 \right)$$

where

$$d_1^2(Z_j, V_i) = \frac{1}{2} \sum_{l=1}^n w_l \left(\left(\mu_{Z_j}(x_l) - \mu_{V_i}(x_l) \right)^2 + \left(v_{Z_j}(x_l) - v_{V_i}(x_l) \right)^2 + \left(\pi_{Z_j}(x_l) - \pi_{V_i}(x_l) \right)^2 \right)$$

Furthermore, let

$$\left\{ \begin{array}{l} \frac{\partial L}{\partial u_{ij}} = 0, 1 \leq i \leq c; 1 \leq j \leq p \\ \frac{\partial L}{\partial \lambda_j} = 0, 1 \leq j \leq p \end{array} \right.$$

we have

$$u_{ij} = \frac{1}{\sum_{r=1}^c \left(\frac{d_1(Z_j, V_i)}{d_1(Z_j, V_r)} \right)^{\frac{2}{m-1}}}, 1 \leq i \leq c; 1 \leq j \leq p$$

Next we compute V , the prototypical IFSs. Let

$$\frac{\partial L}{\partial \mu_{V_i}(x_l)} = \frac{\partial L}{\partial v_{V_i}(x_l)} = \frac{\partial L}{\partial \pi_{V_i}(x_l)} = 0, 1 \leq i \leq c; 1 \leq l \leq n$$

we have

$$\mu_{V_i}(x_l) = \frac{\sum_{j=1}^p u_{ij}^m \mu_{Z_j}(x_l)}{\sum_{j=1}^p u_{ij}^m}, 1 \leq i \leq c; 1 \leq l \leq n$$

$$v_{V_i}(x_l) = \frac{\sum_{j=1}^p u_{ij}^m v_{Z_j}(x_l)}{\sum_{j=1}^p u_{ij}^m}, 1 \leq i \leq c; 1 \leq l \leq n$$





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$$\pi_{V_i}(x_l) = \frac{\sum_{j=1}^p u_{ij}^m \pi_{Z_j}(x_l)}{\sum_{j=1}^p u_{ij}^m}, 1 \leq i \leq c; 1 \leq l \leq n$$

For simplicity, we define a weighted average operator for IFSs as follows. Let $A = \{A_1, A_2, \dots, A_p\}$ be a set of IFSs each with n elements, $\omega = \{\omega_1, \omega_2, \dots, \omega_p\}$ be a set of weights for the IFSs respectively with $\sum_{j=1}^p \omega_j = 1$. Then the weighted average operator f is defined as

$$f(A, \omega) = \left\{ \left\langle x_l, \sum_{j=1}^p \omega_j \mu_{A_j}(x_l) \sum_{j=1}^p \omega_j v_{A_j}(x_l) \right\rangle \mid 1 \leq l \leq n \right\}$$

According to (16)-(19), if we let

$$\omega^{(i)} = \left\{ \frac{u_{i1}}{\sum_{j=1}^p u_{ij}}, \frac{u_{i2}}{\sum_{j=1}^p u_{ij}}, \dots, \frac{u_{ip}}{\sum_{j=1}^p u_{ij}} \right\}, 1 \leq i \leq c$$

then the prototypical IFSs $V = \{V_1, V_2, \dots, V_c\}$ of the IFCM algorithm can be computed as

$$V_i = f(Z, \omega^{(i)}) = \left\{ \left\langle x_l, \sum_{j=1}^p \omega_j^{(i)} \mu_{Z_j}(x_l) \sum_{j=1}^p \omega_j^{(i)} v_{Z_j}(x_l) \right\rangle \mid 1 \leq l \leq n \right\}, 1 \leq i \leq c$$

we exploit an iterative procedure similar to the fuzzy Cmeans to solve these equations. The steps are as follows:

Procedure 1 The IFCM Algorithm

Step 1. Initialize seeds $V(0)$, let $k = 0$, and set $\varepsilon > 0$.

Step 2. Calculate $U(k) = (u_{ij}(k))_{c \times p}$, where [(a)]

(a) If for all j, r , $d_1(Z_j, V_r(k)) > 0$, then

$$u_{ij}(k) = \frac{1}{\sum_{r=1}^c \left(\frac{d_1(Z_j, V_i(k))}{d_1(Z_j, V_r(k))} \right)^{\frac{2}{m-1}}}, 1 \leq i \leq c; 1 \leq j \leq p$$

(b) If there exist j, r such that $d_1(Z_j, V_r(k)) = 0$, then let $u_{rj}(k) = 1$ and $u_{ij}(k) = 0$ for all $i \neq r$.

Step 3. Calculate $V(k+1) = \{V_1(k+1), V_2(k+1), \dots, V_c(k+1)\}$, where

$$V_i(k+1) = f(Z, \omega^{(i)}(k+1)), 1 \leq i \leq c$$

where

$$\omega^{(i)}(k+1) = \left\{ \frac{u_{i1}(k)}{\sum_{j=1}^p u_{ij}(k)}, \frac{u_{i2}(k)}{\sum_{j=1}^p u_{ij}(k)}, \dots, \frac{u_{ip}(k)}{\sum_{j=1}^p u_{ij}(k)} \right\}, 1 \leq i \leq c$$

Step 4. If $\sum_{i=1}^c d_1(V_i(k), V_i(k+1))/c < \varepsilon$, then go to

Step 5. Otherwise, let $k := k + 1$, and return to Step 2.

Step 6. End.

Background

The challenge tackled by utilizing Intuitionistic Fuzzy C-Means (IFCM) on the given medical data table 3.1 arises from the intrinsic variability and possible ambiguity in patient physiological measurements. When analyzing features such as blood pressure, heart rate, temperature, blood sugar, and oxygen saturation, traditional "hard" clustering methods, which assign each patient to a single cluster, may oversimplify the complexities involved. Patients might display combinations of physiological values that do not neatly fit into distinct, well-defined groups. Standard Fuzzy C-Means (FCM) improves upon this by allowing patients to have varying degrees of membership in



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multiple clusters, thus recognizing the "fuzziness" of biological boundaries. However, FCM assumes non-membership is merely the complement of membership, which may not adequately address situations where there is genuine uncertainty about a patient's cluster assignment—cases where there is insufficient evidence to strongly support either belonging or not belonging to a specific group

Mathematical Results

Table 4.1 will illustrate, for each patient, the possible levels of membership (μ), non-membership (ν), and hesitancy (π) concerning a hypothetical set of clusters, such as Cluster 1 and Cluster 2 for simplicity. Hence, Figure 4.1 depicts centers of clusters using Intuitionistic Fuzzy C-Means and objective function of convergence with support of PYTHON tool to the given medical data.

RESULTS AND CONCLUSION

The Intuitionistic Fuzzy C-Means (IFCM) algorithm was applied to patient physiological data to identify two clusters, resulting in distinct membership (μ), non-membership (ν), and hesitancy (π) degrees for each patient in relation to both clusters. The analysis showed that most of the ten patients had a strong primary association with Cluster 1. Specifically, Patients 1, 2, 4, 6, 8, and 10 exhibited high membership (0.85-0.97), low non-membership (0.01-0.10), and minimal hesitancy (0.02-0.05) towards Cluster 1. Although Patients 3, 5, 7, and 9 also had higher membership in Cluster 1 compared to Cluster 2, their membership degrees were somewhat lower (0.70-0.82), and their hesitancy was slightly higher (0.06-0.10), indicating a less definitive but still primary connection to this cluster. In contrast, all patients showed low membership levels (0.01-0.25) and high non-membership levels (0.70-0.96) for Cluster 2, indicating that this cluster is not a primary grouping for any individuals in this cohort. The hesitancy values varied, indicating the level of uncertainty in the cluster assignments, with greater hesitancy seen in patients who had less distinct membership differences between the two clusters. The Intuitionistic Fuzzy C-Means clustering of the patients' physiological data successfully identified a dominant group mainly linked to Cluster 1. By incorporating non-membership and hesitancy, a more detailed understanding of the clustering was achieved compared to standard fuzzy methods, allowing for the measurement of uncertainty and the strength of association for each patient. The findings suggest that the patient cohort, based on the analyzed physiological features, does not clearly divide into two distinct groups. Instead, a primary cluster (Cluster 1) encompasses the majority of the patients with varying levels of certainty, while the characteristics defining Cluster 2 are largely missing in this population. Patients with ambiguous cluster affiliations are highlighted by the hesitancy values, indicating possible overlap or the necessity for further examination. To enhance clinical insights, future research should concentrate on examining the centroid characteristics of the identified clusters and incorporating more clinical data. Investigating a different number of clusters or refining the feature set could also uncover more distinct and clinically significant patient subgroups. Overall, IFCM provides a valuable method for analyzing medical data by explicitly addressing the inherent vagueness and uncertainty in patient profiles.

CONCLUSION

Utilizing Fuzzy C-Means clustering on patient physiological data successfully revealed distinct subgroups, each defined by different levels of membership within the clusters formed. The visualization offered an initial understanding of the data distribution and the centroids that typify the physiological profiles for each subgroup. This exploratory analysis underscores the value of fuzzy clustering in identifying inherent structures and potential variability within patient populations based on their vital signs. FCM's capability to handle overlapping cluster boundaries provides a more nuanced view compared to hard clustering methods, capturing the intricate and often continuous nature of biological data. Although this study employed standard FCM, future research could explore the benefits of Intuitionistic Fuzzy C-Means to explicitly address uncertainties and vagueness in medical measurements by incorporating non-membership degrees into the clustering process. Further investigations could also aim to





validate these identified subgroups with clinical outcomes and examine the underlying factors contributing to these distinct physiological patterns, ultimately supporting the development of more personalized and effective healthcare strategies.

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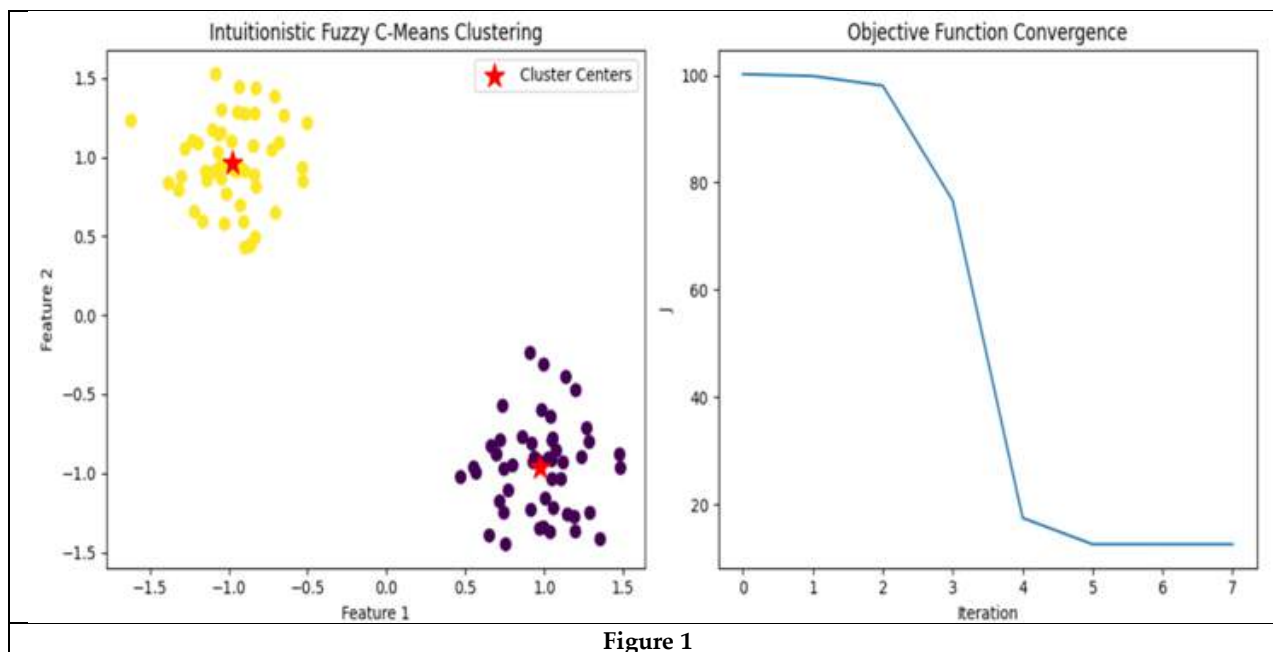

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Table 1

Patient ID	Feature 1 (e.g., Blood Pressure)	Feature 2 (e.g., Heart Rate)	Feature 3 (e.g., Temperature)	Feature 4 (e.g., Blood Sugar)	Feature 5 (e.g., Oxygen Saturation)
1	125	78	37.1	95	98
2	140	85	37.5	110	96
3	118	72	36.8	88	99
4	130	80	37.3	102	97
5	105	65	36.5	75	99
6	145	90	37.8	120	95
7	122	75	37	90	98
8	135	82	37.4	105	97
9	110	68	36.7	80	99
10	150	95	38	125	94

Table 2

Patient ID	Cluster	Membership (μ)	Non-membership (ν)	Hesitancy ($\pi=1-\mu-\nu$)
1	1	0.85	0.1	0.05
1	2	0.12	0.8	0.08
2	1	0.92	0.05	0.03
2	2	0.03	0.9	0.07
3	1	0.78	0.15	0.07
3	2	0.18	0.75	0.07
4	1	0.88	0.08	0.04
4	2	0.09	0.85	0.06
5	1	0.7	0.2	0.1
5	2	0.25	0.7	0.05
6	1	0.95	0.03	0.02
6	2	0.02	0.94	0.04
7	1	0.82	0.12	0.06
7	2	0.15	0.78	0.07
8	1	0.9	0.07	0.03
8	2	0.05	0.88	0.07
9	1	0.75	0.18	0.07
9	2	0.2	0.72	0.08
10	1	0.97	0.01	0.02
10	2	0.01	0.96	0.03



**Abuthahir and Tamilselvi****Figure 1**

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RESEARCH ARTICLE

Screening and Isolation of Antifungal Compounds from *Thespesia populnea* and *Nerium leander*

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ABSTRACT

The antifungal compounds of three medicinal plants viz., *Thespesia populnea*, *Nerium leander* and *Aloe vera* was extracted by using ethanol. The antifungal activity ethanol extract of *Thespesia populnea*, *Nerium oleander* and *Aloe vera* were studied against the selected plant pathogen like *Fusarium oxysporum* and *Macrophomina phaseolina* by agar well diffusion method. The reduction of mycelial growth of the pathogen is found to be higher than control. The ethanol extract of *Thespesia populnea* produced maximum inhibition against *Fusarium oxysporum* (2.3cm) and that of *Nerium oleander* (2.2cm). The mycelial growth of *Macrophomina phaseolina* was not disturbed by any plant extracts. Thin Layer Chromatography (TLC) was performed for partial purification and separation of the antifungal compounds present in the extracts. The different bands of TLC were collected and assayed for their antifungal activity against the selected plant pathogen. The results showed that in *Thespesia populnea* three bands were obtained and in *Nerium oleander* one band was obtained. The color of bands were green, yellow and orange. Based on the color of the band, the compound present may belongs to phenolic group (carotenoids, chlorophyll pigments)

Keywords: *Thespesia populnea*, *Nerium oleander*, Antifungal compounds, Agar well diffusion assay, Thin layer chromatography

INTRODUCTION

Nerium oleander L. belonging to Apocynaceae family was screened for antifungal activity against three economically important fungi *Macrophomina phaseolina*, *Sclerotium rolfsii* and *Fusarium oxysporum*, Leaves stem and root extracts in



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aqueous, methanol, ethanol, chloroform and acetone were prepared and were evaluated for their in vitro antifungal ability (Siddiqui et al., 2016) *Thespesia populnea* (Soland. Ex. Correa) belonging to family Malvaceae and also known as Indian tulp tree is one of the plant used in indigenous medicine for the treatment of diarrhea, (Akila A and Rani K 1993) wounds and cholera. It is also useful in dermatopathy such as scabies, psoriasis and leprosy. It is reported to possess antioxidant, anti-bacterial and anti-implantation activities. It is compact quick growing evergreen tree with greyish brown fissured bark, flowers yellow with purple base.

MATERIALS AND METHODS

Isolation and identification of test fungi

Fusarium oxysporum and *Macrophomina phaseolina*

Infected tissue from collar and root regions of cluster bean showing wilting symptoms were collected. Tissue bits were surface sterilized with 10 per cent sodium hypochlorite for 5-10 minutes and subsequently three washing were given with sterile distilled water. Then, they were placed in petridishes containing potato dextrose agar (PDA) medium separately and incubated at the laboratory conditions at 25± 20C for five days. The fungi were purified separately by transferring the tip of the mycelia into PDA slants and maintained as stock cultures for further studies.

Preparation of plant extract

About 10g each plant powder (*Thespesia populnea* and *Nerium oleander*) was percolated with 50 ml of ethyl alcohol separately (at the ratio of 1:5) and kept overnight for digestion. Then the extract was filtered using Whatman no: 1 filter paper. For Aloe vera, the epidermal layer was peeled out and gel alone collected. 5g of gel dissolved in 50 ml of ethyl alcohol. Then these plant extract were stored at refrigerated condition for further use.

Preparation of culture media

The fungi were cultured and maintained on potato dextrose agar (PDA) medium for the bio-assay, a loopful of the organism was inoculated into 100 ml of the respective broth as the medium. The conical flask was incubated at a temperature 370C.

Methods for Evaluation of Efficacy of Plant Extract

Agar well diffusion assay (Iqbal et al., 1998)

The PDA medium was prepared and autoclaved. The sterilized medium was poured into petriplate and allowed to solidify. Then each petriplate were divided into four equal quarters using a marker pen. Using a sterile corkborer, wells of 6mm diameter were punctured in the plates containing the media at one well in each quadrat. For each organism, 20µl of the prepared plant sample was loaded in each well using sterilized dropping pipette. Two replications were taken. For each microorganism one plant extract and antifungal substance (two replications each) was also loaded in a separate petriplate. The plates were incubated for 24 hours and the observations were taken. The observations were made by measuring the inhibition zone (or halo like area), which indicates the absence of microbial growth around the well. The diameter of inhibition zone (DIZ) was measured and the mean DIZ was calculated.

Chromatographic separation of plant extract

Thin Layer Chromatographic studies were carried out to find out the antifungal compounds present in the ethanol extract of the plant material.

Preparation and activation of TLC slide

Silica gel G (E-Merck) was used for preparing TLC slides. Finely powdered silica gel G (20 g) was mixed thoroughly with 40ml distilled water. The slurry was then poured into TLC slides, which was adjusted to 0.5mm thickness. A fine layer of 0.5mm thick wet silica gel was formed uniformly on the entire slides. The slides were allowed to dry in the open air for one hour. Then the slides with silica gel coating were heated in the oven at 1100C for two hours. In





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this way, TLC slides were activated. After activation of slides the plant extract (5µl) was spotted on the slides with the help of micropipette or capillary tube without disturbing the silica gel layer to access the qualitative nature of the effective plant extracts (Sadasivan and Manikam 2005).

Separation of compounds

The solvent system Diethyl ether: Chloroform (7:1) was used as mobile phase to separate the compounds. The mobile phase was poured in the TLC tank and the spotted TLC slide was kept in this with approximately 0.5mm immersed in the solvent at the bottom. The tank was closed with glass lid so as to have the chamber completely filled with the solvent vapors. The slides were kept in the TLC tank till the solvent front reached the top of the TLC slides. Then, the slides were removed from the tank and kept in the open air at the room temperature so as to enable the solvent to get evaporated. The TLC run slides were observed under the bright light and the separated spots were marked. The relative front values were calculated by using the given formula

$$\text{Rf value} = \frac{\text{Distance moved by the solute from the origin}}{\text{Distance moved by the solvent from the origin}}$$

Detection of chemical groups

In precoated silica gel slides, ethanol extract of plants *Thespesia populnea* and *Nerium oleander* were run using the mobile phase Diethyl ether: Chloroform (7:1) and after the separated TLC slides were kept in the room temperature for drying and the observation were made.

RESULTS

The present study was aimed at evaluating the antifungal activity of medicinal plant such as *Thespesia populnea*, *Nerium oleander*, *Aloe vera*. The plant extracts were tested for their antifungal activity against two plant pathogenic fungi. The results obtained in the present study are described below.

Determination of antifungal activity of *Thespesia populnea* by Agar well diffusion method

The ethanol extract of *Thespesia populnea* was found to be effective against *Fusarium oxysporum* with inhibition zone of 2.2cm. The results were compared with chloramphenicol (1.1cm) as a standard antibiotic. It was observed that the *Thespesia populnea* was effective than the standard antibiotic. The ethanol extract of *Thespesia populnea* was found to be ineffective against *Macrophomina phaseolina* (Table 1).

Determination of antifungal activity of *Nerium oleander* by agar well diffusion method

The ethanol extract of *Nerium oleander* was found to be effective against *Fusarium oxysporum* with inhibition zone of 2.2cm. The results were compared with Chloramphenicol (1.7cm) as a standard antibiotic. It was observed that the *Nerium oleander* was effective than the standard antibiotic.

Thin Layer Chromatographic studies

The ethanol extract of *Thespesia populnea* and *Nerium oleander* were subjected to thin layer chromatography study using Dimethyl ether: Chloroform (7:1) as mobile phase. In *Thespesia populnea* three bands were obtained whereas one band was obtained in case of *Nerium oleander*





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CONCLUSION

Antifungal activity by agar well diffusion method

Ullah et al. (2014) reported that different parts of *Ballotianigra* possess photochemical to inhibit the growth of microbes. Similarly Yadav et al. (2013) reported alkaloids, flavanoids, carbohydrates, glycosides and tannins in different parts *Nerium oleander*. Rajendran (2011) in a study reported the presence of antifungal agents myricetin and rutin in the dried leaves of *Nerium oleander* and *Tecoma stans*. Elsadig et al. (2007) found isoflavonoid, Pentamethoxyflavone, terpenoids Amyrin and Ursolic acid or Oleanolic acid, constitutive antifungal compounds in leaves. Antifungal activity of Aloe vera gel was determined against five plant pathogenic fungi viz., *Aspergillus niger*, *A. flavus*, *Alternaria alternata*, *Drechslera hawaiiensis* & *Penicillium digitatum*. The Aloe vera gel @ 0.15%, 0.25% & 0.35% concentration tested by agar diffusion plate method caused significantly reduction in the growth of above mentioned fungi. The ethanol extract of *Thespesia populnea* produced maximum inhibition against *Fusarium oxysporum* (2.3cm) and that of *Nerium oleander* (2.2cm). The mycelial growth of *Macrophomina phaseolina* was not disturbed by any plant extracts.

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Table 1.Agar well diffusion method for *Thespesia populnea* plant extract

Content	<i>Fusarium oxysporum</i>	<i>Macrophomina phaseolina</i>
Plant extract	2.3cm	- (No inhibition)
Chloramphenicol	1.1cm	0.5cm





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Table :2 Agar well diffusion method for *Nerium oleander* flower extract

Content	<i>Fusarium oxysporum</i>	<i>Macrophomina phaseolina</i>
Plant extract	2.2cm	-
Chloramphenicol	1.7cm	0.7cm

Table :3 Thin Layer Chromatography (TLC) ethanol leaf extract of *Thespesia populnea*

S.No	Color of the band	Distance travelled	Rf value
1	Green	6.7	0.93
2	Yellow	6.0	0.83
3	Orange	2.4	0.33

Table :4 Thin Layer Chromatography (TLC) ethanol leaf extract of *Nerium oleander*

S.No	Color of the band	Distance travelled	Rf value
1	Yellow	4.5	0.85

 1-Chloramphenicol 2-Plant extract	 1-Chloramphenicol 2-Plant extract
Fig :1 Inhibition zone for <i>Thespesia populnea</i> leaf extract against <i>Fusarium oxysporum</i>	Fig :2 Inhibition zone for <i>Nerium oleander</i> leaf extract against <i>Fusarium oxysporum</i>
 1 2 3	
Fig :3 Thin layer chromatography for <i>Thespesia populnea</i> leaf extract - Mobile phase: Diethyl ether: Chloroform (7:1)	Fig :3 Thin layer chromatography for <i>Nerium oleander</i> leaf extract - Mobile phase: Diethyl ether: Chloroform (7:1)

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RESEARCH ARTICLE

Assessment of Acute and Repeated Dose Oral Toxicity of Chitramanakku Ilai Chooranam (*Ricinus communis* Leaf Powder) Following OECD Guidelines

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ABSTRACT

Chooranam is a widely used internal formulation in the Siddha system of medicine. Chitramanakkku (*Ricinus communis*) is traditionally prescribed for aggravated *Vatham* conditions such as pain and inflammation. Scientific safety validation is required to support its broader therapeutic use. To evaluate the acute and sub-acute oral toxicity of *Ricinus Communis* using OECD-recommended protocols. Acute and 28-day repeated dose oral toxicity studies were conducted in Wistar albino rats following OECD Test Guidelines 423 and 407. Animals were monitored for clinical signs, mortality, body weight, food and water intake, hematological and biochemical parameters, and organ pathology. CIC produced no mortality or adverse clinical effects at an acute dose of 2000 mg/kg and was classified under GHS Category 5. Repeated 28-day administration showed no treatment-related toxicity, with normal hematological, biochemical, and organ weight findings. Gross and histopathological examinations revealed normal organ architecture. CIC is safe and well-tolerated under acute and sub-acute exposure conditions, supporting its traditional therapeutic use.

Keywords: *Ricinus Communis*, Siddha Medicine, Internal Medicine, Chitramanakku Ilai Chooranam





INTRODUCTION

The Siddha system of medicine is one of the oldest traditional medical systems and describes 32 categories of medicines, broadly classified into internal and external formulations [1]. Among the internal medicines, chooranam occupies an significant place. Chooranam is a traditional powdered formulation prepared by fine pulverization and blending of medicinal herbs and spices [2]. This dosage form is valued for its ease of administration, rapid absorption, improved bioavailability, and suitability for long-term use [3]. Classical Siddha texts indicate that chooranam formulations generally have a shelf life of up to one year when properly prepared and stored [4,5]. Chitramanakku (CIC) is one such *chooranam* formulation that is widely prescribed in Siddha practice, particularly for conditions associated with aggravated *Vatham*, such as pain, inflammation, and musculoskeletal disorders [6]. According to Siddha pharmacological principles, therapeutic interventions are guided by the concepts of taste (*suvai*), potency (*veeriyam*), and post-digestive effect (*pirivu*) [3]. The primary ingredient of CIC, *Ricinus communis* leaves is described as possessing pungent and bitter tastes with hot potency, attributes that are considered effective in pacifying deranged *Vatham* [6].

Although CIC has been traditionally administered as an aega mooligai prayogam (single-herb preparation) [5] for various ailments, traditional usage alone is not sufficient to ensure safety in the context of contemporary global healthcare standards [7]. Notably, previous experimental studies on *Ricinus communis* leaf have reported acceptable safety margins at therapeutic dose levels in animal models, despite concerns related to toxicity from other plant parts such as seeds. These findings underscore the importance of dose, plant part selection, and processing methods in determining safety. In line with the growing emphasis on evidence-based validation of traditional medicines, systematic toxicological evaluation is essential to establish the safety profile of CIC for wider clinical acceptance and global use. Therefore, the present study was designed to assess the acute and sub-acute oral toxicity of *Ricinus Communis* in Wistar albino rats, following internationally accepted OECD Test Guidelines 423 (acute toxicity) and 407 (28-day repeated dose toxicity) [8,9]. This investigation aims to scientifically substantiate the traditional claims of safety and support the rational use of CIC in contemporary therapeutic practice

METHODOLOGY

Experimental Animals:

Toxicological evaluation of *Chitramanakku Ilai Chooranam* (CIC) was carried out in animal models following prior approval from the Committee for Control and Supervision of Experiments on Animals (CCSEA). The study was reviewed and approved by the Institutional Animal Ethics Committee (IAEC) of Arulmigu Kalasalingam College of Pharmacy, Thirunelveli, and conducted in the Institute's animal house facility. Wistar albino rats (*Rattus norvegicus*) of both sexes, weighing 140–160 g, were used for the study. The selected female rats were nulliparous and non-pregnant [8]. The animals were procured from an authorized animal breeder at the animal laboratory of TANUVAS, Madhavaram, Chennai, and housed at the Animal House facility, Arulmigu Kalasalingam College of Pharmacy. The rats were maintained in polypropylene cages under controlled environmental conditions with a temperature of 22 ± 2 °C, relative humidity of 40–65%, and a 12 h light/dark cycle. A 7-day acclimatization period was provided prior to the experiment. The animals had free access to standard feed and RO water *ad libitum*. The toxicity study was carried out in accordance with OECD guidelines 423 and 407 [8,9].

Effect of acute Toxicity Study (14 Days) of *Ricinus Communis*

The acute toxicity study was performed according to OECD Test Guideline 423. This method uses a stepwise approach with three animals of the same sex per dose, typically requiring two to four steps to assess mortality and classify acute toxicity. It minimizes animal use, provides reproducible results, and supports hazard classification rather than precise LD₅₀ determination, although an approximate LD₅₀ may be estimated when partial mortality occurs at multiple dose levels[8,10].



**Senthamil Veni et al.,****Experimental procedure:**

Twelve healthy, nulliparous, non-pregnant female Wistar albino rats were used and randomly assigned to two groups of three animals each after a 7-day acclimatization period. Animals were fasted overnight prior to dosing, with free access to water, and individual body weights were recorded to calculate dose levels. In the initial step, three rats were administered a single oral dose of CIC at 5 mg/kg body weight by gavage and observed for clinical signs of toxicity and mortality over a 14-day period. As no adverse effects were observed, subsequent groups received progressively higher single oral doses of CIC at 50, 300, and 2000 mg/kg body weight, respectively, following the same dosing and observation procedures. Throughout the study, animals were monitored for clinical signs of toxicity and changes in body weight. At the end of the 14-day observation period, all animals were euthanized and subjected to gross necropsy to identify any pathological alterations. Tissues showing gross lesions were further examined histopathologically. The maximum tolerated dose (MTD) of CIC was determined in accordance with the Globally Harmonised System (GHS) of Classification.

Determination of Animal Dose Level

As there is no toxicity observed at 2000mg/kg bw. The doses were determined from the results of acute toxicity study. The doses were as follows: Low dose – 50 mg/kg b. wt Mid dose – 300 mg/kg b. wt, High dose – 2000 mg/ kg b.wt.

Effect of 28 Days Repeated Oral Toxicity Study of Chitramanakku ilai chooranam

A 28-day repeated oral toxicity study was performed according to the OECD guideline, TG 407 (Revised - 18 December 2007). The OECD 407 guideline is important for assessing the subacute toxicity of a drug because it provides a standardized 28-day repeated-dose oral toxicity study that helps identify early harmful effects resulting from continuous exposure. It enables detection of target organ toxicity, establishes dose-response relationships, and determines the no-observed-adverse-effect level (NOAEL) [9]. A total of thirty healthy adult Wistar albino rats (15 males and 15 females), aged 6–8 weeks and weighing 150–180 g, were used for the study. The human therapeutic dose of MSC (2000 mg twice daily) was converted to the equivalent rat dose based on body surface area, resulting in a low dose of 180 mg/kg/day. Based on this, the animals were randomly divided into five groups (n = 6; 3 males and 3 females per group): Group I – control Group II - vehicle control, Group III – low dose (50 mg/kg/day), Group IV – mid dose (300 mg/kg/day), and Group V – high dose (2000 mg/kg/day). All treatments were administered once daily by oral gavage for 28 consecutive days. Animals were observed daily for clinical signs of toxicity and mortality. Body weights were recorded on Day 0, weekly thereafter, and on the day of necropsy. Food intake was monitored weekly, and mean consumption was calculated for each group. Clinical observations included general behaviour, skin and fur condition, eyes and mucous membranes, respiration, motor activity, reflexes, and signs of distress such as tremors, convulsions, lethargy, sleep, diarrhoea, or coma. Mortality and morbidity were checked twice daily.

At the end of the treatment period, animals were fasted overnight and euthanized using carbon dioxide inhalation. Blood samples were collected by cardiac puncture for hematological and biochemical analyses. Hematological parameters included hemoglobin, RBC, WBC with differential count. Biochemical markers such as urea, creatinine, bilirubin, SGOT, SGPT, and ALP were assessed using automated analyzers. Following blood collection, gross necropsy was performed, and major organs including brain, heart, lungs, liver, and kidneys were examined for lesions and weighed. Relative organ weights were calculated using the formula: (organ weight / body weight) × 100.

Statistical Analysis

Data were expressed as mean ± SEM, and statistical analysis was performed using one-way ANOVA followed by Tukey's multiple comparison test, with $p < 0.05$ considered statistically significant.





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RESULTS

The results of Acute and Subacute toxicity is represented in table 1 to 11. These tables provide a comprehensive overview of the evaluated parameters, including clinical observations, mortality data, body weight variations, food and water consumption, hematological indices, biochemical markers, organ weight measurements, and histopathological findings. The acute toxicity assessment primarily focuses on the immediate toxic manifestations while the subacute toxicity evaluation examines the cumulative effects of repeated exposure over the specified study period.

DISCUSSION

The toxicological assessment of *Chitramanakkul ilai chooranam* (CIC) (CIC) indicates that the formulation is safe and well-tolerated following acute and repeated 28-day oral administration in Wistar albino rats. The acute oral toxicity study showed no mortality, abnormal clinical signs, or behavioral changes at an even at the highest dose of 2000 mg/kg body weight. Thus, CIC is classified as “Category 5 - unclassified” under the Globally Harmonized System (GHS) [10]. Evaluation of food consumption constituted an important component of the safety assessment, as adequate nutrient intake is essential for maintaining normal physiological function in experimental animals [11]. Ensuring appropriate nutrition allows observed effects to be attributed to the test substance rather than to secondary consequences of nutritional deficiency or imbalance. Consistent feed and water intake across groups further supports the absence of treatment-related systemic toxicity or physiological stress [12,13]. The progressive increase in body weight observed in all treated groups was comparable to that of the control group, indicating that CIC did not adversely affect normal growth patterns or metabolic processes [11]. In the repeated 28-day oral toxicity study, CIC did not produce any treatment-related adverse effects on general health and body weight progression.

In addition, assessment of hematological parameters is critical, as the hematopoietic system is highly responsive to toxic insults and reflects a wide range of pathological conditions [13]. The evaluation of blood parameters therefore provides essential insight into the potential effects of the test substance on blood cell production, immune competence, and physiological homeostasis [12]. Hematological parameters remained within normal physiological limits, suggesting the absence of myelotoxic or immunological disturbances. Biochemical analyses further demonstrated that hepatic and renal function markers were unaltered, indicating preserved liver and kidney function. Minor variations observed in certain parameters were within normal biological ranges and were not considered toxicologically significant. Gross pathological examination of major organs revealed normal architecture with no evidence of degenerative or inflammatory lesions, thereby corroborating the biochemical and clinical observations. Relative organ weight, a sensitive and reliable indicator of target organ toxicity, showed only minimal variations with no statistically significant or dose-dependent changes. These findings indicate that repeated exposure to CIC did not induce organ hypertrophy or atrophy and further support its overall systemic safety. Thus, the results confirm that *Ricinus Communis* does not elicit acute or sub-acute toxicity under the tested conditions and can be considered safe for therapeutic use when administered at appropriate doses.

CONCLUSION

Acute and sub-acute oral toxicity studies of CIC were conducted in Wistar albino rats in accordance with OECD guidelines. CIC did not produce any signs of toxicity or mortality at a limit dose of 2000 mg/kg body weight, thereby placing it under Category 5 of the Globally Harmonized System (GHS) for acute toxicity. Furthermore, the 28-day repeated oral toxicity study revealed no mortality or treatment-related adverse effects on any specific organ. These findings confirm the establishment of a no-observed-adverse-effect level (NOAEL) for CIC under the tested conditions.





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Table no –1 Physical and behavioral examinations

Group no.	Dose(mg/kg)	Observation sign	No. of animal affected	Mortality
Group-I	5mg/kg	Normal	0 of 3	0 of 3
Group-II	50mg/kg	Normal	0 of 3	0 of 3
Group-III	300mg/kg	Normal	0 of 3	0 of 3
Group-IV	2000mg/kg	Normal	0 of 3	0 of 3

Statistical significance (p) calculated by one way ANOVA followed by Dunnett's (n=3); nsp >0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with control group. Data obtained in this study indicated nsp >0.05 no significant changes the physical and behavioral signs of any toxicity due to administration of *Ricinus Communis* at the doses of 5mg/kg, 50mg/kg, 300mg/kg and 2000mg/kg to rats.





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Table No. 2 Home cage activity

Functional and Behavioural observation	Observation	5mg/kg Group (G-I)	50mg/kg (G-II)	300mg/kg (G-III)	2000mg/kg (G-IV)
		Female n=3	Female n=3	Female n=3	Female n=3
Body position	Normal	3	3	3	3
Respiration	Normal	3	3	3	3
Clonic involuntary Movement	Normal	3	3	3	3
Tonic involuntary Movement	Normal	3	3	3	3
Palpebral closure	Normal	3	3	3	3
Approach response	Normal	3	3	3	3
Touch response	Normal	3	3	3	3
Pinna reflex	Normal	3	3	3	3
Tail pinch response	Normal	3	3	3	3

Statistical significance (p) calculated by one way ANOVA followed by Dunnett's (n=6); $^{ns}p > 0.05$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$, calculated by comparing treated groups with control group. Data obtained in this study indicated $^{ns}p > 0.05$ no significance changes in Home cage activity, signs of any toxicity due to administration of *Ricinus Communis* at the doses of 5mg/kg, 50mg/kg, 300mg/kg and 2000mg/kg to rats.

Table no-3 Hand held observation

Functional and Behavioral observation	Observation	(G-I)	(G-II)	(G-III)	(G-IV)
Reactivity	Normal	3	3	3	3
Handling	Normal	3	3	3	3
Palpebral closure	Normal	3	3	3	3
Lacrimation	Normal	3	3	3	3
Salivation	Normal	3	3	3	3
Piloerection	Normal	3	3	3	3
Pupillary reflex	Normal	3	3	3	3
Abdominal tone	Normal	3	3	3	3
Limb tone	Normal	3	3	3	3

Statistical significance (p) calculated by one way ANOVA followed by Dunnett's (n=6); $^{ns}p > 0.05$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$, calculated by comparing treated groups with control group. Data obtained in this study indicated $^{ns}p > 0.05$ no significance changes in hand held observation and signs of any toxicity due to administration of *Ricinus Communis* at the doses of 5mg/kg, 50mg/kg, 300mg/kg and 2000mg/kg to rats.

Table :5 Effect of Sub- Acute Dose (28 Days) of *Ricinus Communis* on Body Weight In Gram

Group	Normal control	Vehicle Control	Low	Mid	High
1 st day	191.02±0.15	189.03±0.06	211.08±0.08	185.02±0.03	190.06±0.03
7 th day	197.07±0.03	194.04±0.08	215.10±0.09	187.09±0.10	196.02±0.07
14 th day	203.08±0.02	207.09±0.03	216.04±0.04	188.03±0.15	198.94±0.09
21 st day	211.05±0.09	214.07±0.09	217.07±0.06	189.04±0.08	206.06±0.05
28 th day	215.12±0.10	218.07±0.08	219.06±0.07	193.02±0.09	208.06±0.08

Values are expressed as mean ± SEM Statistical significance (p) calculated by one way ANOVA followed by Dunnett's (n=6); $^{ns}p > 0.05$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$, calculated by comparing treated groups with control group. The effect of CIC was observed, on the body weight changes, significantly increase ($^{*}p < 0.05$) in body weight in all the treated animals were observed. The values are expressed as mean ± S.E.M. n=6. The results of group I were compared with other groups such as II, III, IV.





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Table:6 Effect of Sub- Acute Dose (28 Days) of on Food Intake In Gram

GROUP	CONTROL	VEHICLE CONTROL	LOW	MEDIUM	HIGH
1st day	22.12±0.15	20.16±0.13	19.12±0.07	19.11±0.11	21.12±0.10
7th day	21.04±0.27	22.53±0.09	20.09±0.16	21.09±0.13	22.19±0.22
14th day	20.14±0.09	20.18±0.16	21.16±0.19	20.80±0.19	21.19±0.10
21st day	19.22±0.08	21.09±0.15	22.19±0.78	22.03±0.10	20.25±0.15
28th day	21.29±0.04	22.94±0.12	22.09±0.19	21.04±0.09	21.83±0.08

Values are expressed as mean ± SEM Statistical significance (p) calculated by one-way ANOVA followed by Dunnett's (n=6); ^{ns}p>0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with control group. The Food intake values was compared in Group I to other groups II, III, IV, and V. in experimental rat. Final study, significantly increase in the Food intake values. The values are expressed as mean ± S.E.M. n=6.

Table:7. Effect of Sub acute dose of Chitramanakku ilai chooranam (CIC) on Water Intake in ml

GROUP	CONTROL	VEHICLE CONTROL	LOW	MIDUM	HIGH
1st day	12.08±0.16	16.35±0.16	12.25 ±0.31	13.27±0.09	13.06±0.08
7th day	16.17±0.92	15.19±0.16	13.91 ±0.47	16.08±0.07	12.09±0.31
14th day	13.29±0.19	14.27±0.52	12.83 ±0.41	15.14±0.06	14.41±0.41
21st day	16.27±0.32	15.26±0.12	13.29 ±0.11	14.35±0.05	15.53±0.83
28th day	15.02±0.29	13.45±0.35	12.57±0.14	12.43±0.04	16.43±0.54

Values are expressed as mean ± SEM. Statistical significance (p) was calculated by one-way ANOVA followed by Dunnett's (n=6); ^{ns}p>0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with the control group. Water intake was compared in Group I and the other groups (II, III, IV, and V) in experimental rats. In the final study, there was a significant increase in water intake. Values are expressed as mean ± S.E.M. n=6.

Table :8 CIC on organ weight (Physical Parameter) In Grams

Group	Control	Vehicle Control	Low	Mid	High
HEART	2.52±1.23	2.4±0.21	2.47±0.21	2.52±0.25	2.59±0.23
LIVER	4.72±0.56	4.46±0.31	4.74±0.34	4.19±0.38	4.58±0.16
LUNGS	2.3±0.32	1.89±0.22	1.84±0.38	1.79±0.26	1.83±0.38
KIDNEY L	1.44±0.66	1.37±0.58	1.36±0.10	1.43±0.12	1.41±0.28
KIDNEY R	1.48±0.13	1.34±0.02	1.32±0.47	1.46±0.28	1.42±0.37

Values are expressed as mean ± SEM Statistical significance (p) calculated by one way ANOVA followed by Dunnett's (n=6); ^{ns}p>0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with control group. The effect of CIC on kidney, heart, liver and lungs of the rats were recorded. not significant p>0.05 changes in the weights of various organs of the animals occurred with higher doses of the extract but macroscopic examinations visualized no changes in color of the organs of the treated animals compared with the control group.

Table no :9 Effect of Sub acute dose of Chitramanakku Ilai Chooranam (CIC) on Haematological Parameters

Drug treatment	RBC Millin/mm ³	WBC Thou/mm ³	Haemoglobin gm/dl	Differential count %			
				Neutrophils	Eosinophils	Monocyte	Lymphocyte
Control	4.60±0.05	5.40±0.03	10.18±0.11	50.06±0.56	3.08±0.07	8.12±0.13	35.44±0.04
Vehicle Control	4.80±0.03	8.10±0.04	12.06±0.09	53.07±0.02	3.25±0.09	6.09±0.01	38.46±0.17
LOW	4.63±0.05	7.82±0.07	11.55±0.03	54.11±0.08	3.41±0.18	8.20±0.03	35.19±0.10
MID	4.70±0.03	6.71±0.08	10.08±0.09	52.42±0.11	3.22±0.14	7.28±0.02	33.08±0.08
HIGH	4.90±0.04	7.20±0.09	12.27±0.14	53.04±0.11	3.15±0.02	8.36±0.02	35.36±0.19





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Values are expressed as mean $\pm$ SEM Statistical significance (p) calculated by one way ANOVA followed by Dunnett's (n=6); ^{ns}p>0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with control group. The effect of CIC were observed for its effect on hematological parameters in experimental rat. Final study, not significant (p<0.05) in the haemoglobin, RBC values are increased after treated groups. The values are expressed as mean $\pm$ S.E.M. n=6. The results of group I were compared with other groups such as II, III, IV.

Table : 10 Effect of Sub- Acute Dose(28 Days) of CIC on Biochemical Parameter

Drug Treatment	SGPT (U/L)	SGOT(U/L)	Urea (mg/dl)	Creatinine (mg/dl)	Bilirubin
Control	32.09 $\pm$ 0.08	22.38 $\pm$ 0.08	23.07 $\pm$ 0.09	0.88 $\pm$ 0.33	0.97 $\pm$ 0.34
Vehicle Control	27.45 $\pm$ 0.04	30.26 $\pm$ 0.15	3.28 $\pm$ 0.08	0.78 $\pm$ 0.35	0.75 $\pm$ 0.33
LOW	26.18 $\pm$ 0.03	18.38 $\pm$ 0.10	28.28 $\pm$ 0.19	0.64 $\pm$ 0.25	0.74 $\pm$ 0.14
MID	29.08 $\pm$ 0.18	26.16 $\pm$ 0.17	25.72 $\pm$ 0.15	0.62 $\pm$ 0.15	0.75 $\pm$ 0.44
HIGH	28.17 $\pm$ 0.05	20.03 $\pm$ 0.04	27.08 $\pm$ 0.28	0.94 $\pm$ 0.19	0.76 $\pm$ 0.39

Values are expressed as mean $\pm$ SEM Statistical significance (p) calculated by one way ANOVA followed by Dunnett's (n=6); ^{ns}p>0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with control group. The SGPT, SGOT, ALP, UREA and Creatinine values was compared in Group I and other groups II, III, IV. The biochemical Parameters in experimental rat not significant (p<0.05) in The SGPT, SGOT, ALP, Bilirubin, urea and Creatinine values. The values are expressed as mean $\pm$ S.E.M. n=6.

Table: 11 Effect of Sub Acute Doses (28 Day) of CIC on electrolytes

GROUP	CONTROL	VEHICLE CONTROL	LOW	MEDIUM	HIGH
Sodium (mmol/L)	135.09 $\pm$ 0.16	135.33 $\pm$ 0.03	136.05 $\pm$ 0.15	137.07 $\pm$ 0.11	138.57 $\pm$ 0.32
chloride(mmol/L)	101.45 $\pm$ 0.19	98.24 $\pm$ 0.18	101.08 $\pm$ 0.19	98.35 $\pm$ 0.28	101.06 $\pm$ 0.55
potassium(mmol/L)	3.87 $\pm$ 0.11	4.21 $\pm$ 0.13	4.08 $\pm$ 0.14	4.08 $\pm$ 0.41	4.89 $\pm$ 0.12

Values are expressed as mean $\pm$ SEM Statistical significance (p) calculated by one-way ANOVA followed by Dunnett's (n=6); ^{ns}p>0.05, *p<0.05, **p<0.01, ***p<0.001, calculated by comparing treated groups with control group. There was no significant changes in the Electrolyte level in all the treated animals compared to the control. The values are expressed as mean $\pm$ S.E.M. n=6. The results of group I were compared with other groups such as II, III, IV and V

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RESEARCH ARTICLE

Ayurvedic Management of Sidhma Kustha (Psoriasis) : A Case Report

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ABSTRACT

Skin is considered a reflection of internal health in *Ayurveda*, mirroring both physical and mental states. In the present era, skin disorders such as *Psoriasis* are on the rise due to improper dietary habits, stress, and a sedentary lifestyle. Modern science identifies psoriasis as a chronic, immunologically influenced inflammatory disease. Condition prevalence ranges between 0.5% and 3% worldwide. Despite various treatments, achieving complete remission remains challenging. In Ayurvedic texts, *Psoriasis* closely resembles *Sidhmakushta*, a subtype of *Kushtha Roga*, primarily involving *Vata* and *Kapha* doshas with features like *Aswedanam*, *Suklaraktabhabhasah*, *Visirya*, and *Bahirdaruni*. We present the case of a 32-year-old man diagnosed with chronic plaque psoriasis. Experiencing multiple scaly, erythematous plaques with intense itching for five months. He had previously undergone allopathic management with limited relief. Based on Ayurvedic *Samprapti*, *Shodhana* and *Shamana* chikitsa were administered, including *Panchtikta Kwatha*, *Nimbadi Kwatha*, *Mahamajisthadi Kwatha*, *Panchatiktaghrita Guggulu*, and *Nalpamaradi Taila*, along with *Pathya-Apathya* guidance. The patient followed a restricted diet, avoiding *Viruddha Ahara*, *Amla*, and *Katu* substances and discontinued *Divasvapna* (daytime sleeping). Clinical outcomes were assessed using the PASI score, which significantly reduced from 21.4 to 1.2 within 85 days, showing a 94.39% improvement. No adverse effects were noted. This case highlights that, through appropriate diagnosis based on *Dashavidha Pariksha*, understanding *Dosha-Dushya Sammurchana*, and following classical therapeutic protocols, chronic conditions like *Sidhmakushta* can be effectively managed. It reinforces the holistic and evidence-based potential of Ayurveda in treating relapsing skin diseases like psoriasis.

Keywords: Ayurveda, *kushtha*, *Sidhmakushta*, Psoriasis area severity index score, Psoriasis.





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INTRODUCTION

The skin acts as the body's primary protective barrier, protecting internal organs and regulating temperature, fluid balance, and sensory perception. In Ayurveda, it is considered a mirror of one's overall health, reflecting the physical, mental, and emotional state. In today's era of rapid modernisation, the prevalence of skin disorders has risen significantly due to lifestyle changes, poor dietary habits, stress, and unhygienic conditions. These conditions not only affect the body physically but also have a profound psychological impact, often leading to embarrassment, anxiety, low self-esteem, and depression in affected individuals. Psoriasis is a chronic, relapsing condition that demands long-term management to control symptoms and prevent recurrence. Treatment choice depends on disease severity, comorbidities, and healthcare accessibility, requiring an individualised approach for effective and sustained therapeutic outcomes. Classification of psoriasis into mild or moderate-to-severe types depends on the severity of skin lesions, BSA involvement, and degree of impairment in quality of life.[1] It is a chronic and recurrent immune-driven dermatosis seen in nearly 1%-2% of individuals worldwide and is recognised as a significant global health concern due to its multifactorial nature and impact.[2] Characterised by erythematous, scaly plaques, the condition typically affects the extensor surfaces, scalp, and lower back.[3] Psoriasis is a global health burden, impacting approximately 0.5% to 3% of people worldwide.[4] Although the exact cause is unknown, psoriasis is believed to be an autoimmune disorder primarily mediated by T lymphocytes.[5] It significantly affects psychosocial well-being, often interfering with the patient's quality of life.[6] The disorder presents in multiple variants, with plaque-type representation being the most common. Its lesions typically appear on the trunk, limbs, and scalp.[7] Despite tremendous advancements in modern science, particularly in dermatology, there is still no proven treatment for psoriasis.

In Ayurveda, all skin diseases come under *Kushtha Roga*. In Ayurveda, psoriasis is analogous to *Sidhmakushtha* condition involving *Vata-Kapha dosha* predominance, described under chronic skin disorders. Also Vata - Pitta - Kapha manifestation characterised by symptoms such as *alabupuspasadsaksam* (resembling flowers of a gourd), *prash* (dry lesions), *Arunabh* (whitish), *Visirya* (Broken), *Aswedanam* (anhidrosis), *Bahirdaruni* (Thin appearing skin outside), *Antahsnigdhani* (unctuous inside), *Suklaraktabhabhasah* (whitish and reddish tinged lesions), *daughdhikapuspavat* (resembles *daughdhika* flower) [8] etc, explained Classical texts cite *Sidhmakushtha* (causes) as consuming incompatible foods (*Viruddhaahara*), suppressing natural urges (*Vega dharana*), along with day sleeping (*Divasvapna*) and indulgence in sinful actions (*Papakarma*), which together contribute to the disease's development. This case report aims to explore the Ayurvedic approach in managing a case of *Sidhmakushtha*, highlighting classical principles and clinical outcomes.

MATERIALS AND METHODS

Patient Information

A 32-year-old male visited the Ayurveda OPD with chief complaints of multiple thickened, erythematous plaques over the back region. Legs, along with arms, outpatient department (OPD) on June 07, 2024, complaining of back and leg itching. The Distribution appears symmetrical across all four limbs in the past 2 months, 25 days. The patient had been treated under modern medicine for psoriasis, which included methotrexate (2 mg once weekly), Apremilast (30 mg, twice daily), a 6% topical lotion, and liquid paraffin, both applied twice a day. A weekly dose of Vitamin D3 (60,000 IU) was also administered. This treatment was recommended by an allopathic dermatologist. The patient had no prior record of diabetes, high blood pressure, or any serious health conditions. Additionally, no drug allergies were noted, no past surgeries, and no habits of smoking, alcohol use, or substance abuse. The patient had reduced appetite, normal thirst, and regular bowel and bladder Function. Sleep was frequently disturbed due to intense itching. Dietary history revealed excessive intake of milk, curd, salty and sour foods. The patient also reported a habit of sleeping during the daytime, contributing to the aggravation of symptoms.



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Clinical Observations

The patient had several scaly, Multiple hyperpigmented, dry plaques and well-defined margins. Silvery-white scaling is prominent on several lesions, suggestive of psoriasiform pathology. Some plaques show thickening and raised surfaces (induration), dooshi vish present ++. Older lesions show post-inflammatory hyperpigmentation [Figure1]. The presentation was distributed symmetrically. Involves both lower limbs extensively (legs, knees, dorsum of feet), affects the upper limbs and back. Koebner's phenomenon signs were positive (lesions appearing at sites of friction). The patch appears dry and rough. Flaky scales are seen on legs and arms. No signs of oozing, discharge, or infection in the visible areas. The varying sizes of plaques are round to irregular in shape. He showed signs of poor appetite and irregular sleep routines. Five months ago, a small, round patch appeared on the patient's back. Patches progressively appeared on the shoulders, limbs, and back, accompanied by intense itching and silvery scaling. On clinical examination, the patient was afebrile with stable vital signs. Pallor, icterus, clubbing, cyanosis, and lymphadenopathy were not observed. Systemic assessment encompassed the cardiovascular, respiratory, urinary, and CNS, which showed normal findings, indicating overall systemic stability.

Timeline

With reference to the *Dosha* and *Dushya* involved, the patient underwent *Shodhana* (purificatory) and *Shamana* (pacifying) therapies alongside strict dietary modifications. He avoided sour foods like lemon and tamarind, salty snacks, spicy, packaged, curd, jaggery, meat, fish, and sesame seed. Advising against daytime sleep and emphasizing personal hygiene, oral and topical Ayurvedic medicines were prescribed. Treatment efficacy was assessed through evaluations conducted before therapy, posttherapy, and during follow-up. [Table1]

Diagnosis

The patient first sought medical advice on February 04, 2024, and was diagnosed with psoriasis. He was placed on allopathic treatment, which he continued for three months before voluntarily discontinuing the medications. As his condition showed no improvement, he consulted another allopathic dermatologist on May 17, 2024, who advised maintaining the same treatment plan. Due to inadequate relief, the patient later presented to our Ayurvedic OPD seeking alternative care. A preliminary evaluation using the Psoriasis Area and Severity Index (PASI) revealed a score of 21.4. All allopathic medications were ceased prior to initiating Ayurvedic intervention. Patient's clinical presentation was evaluated through classical signs of *Sidhmakushtha*, including *Aswedanam*, *Suklaraktabhabhasah* and discolouration (*Krishna Aruna Varna*). Routine lab tests on June 9, 2024, showed normal results (CBC, LFT) except a platelet count of 154,000/ μ L. Ayurvedic consultation and Ayurvedic treatment begin on June 7, 2024, with *Shamanachikitsa* administered for two months. Progress was monitored using the PASI score and symptom changes, indicating noticeable improvement throughout the treatment period. The individual's strength was assessed through *Dashavidha Aturapariksha* (tenfold patient examination). [9] The patient's constitution (*Prakriti*) was identified as *Pitta-Vataja*. His tissue quality (*Sara*), structural build (*Samhanana*), body measurement (*Pramana*), digestive strength (*Ahara Shakti*), mental strength (*Satva*), and age (*Vaya*) were found to be of a moderate (*Madhyama*) level. However, his capacity for physical exertion (*Vyayama Shakti*) and dietary adaptability (*Satmya*) were low (*Avara*). The observed imbalance (*Vikriti*) was of *Vata-Pitta-Kaphaja* origin. These factors provided a holistic basis for personalised Ayurvedic management.

Samprapti Ghataka (Ayurvedic Pathogenesis)

The condition showed dominance of *Vata-Kapha* doshas. The *Dushyas* (affected tissues) included *Twak* (skin), *Mamsa* (muscle), *Rakta* (blood), and *Ambu* (fluids), and *Raktavaha*, responsible for nutrient Fluids and blood transport channels. The *Rogadhithana* (site of manifestation) was *Twak*. *Agni* (Digestive fire) was observed to be *Manda* (mildness), indicating sluggish metabolism. The *Svabhava* (nature of the disease) was *ChirakaalaAnubandhini*, suggesting its chronic and persistent course. This guided the selection of appropriate Ayurvedic interventions.

Therapeutic Intervention

The therapeutic measures administered during the intervention period are listed in Table 1.





RESULTS AND DISCUSSION

Results and Following up

Following two months and 25 days of treatment, scaling, itching, and plaques significantly decreased, with marked improvement in overall condition.[Fig.1] By the conclusion of therapy, the PASI score had reduced to 1.2. [Table 2]. This corresponds to a 94.39% reduction in PASI score, indicating substantial clinical improvement through classical Ayurvedic intervention.

DISCUSSION

The primary factors contributing to the development of *Sidhmakushtha* involve the predominance and imbalance of *Vata* and *Kapha* doshas, which affect the *Sapta Dushya*. Taking in *Nidana*, or causative agents, leads to simultaneous aggravation of these *doshas* and results in *Shaithilyata*, meaning weakness or laxity, in the affected *Dhatu*s. This weakened state of *Dhatu*s further promotes the clinical presentation of *Kushtha*. [10] In this particular case, the patient's unhealthy dietary habits such as excessive consumption of milk mixed with salt, curd, and overly salty or sour foods along with daytime sleeping, likely triggered the *dosha* imbalance, contributing to the disease's onset. Although the exact pathological mechanism from a modern scientific perspective remains to be fully elucidated, Ayurvedic principles guided the treatment approach. Considering the dominant involvement of *Vata* and *Kapha* doshas and the affected tissues, the patient was administered a *Vata-Kapha* pacifying regimen combined with a *Pathya* diet emphasising light, easily digestible. The prescribed diet comprised bitter vegetables such as aged cereals. [11]

Interventions' Probably Method of Action

Panchatikta Kwath, composed of *Nimba*, *Vasa*, *Guduchi*, *Patola*, and *Kantakari*, exhibits strong *Kushthaghna* and *Raktashodhaka* properties. Its *Tikta Rasa* and *Ushna Virya* reduce *Kleda*, purify *Rakta*, cleanse *Srotas*, and pacify *Vata-Pitta*, thereby arresting the progression of *Kushtha* like *Sidhma*. *Nimbadi Kwath*, containing *Nimba*, *Guduchi*, *Triphala*, *Vacha*, and *Trikatu*, acts through its *Tikta* and *Kashaya Rasa*. It purifies *Rakta*, reduces *Kleda*, and pacifies *Tridosha*. Its ingredients synergistically support *Srotoshodhana*, anti-inflammatory action, and skin detoxification in conditions of *Kushtha*. *Bilvadi Gulika* contains *Bilva*, *Agnimantha*, *Shunti*, *Pippali*, *Maricha*, *Vacha*, and other herbs with *Deepana*, *Pachana*, *Krimighna*, and *Vishaghna* properties. It detoxifies the body, calms *Vata* and *Kapha*, and acts as an antimicrobial and antiallergic agent useful in skin diseases with an underlying *Ama* or toxin load. *Aragwadhadi Kapila*, containing *Aragwadha*, *Nimba*, *Haridra*, *Guduchi*, and *Triphala*, acts as a potent *Kushthaghna*, *Raktashodhaka*, and *Kledashoshaka*. It detoxifies the skin, purifies blood, and pacifies *Pitta* and *Kapha*.

Its *Tikta-Kashaya Rasa* and *Ushna Virya* help break the pathogenesis of skin disorders like *Kushtha*. *Mahamajishthadi Kwatha*: It is indicated in all types of *Kushtha*. *Manjistha* is known for its *Varnya*, *Kushthaghna*, and *Rakta Shodhaka*, *krimighna*, *Shonita sthapaka* actions. It purifies blood, alleviates inflammation and pain, and modern studies support its antioxidant and anticancer potential, enhancing its therapeutic relevance. *Nalpamaradi Taila*, comprising *Nalpamara* (*Ficus* species) barks, *Haridra* (turmeric), *Manjistha*, *Chandana* (sandalwood), *Vetiver*, and *Sesame* oil, exhibits *Kushthaghna*, *Raktashodhaka*, *Shothahara*, and *Varnya* properties. It purifies blood, alleviates skin inflammation, reduces pigmentation, and enhances complexion, effectively managing various skin disorders. *Panchamahatiktaka Ghrita guggulu*, with its *Kushthaghna* and *Vata-Pitta Shamana* properties [12], reduces *Kleda*, purifies microchannels (*Srotas*), pacifies vitiated *Doshas*, and effectively interrupts the disease process in *Sidhmakushtha*. *Dadhi* (curd) prevents skin dryness and scaling when applied topically. Clinical studies also demonstrate its antimicrobial properties, making it beneficial in managing various skin conditions. Prescribed oil from coconuts has anti-inflammatory and skin-protection properties. Applying it helps reduce itching, dryness, and redness in skin lesions. [12] When combined with *Wrightia tinctoria* leaf extract, it exhibits significant anti-psoriatic and antioxidant effects, enhancing therapeutic outcomes. [13]



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CONCLUSION

Based on the positive symptom improvement seen in this case, it suggests that while full recovery might not be achieved in a brief treatment period of two months and 25 days, Ayurvedic treatments can still deliver significant relief in psoriasis symptoms without notable adverse consequences.

Consent Declaration from the Patient

The authors confirm that informed consent was obtained from the patient for the publication of this case report, including the use of clinical details and images. The patient was informed that their name and initials would not be disclosed, and while all reasonable efforts will be made to protect their identity, complete anonymity cannot be guaranteed.

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Table 1. Therapeutic interventions used in the treatment

Sr. No	Medicine	Dose	Time
1.	<i>Panchtikthaka kwath</i>	20ml	TID Before Food
2.	<i>Nimbadi Kwath</i>	15ml	TID After Food
3.	<i>Vilvadi Gulika</i>	500mg	2-0-2 After Food
4.	<i>Aragwadhadi Kapila</i>	500gm	1-0-1 Before Food
5.	<i>Nalpamaradi Taila</i>	30ml	External apply Daily once



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6.	<i>Mahamajisthadi Kwatha</i>	40ml	Daily Once After Food
7.	<i>panchtiktaghrita Guggulu</i>	500mg	2-0-2 After Food

Table 2: PASI (Psoriasis Area Severity Index) Score of the Patient

	Cephalic region including the neck (10%)	The hands (20%)	Back (30%)	Leg (40%)
Skin area involved (%)	-	50%	40%	60–70%
Area score	-	4	3	4
Erythema (redness)	-	2	2	2
Induration (thickness)	-	2	2	2
Desquamation (scaling)	-	2	2	3
Score	-	4.8	5.4	11.2

The total PASI score, which was 21.4 at baseline (comprising 11.2 for lower limbs, 5.4 for trunk, 4.8 for upper limbs, and 0 for head), significantly reduced to 1.2 following Ayurvedic management, with only minimal involvement in the lower limbs



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RESEARCH ARTICLE

From Colic to Comfort : Wonders of *Berberis vulgaris* Q in Renal Calculi : A Clinical Case Report

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ABSTRACT

: A case of renal calculi was treated at the PIHR Hospital OPD following homoeopathic principles of case taking. The patient presented with chief complaint of left sided flank pain for 15 days which was aggravated at night⁺⁺⁺, sitting⁺⁺ and ameliorated by standing. Also, it was associated with nausea and vomiting and H/o Hematuria. Ultrasonography revealed 6.5 mm calculus in left lower ureter (3cm proximal to UVJ) with resultant proximal mild hydronephrosis. Bilateral kidneys show 2 to 3 renal concretions of average size 2-3 mm. Based on totality of symptoms *Berberis vulgaris* Q – 15 drops in ½ cup of water TDS for 15 days was prescribed. Significant symptomatic relief was observed within two weeks, with pain on the Numerical Ratings Scale reducing from 7/10 to 0/10. Follow-up ultrasonography after fourteen weeks showed complete resolution of calculi in both kidneys. This case report highlights the clinical effectiveness of *Berberis Vulgaris* Q in management of renal calculi.

Keywords: Renal calculi, Homoeopathy, *Berberis vulgaris* Q, Pain NRS, Case report

INTRODUCTION

Renal calculi, more commonly referred to as kidney stones, are one of the most common and painful urological condition encountered globally³⁴. The estimated global prevalence is 12% of the population, with a consistent rise in incidence and prevalence in both developed and developing countries⁷. In India, the overall prevalence of urolithiasis is approximated to be about 12% of the population⁷. There is a significant predominance in males with a male-to-female ratio of about 4:3⁶.



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Renal calculi can be managed through various therapeutic systems, including conventional Allopathic, Ayurvedic, Homoeopathic, Herbal medicine systems etc. Conventional management includes analgesics, hydration, medical expulsive therapy, or surgical intervention. Homoeopathy is a gentle system of healing. There are many remedies for renal calculi in Homoeopathy like *Berberis Vulgaris*, *Calcarea Renalis*, *Cantharis*, *Hydrangea*, *Lycopodium Clavatum*, *Nux Vomica*, *Pareira B*, *Sarsaparilla*, *Ocimum Can*, *Tabacum*, *Uva Ursi*, *Nux Vomica*, etc². *Berberis vulgaris* being one of the most frequently indicated medicines due to its affinity for the urinary tract specially for the left sided Renal colic where there is characteristic stitching, cutting pain from left kidney following course of ureter into bladder and urethra which is worse by touch, when sitting and lying, from jar, from fatigue.¹

Many individuals tend to neglect treatment for renal calculi and often seek medical treatment when they experience severe colicky pain, which can delay timely management and increase the risk of complications. Irrespective of size, all renal calculi require appropriate evaluation and management to prevent potential complications and preserve renal function. In this context, this case highlights the efficacy of *Berberis vulgaris* Q in alleviating the colicky pain and facilitating the resolution of renal calculi.

OBJECTIVES

To evaluate the efficacy of *Berberis vulgaris* Q in relieving renal colic using pain NRS.

To evaluate the efficacy of *Berberis vulgaris* Q in expulsion of renal calculi.

MATERIALS AND METHODOLOGY

- **Study Setting:** The study is conducted at O.P.D of Parul Institute of Homoeopathy & Research & Hospital, Ishwarpura, Limda, Vadodara, Parul University
- Date: 30/07/25
- Name: SHS
- Age: 45 years
- Gender: Male
- Education: 10th std
- Religion: Hindu
- Occupation: Business
- Address: Ahmedabad

Clinical findings:

- Diagnosed case of renal calculi for 5 days.
- Left sided Needle like flank pain for 15 days
- Pain < at night⁺⁺⁺, sitting⁺⁺
- Pain > by standing.
- Nausea and vomiting of ingesta with pain.
- H/o Hematuria one week before.
- Appetite decreased due to complaint.
- Desire: Spicy, salty, warm food
- Thirst: 1-2 lit/day
- Urine: 4-5/day and 2-3/night, clear, pale yellow, profuse, no burning
- Sleep disturbed due to pain.
- USG-KUB: 6.5 mm calculus in left lower ureter (3cm proximal to UVJ) with resultant proximal mild hydronephrosis. Bilateral kidneys show 2 to 3 renal concretions of average size 2-3 mm.



**Khyati Lakhani et al.,****Past History**

Umbilical Hernia operated 3 years back.

Backache before 2 years relived by taking Homoeopathic medicine.

Cold and cough at change of weather for 3 years.

Family History:

Mother: Dead: H.T, D.M

Father: Dead: Inguinal Hernia

Miasmatic Evaluation:

Psoric-Sycotic

Diagnostic Assessment:

1. Clinical Symptoms
2. USG –KUB

Analysis of symptoms:**Evaluation of symptoms:****Totality of symptoms:**

1. Desire: Spicy, salty, warm food
2. Pain < at night⁺⁺⁺, sitting⁺⁺
3. Pain > by standing
4. Nausea and vomiting of ingesta with pain
5. Left sided Needle like flank pain Nausea and vomiting of ingesta with pain.
6. H/o Hematuria
7. Left sided renal calculi

Repertorial Totality: Repertorisation Sheet - Zomeo Pro LAN -Kent's Repertory

Therapeutic intervention

Berberis vulgaris Q – 15 drops in ½ cup of water TDS for 15 days.

FOLLOW UP :**OUTCOME**

Over a period of two weeks, the patient showed marked symptomatic improvement. In the first visit the patient rated his renal calculi pain as 7/10 on the pain NRS. After Homoeopathic administration of *Berberis vulgaris* Q, the pain gradually reduced and finally reached 0/10, indicating complete relief. Follow-up ultrasonography on 25/11/25 (after fourteen weeks) showed no evidence of the calculus in both kidneys with sense of wellbeing.

DISCUSSION

This evidence-based case highlights the effectiveness of *Berberis vulgaris* Q as a safe, non-invasive, cost-effective therapeutic measure for managing renal calculi. Future studies with large sample size and a multidisciplinary approach is required to strengthen the scientific basis and therapeutic application of *Berberis vulgaris* mother tincture for benefit of humanity in cases of renal calculi.





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CONSENT

Written informed consent was obtained from the patient.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

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Table 1 Analysis of symptoms

No	Symptom	Analysis of symptoms
1	Left sided renal calculi	Physical Particular
2	Left sided Needle like flank pain	Physical Particular
3	Pain < at night ⁺⁺⁺ , sitting ⁺⁺	Physical Particular with aggravating modality
4	Pain > by standing	Physical Particular with ameliorating modality
5	Nausea and vomiting of ingesta with pain.	Physical Particular
6	H/o Hematuria	Physical Particular
7	Desire: Spicy, salty, warm food	Physical General

Table 2. Evaluation of symptoms

No	Symptom	Analysis of symptoms
1	Desire: Spicy, salty, warm food	Physical General
2	Pain < at night ⁺⁺⁺ , sitting ⁺⁺	Physical Particular with aggravating modality
3	Pain > by standing.	Physical Particular with ameliorating modality
4	Left sided Needle like flank pain	Physical Particular
5	Nausea and vomiting of ingesta with pain.	Physical Particular
6	H/o Hematuria	Physical Particular
7	Left sided renal calculi	Physical Particular



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Table 3 Follow Up

Date	Change in symptomatology	Pain NRS Score	Prescription
Baseline 30/7/25	Needle like pain in left flank region with nausea and vomiting.	7/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days.
Follow up No.1 13/8/25	Needle like pain in left flank region gradually reduced in first week. And in second week there was no pain. No nausea and vomiting Appetite: Improved Sleep: sound	0/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days.
Follow up No.2 29/8/25	No episode of pain Appetite: Improved Sleep: sound	0/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days.
Follow up No.3 12/9/25	No episode of pain Appetite: Improved Sleep: sound	0/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days.
Follow up No.4 27/9/25	No episode of pain Appetite: Improved Sleep: sound	0/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days.
Follow up No.5 13/10/25	No episode of pain Appetite: Improved Sleep: sound	0/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days.
Follow up No.6 28/10/25	No episode of pain Appetite: Improved Sleep: sound	0/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days.
Follow up No.7 12/11/25	No episode of pain Appetite: Improved Sleep: sound	0/10	Rx, <i>Berberis vulgaris</i> Q – 15 drops in ½ cup of water TDS for 15 days. Patient was advised for USG-KUB
Follow up No.8 25/11/25	No episode of pain Appetite: Improved Sleep: sound USG -KUB: No evidence of renal calculi or hydronephrosis is seen.	0/10	Medicine was stopped





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Remedy	Berb	Lyc	Phos	Ars	Calc	Canth	Nat-m
Totality	9	9	9	8	8	7	7
Symptoms Covered	5	4	4	3	3	3	3
[Kent] [Stomach]Desires:Salt things:	0	0	3	0	2	0	3
[Kent] [Stomach]Desires:Warm:Food:	0	2	0	3	0	0	0
[Kent] [Kidney]Pain:Sitting,while:	2	0	0	0	0	0	0
[Kent] [Kidney]Pain:Stitching,stinging,stickings:Night:	0	0	0	0	0	0	0
[Kent] [Kidney]Pain:Standing amel:	1	0	0	0	0	0	0
[Kent] [Kidney]Pain:Stitching,stinging,stickings:	3	2	1	2	0	2	2
[Kent] [Urine]Bloody:	1	2	3	3	3	3	2
[Kent] [Urine]Sediment:Renal calculi:	2	3	2	0	3	2	0

Fig.1. Repertorial Totality: Repertorisation Sheet - Zomeo Pro LAN -Kent's Repertory

NAME: [REDACTED] M / 45 YRS DATE: 26/07/2025 SONOGRAPHY OF ABDOMEN AND PELVIS Observations: LIVER: Liver appears normal in size and shows increased parenchymal echoes. No evidence of focal or diffuse lesion is seen. No evidence of dilated IHBR is seen. Intrahepatic portal radicles appear normal. GALL BLADDER: Gall bladder appears normal. No evidence of calculus or changes of cholecystitis are seen. CBD appears normal. PANCREAS: Pancreas appears normal in size and shows normal parenchymal echoes. No evidence of pancreatitis or pancreatic mass lesion is seen. SPLEEN: Spleen appears normal in size and shows normal parenchymal echoes. No evidence of focal or diffuse lesion is seen. KIDNEYS: Both kidneys are normal in size, shape and position. Cortical and central echoes appear normal. Bilateral cortical thickness appears normal. A calculus of size 6.5 mm is seen in LEFT LOWER URETER (3 cm proximal to VUJ) with resultant proximal mild hydronephrosis. Bilateral kidneys show 2 to 3 renal concretions of average size 2-3 mm. BLADDER: Bladder is normally distended and appears normal. No evidence of bladder calculus, diverticulum or mass lesion is seen. PROSTATE: Prostate appears normal in size and shows normal parenchymal echoes. On 12-14 Hertz USG Visualized bowel: No abnormal bowel wall dilatation or thickening is noted. No evidence of ascites. No evidence of significantly enlarged lymph nodes noted. Impression: - A calculus of size 6.5 mm is seen in LEFT LOWER URETER (3 cm proximal to VUJ) with resultant proximal mild hydronephrosis. - Bilateral kidneys show 2 to 3 renal concretions of average size 2-3 mm. - Grade I fatty liver. - A defect of size 13 mm is noted in umbilical region through which omental fat herniates suggestive of umbilical hernia. DR. BHAVIK PATEL (DNB) DR. LAKASH JAIN (MD) FMF(UK) DR. AKSHAY PENDKAR (MD) DR. KEMU SHAH (MD) Tata Memorial Hospital, Mumbai Tata Memorial Hospital, Mumbai GOLD MEDALIST	NAME: [REDACTED] M / 45 YRS DATE: 25/11/2025 SONOGRAPHY OF ABDOMEN AND PELVIS Observations: LIVER: Liver appears normal in size. No evidence of focal or diffuse lesion is seen. No evidence of dilated IHBR is seen. Intrahepatic portal radicles appear normal. GALL BLADDER: Gall bladder appears normal. No evidence of calculus or changes of cholecystitis are seen. CBD appears normal. PANCREAS: Pancreas appears normal in size and shows normal parenchymal echoes. No evidence of pancreatitis or pancreatic mass lesion is seen. SPLEEN: Spleen appears normal in size and shows normal parenchymal echoes. No evidence of focal or diffuse lesion is seen. KIDNEYS: Both kidneys are normal in size, shape and position. Cortical and central echoes appear normal. Bilateral cortical thickness appears normal. No evidence of renal calculus, hydronephrosis is seen. BLADDER: Bladder is normally distended and appears normal. No evidence of bladder calculus, diverticulum or mass lesion is seen. PROSTATE: Prostate appears normal in size and shows normal parenchymal echoes. On 12-14 Hertz USG Visualized bowel: No abnormal bowel wall dilatation or thickening is noted. No evidence of ascites. No evidence of significantly enlarged lymph nodes noted. No evidence of any appendicitis. Impression: - Umbilical hernia is seen with defect of size 13 mm and herniation of omental fat. - Grade I fatty liver. DR. BHAVIK PATEL (DNB) DR. LAKASH JAIN (MD) FMF(UK) DR. AKSHAY PENDKAR (MD) DR. KEMU SHAH (MD) Tata Memorial Hospital, Mumbai Tata Memorial Hospital, Mumbai GOLD MEDALIST

Figure. No. 2. USG-KUB before Treatment part

Figure. No. 3 USG-KUB after Treatment part

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RESEARCH ARTICLE

Polypharmacological Evaluation of *Justicia adhatoda* Alkaloids as Dual Inhibitors of Enoyl-ACP Reductase (InhA) and DNA Gyrase B (GyrB) for Tuberculosis Therapy : An *In-Silico* Study

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ABSTRACT

Tuberculosis (TB) caused by *Mycobacterium tuberculosis* is still widely encountered as a common burden of disease worldwide together with the continuance and increasing prevalence of multi- and extensively drug-resistant (MDR and XDR) strains of TB. The rate with which resistance to monotherapy regimens has evolved emphasizes the need to develop novel therapeutic agents with polypharmacological properties. *Justicia adhatoda* Vasaka or Vaseline for short, is medicinal herb that was used in the past to improve respiratory problems, contains the chemical compound quinazoline alkaloids they contain such as vasicine. However, the molecular interactions between the constituents of Vasaka and specific targets of TB are yet to be described in detail. This study aimed to assess the dual targeting potential of alkaloids of *Justicia adhatoda* against two essential mycobacterial enzymes, enoyl-ACP reductase (InhA), which is essential in cell wall biosynthesis (mycolic acid biosynthesis), and the ATPase domain of DNA gyrase (GyrB), which plays a vital role in DNA replication. Molecular docking studies were performed using AutoDock Vina to calculate the binding affinities of the main alkaloids Vasicine and Vasicinone with the crystallographic structures of InhA (PDB ID's 2B3S and 1ENY) and GyrB (PDB ID's 4KFG and 3ZKB). The



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resulting affinity values were benchmarked against those of conventional inhibitors, that is, triclosan and isoniazid were used for InhA, and novobiocin and ciprofloxacin were used for GyrB. The binding profiles of *Justicia adhatoda* alkaloids suggest dual inhibition, effectively targeting both InhA and GyrB. This dual-targeting activity implies a simultaneous disruption of both cell wall synthesis and DNA replication pathways. Polypharmacological inhibition mediated by alkaloids isolated from *Justicia adhatoda*, Vasicine; Noval drugs lead to the development of original antituberculosis drugs. Consequently, more in vitro and in vivo studies are needed to confirm these preliminary observations.

Keywords: *Justicia adhatoda*, tuberculosis, InhA, DNA gyrase B, molecular docking, ADMET.

INTRODUCTION

Tuberculosis is a significant health threat throughout the world especially to people with HIV and those who suffer from drug resistant infections[1]. Current treatment with multiple antibiotics is faced by challenges from resistant strains of *M. tuberculosis*. This lower efficacy has shifted attention to polypharmacological strategies towards multiple bacterial pathways[2]. InhA and GyrB are important drug targets. InhA, in the case of fatty acid synthase II, catalyses the formation of mycolic acid in bacterial cells. While isoniazid is an inhibitor of the InhA, KatG mutations lead to resistance and require the need for direct InhA inhibitors[3]. DNA gyrase, attacked by fluoroquinolones at GyrA, is a site of resistance. GyrB's ATP-binding domain has so far not been exploited. Combining InhA with GyrB provides a synergistic pathogen killing [4]. *Justicia adhatoda* L. (Malabar nut) is a medicinal shrub which is used in Ayurvedic and Unani medicines for treatment of respiratory disorders such as bronchitis and tuberculosis. Its therapeutic effects are due to quinazoline alkaloids, principally vasicine and vasicinone. While their bronchodilatory action is known, their molecular interactions with *M. tuberculosis* targets are unknown[5]. Based on the possible application of quinazoline alkaloids as ATP/NAD mimetics, derivatives of vasicine were explored. This study computationally evaluated the *J. adhatoda* phytochemicals using molecular docking and ADMET studies against InhA (PDB ID's 2B3S, 1ENY) and GyrB (PDB ID's 4KFG, 3ZKB) as two target leads[6].

MATERIALS AND METHODS

Protein Preparation

InhA and GyrB structures (PDB- (2B3S, 4KFG, 3ZKB and 1ENY) were selected on the basis of resolution. PROCHECK was used to validate the protein stereochemistry by Ramachandran plots. The chain A of UCSF Chimera with catalytic residues was prepared. Hydrogens were added using Kollman charges. Solvent and co-crystallized ligands were removed. Energy minimization optimized conformers. AutoDock Tools 1.5.7 define grid boxes at active sites for AutoDock Vina

Dataset Preparation

Dr. Duke's Database contains plant data, chemical data, bioactivity data and ethnobotanical data comprising 129 plant compounds. These were evaluated by Biovia Discovery Studio against Lipinski's Rule of Five for Oral Bioavailability with the following filters: Molecular weight (MW) ≤ 500 Da, Hydrogen bond acceptors ≤ 10 , donors ≤ 5 , Polar surface area, Rotatable bonds ≤ 5 [8]. No. SMILES for 64 compounds were retrieved from csv. 2D structure converted 3D structure using ChemDraw 3D with MMFF94 force field minimization (0.000001 kcal/mol/Å). Structures were converted to PDBQT for Autodock Vina and best candidates drawn[9].

General Procedure

PDB's 2B3S, 1ENY, 4KFG and 3ZKB were converted to AutoDock Vina format by removing both water and ligand. missing atoms corrected and polar hydrogens added, saved as pdbqt. 129 IMPPAT alkaloids were drawn and energy

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minimized using MMFF94 and converted to pdbqt. Ligands were bound to sites on the enzyme, producing 9 conformations. Binding was evaluated using AutoDock Vina and rendered using PYMOL[10]. ADMET was assessed for compounds to be better than standard drugs in docking scores.

RESULT AND DISCUSSION

In-silico Docking Results

Tuberculosis is one of the deadliest of the diseases. FDA-approved drugs for tuberculosis have side effects such as nausea and skin rash. Natural compounds are anti-tuberculosis agents. Plant alkaloids combat tuberculosis by inhibiting both InhA and GyrB. The study was based on the X-ray data of InhA and GyrB complexed with triclosan, isoniazid, novobiocin, and ciprofloxacin (PDB ID: 2B3S, 1ENY, 4KFG, and 3ZKB).

Structure-Based Virtual Screening

The docking process was confirmed by structure based virtual screening. Binding affinities of 129 compounds were compared with the Triclosan (-6.4), Isoniazid (-6.1), Novobiocin (-8.1) and Ciprofloxacin (-7.7 Kcal/mol). Docking scores were used to rank compounds, with affinities of less than -6.4 kcal/mol going to the promising list.

Docking Results

Docking scores in kcal/mol are used to determine binding strength where more negative values represent more binding strength. The *in vitro* analysis of 129 IMPPAT alkaloids for inhibitors of InhA and GyrB yielded compounds better than those of Triclosan and Novobiocin inhibitors. Highest-scoring compounds provided characteristics of vasicine derivatives and receptor interactions.

Analysis of Top Compounds with 2D Interaction Reference

Docking scores are a measure of binding affinity of a ligand to a target in kcal/mol, lower the better the binding. For 129 IMPPAT alkaloids, docking scores were computed against InhA and GyrB targets. Several compounds had better scores inhibitors Triclosan (-6.4 kcal/mol) and Novobiocin (-8.1 kcal/mol). Topscoring compounds, some of which are vasicine derivatives, were analysed for receptor interactions.

Interaction Type

Green illustrates canonical hydrogen bonds - the strongest noncovalent interaction. Light green represents Chydrogen bonds. Pink denotes interactions between ligands and proteins, with the ligands being π -alkyl/ π - π stacked. Purple indicates the hydrophobic contacts of π sigma. Orange indicates π -anion/cation interactions between charged residues. Red indicates decreasing binding affinity by unfavorable interactions.

Interaction Type

Conventional Hydrogen Bond (green): Affects drug specificity through molecular adhesion. π -Alkyl/ π - π Stacked (Pink): Hydrophobic interactions from aromatic rings in protein cavities. π -Sigma (Purple): Strong hydrophobic interaction stabilizes ligand. π -anion (orange): Electrostatic attraction between protein's negative region and ligand rings. Unfavorable donor-donor (red): Repulsion between proton-donating atoms.

Interaction Type

Green (Conventional Hydrogen Bond): High stability for ligand-amino acid bonding. Light Green (Carbon-Hydrogen Bond)- Weaker hydrogen bonding with carbon atoms. Pink (π -alkyl/ π - π stacked)- Enables hydrophobic interactions between aromatic molecules and amino acids for drug retention. Purple (π -Sigma)- Strong hydrophobic interaction for drug positioning. Red (unfavorable)- Represents instability from atom collisions, reducing drug affinity.



**Ritesh Pandit and Sachin Kumar Sharma****Interaction Type**

Green- Classical hydrogen bonds form strong ligand-protein bonds. Pink- π -alkyl/alkyl (Hydrophobic Fit) occurs between aromatic rings and hydrophobic residues. Orange: (Charge Clamps) represent cation/anion interactions.

Conclusion

In silico validation showed *Justicia adhatoda* alkaloids, particularly vasicine and vasicinone, match antituberculosis agents. They enter isoniazid's hydrophobic pocket in Enoyl-Acp Reductase (InhA), interact with PHE A:41 and ILE A:95, and provide stability like triclosan-InhA's ASN A:62 bond. In DNA Gyrase B ATPase, they maintain novobiocin's ASP A:73 bonding and ciprofloxacin's LYS A:108 interaction, affecting cell wall biosynthesis and DNA replication.

ADME Evaluation

Alkaloids with better inhibitory values, based on binding affinities, were screened using Lipinski's rule of five. Table-9 lists all of the 5 physicochemical properties of the selected compounds.

MW: Molecular weight; logP: partition coefficient; nON: number of hydrogen-accepting bonds; nOHNH: no. of hydrogen-donating bonds, and nrotb is the number. of rotatable bonds.

pkCSM study of compounds for ADMET prediction

The table shows pharmacokinetic properties including absorption, metabolism, excretion, and toxicity. It details intestinal absorption percentages and interactions with CYP2D6 and CYP3A4 isoforms. Excretion is measured as clearance values in log (mL/min/kg). Toxicological data includes AMES mutagenicity and skin sensitization tests. The compounds show varied absorption and metabolic properties but no mutagenicity or skin sensitization.

***In-silico* Toxicity Prediction**

ProTox-III assessed compounds for hepatotoxicity, carcinogenicity, immunotoxicity, mutagenicity and cytotoxicity. Vasicine, Vasicinol, and Vasicinone showed no toxicity, while others exhibited immunotoxicity. All compounds were less toxic than standard drugs. Table-11 shows toxicity results.

CONCLUSION

Alkaloid's vasicine and vasicinone from *Justicia adhatoda* inhibit enoyl-acyl carrier protein reductase (InhA) and DNA Gyrase B (GyrB), mimicking antituberculosis agents to inhibit bacterial cell wall growth and DNA replication. The compounds show structural plasticity by recapitulating hydrophobic interactions of Isoniazid and Triclosan in InhA, while maintaining hydrogen-bonding networks of Novobiocin and Ciprofloxacin in GyrB with residues PHE A:41, ILE A:95, and ASP A:73. *In silico* toxicity studies showed vasicine has improved safety over conventional therapies, lacking hepatotoxicity, carcinogenicity, and mutagenicity. Vasicine shows promise for developing drugs against drug-resistant tuberculosis, pending further validation.

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Author Contribution

Ritesh Pandit contributed to conceptualization, draft preparation, methodology, analysis, visualization, data curation and validation. Sachin Kumar Sharma handled review, editing, supervision and software development. Both authors approved the final manuscript.





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Table 1- 2D structures of top compounds with docking scores for Enoyl-ACP Reductase (InhA) (2B3S)

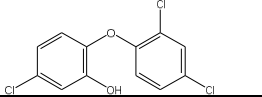
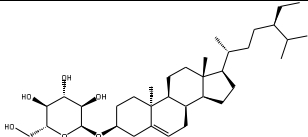
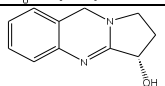
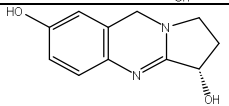
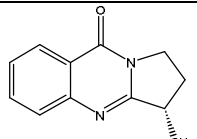
Sr. No.	Compound	2D Structure	Docking Score (kcal/mol)
1.	Triclosan		-6.4
2.	Beta-Sitosterol-Beta-D-Glucoside		-7.3
3.	Vasicine		-7.0
4.	Vasicinol		-7.0
5.	Vasicinone		-7.0





Table 2- 2D structures of top compounds with docking scores for Enoyl-ACP Reductase (InhA) (1ENY)

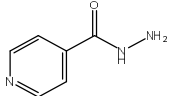
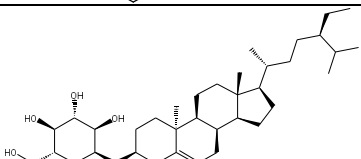
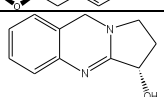
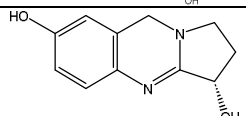
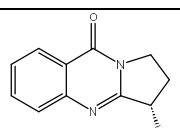
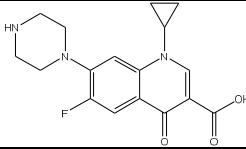
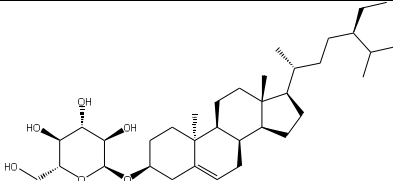
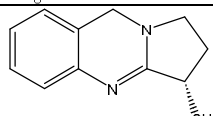
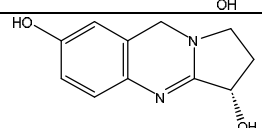
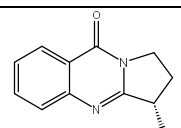
Sr. No.	Compound	2D Structure	Docking Score (kcal/mol)
1.	Isoniazid		-6.1
2.	Beta-Sitosterol-Beta-D-Glucoside		-10.1
3.	Vasicine		-7.6
4.	Vasicinol		-7.4
5.	Vasicinone		-7.7

Table 3- 2D structures of top compounds with docking scores for DNA Gyrase Subunit B (GyrB) (4KFG)

Sr. No.	Compound	2D Structure	Docking Score (kcal/mol)
1.	Ciprofloxacin		-7.7
2.	Beta-Sitosterol-Beta-D-Glucoside		-8.9
3.	Vasicine		-8.6
4.	Vasicinol		-7.9
5.	Vasicinone		-8.0





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Table 5– Amino Acid Interaction

Sr. No.	Amino Acid Interaction
(a)	ASN A:62, GLY A:69,PHE A:29, PHE A:63,MET A:64
(b)	ASP B:67,LEU B:68,ALA A:143,
(c)	GLN B:160,ALA B:152, PRO B:163, ARG B:148
(d)	HIS A:60,THR A:73,GLU A:139, VAL A:61, ALA A:142
(e)	ASN A:62, GLU A:139,VAL A:61, LYS A:70, ALA A:142

Table 6- Amino Acid Interaction

Sr. No.	Amino Acid Interaction
(a)	ILE A:15, GLY A:14,SER A:13,ILE A:95, PHE A:41, VAL A:65
(b)	TYR A:165,ILE A:194,ILE A:122, ILE A:95, PHE A:41
(c)	PHE A:41, VAL A:65, ILE A:122, ILE A:95
(d)	ASP A:64, PHE A:41, VAL A:65, ILE A:95
(e)	PHE A:41, VAL A:65, ILE A:95, ILE A:122

Table 7– Amino Acid Interaction

Sr. No.	Amino Acid Interaction
(a)	VAL A:118, ASP A:73, ASN A:46, LEU A:94, ILE A:90
(b)	GLU A:42, LEU A:115, GLY A:117, HIS A:116, ASP A:49, VAL A:93
(c)	GLY A:77,ILE A:78,VAL A:120, ASN A:46
(d)	GLU A:50, ASN A:46, ASP A:73, THR A:165,ILE A:78
(e)	ASP A:73, THR A:165, ILE A:78,VAL A:167, VAL A:43

Table 8- Amino Acid Interaction

Sr. No.	Amino Acid Interaction
(a)	SER A:169, GLY A:107, ALA A:105, LYS A:108, VAL A:125, VAL A:171, ILE A:84, VAL A:99
(b)	SER A:169, TYR A:114, ARG A:82, ALA A:113, PRO A:85
(c)	ASN A:52,ASP A:79,ILE A:84, VAL A:99
(d)	ASP A:79, GLU A:56, ILE A:84
(e)	TYR A:114, ASN A:52, LYS A:108, VAL A:99, VAL A:125, ILE A:84

Table 9- Properties of Standard and Selected Compounds (Lipinski rule of 5)

Sr. No.	Compounds	MW	logP	nON	nOHNH	nrotb
*	Triclosan	289.54	4.28	2	1	2
*	Isoniazid	137.14	-0.47	3	2	2
*	Novobiocin	612.62	0.65	11	5	10
*	Ciprofloxacin	331.34	1.28	5	2	3
1	Beta-Sitosterol- Beta-D- Glucoside	576.85	3.96	6	4	9
2	Vasicine	188.23	1.57	2	1	0
3	Vasicinol	204.23	0.99	3	2	0
4	Vasicinone	202.21	0.78	3	1	0





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Table 10- Drug-likeness properties

Sr. No.	Compounds	P-GP Substrate	Bioavailability	Log K _p (skin permeation)	BBB Permeant
*	Triclosan	No	0.55	-4.69cm/s	Yes
*	Isoniazid	No	0.55	-7.63cm/s	No
*	Novobiocin	Yes	0.17	-7.68cm/s	No
*	Ciprofloxacin	No	0.55	-9.09 cm/s	No
1	Beta-Sitosterol-Beta-D-Glucoside	No	0.55	-4.32 cm/s	No
2	Vasicine	No	0.55	-7.14 cm/s	No
3	Vasicinol	Yes	0.55	-7.48 cm/s	No
4	Vasicinone	No	0.55	-7.16 cm/s	No

Table 11- ADMET Prediction of Selected Compounds

Sr. No.	Compounds	Pharmacokinetics					
		Absorption	Metabolism		Excretion	Toxicity	
		Intestinal Absorption (HUMAN)				AMES Toxicity	Skin Sensitisation
		Numeric (%Absorbed)	2D6SUB	3A4INH	Numeric (log/ml/min/kg)	Categorical (yes/no)	Categorical (yes/no)
*	Triclosan	87.455	No	Yes	0.058	No	No
*	Isoniazid	92.601	No	No	0.722	No	No
*	Novobiocin	71.504	No	Yes	-0.452	No	No
*	Ciprofloxacin	96.466	No	No	0.633	No	No
1.	Beta-Sitosterol-Beta-D-Glucoside	79.677	No	Yes	0.689	No	No
2.	Vasicine	86.22	No	Yes	0.58	No	No
3.	Vasicinol	80.398	No	No	0.379	No	No
4.	Vasicinone	92.532	No	No	0.568	No	No

Table 12- Toxicity Prediction

Sr. No.	Compound	Hepatotoxicity	Carcinogenicity	Immunotoxicity	Mutagenicity	Cytotoxicity
*	Triclosan	IA	IA	IA	IA	A
*	Isoniazid	A	A	IA	IA	IA
*	Novobiocin	IA	IA	A	IA	IA
*	Ciprofloxacin	IA	IA	IA	A	IA
1	Beta-Sitosterol-Beta-D-Glucoside	IA	IA	A	IA	IA
2	Vasicine	IA	IA	IA	IA	IA
3	Vasicinol	IA	IA	IA	IA	IA
4	Vasicinone	IA	IA	IA	IA	IA





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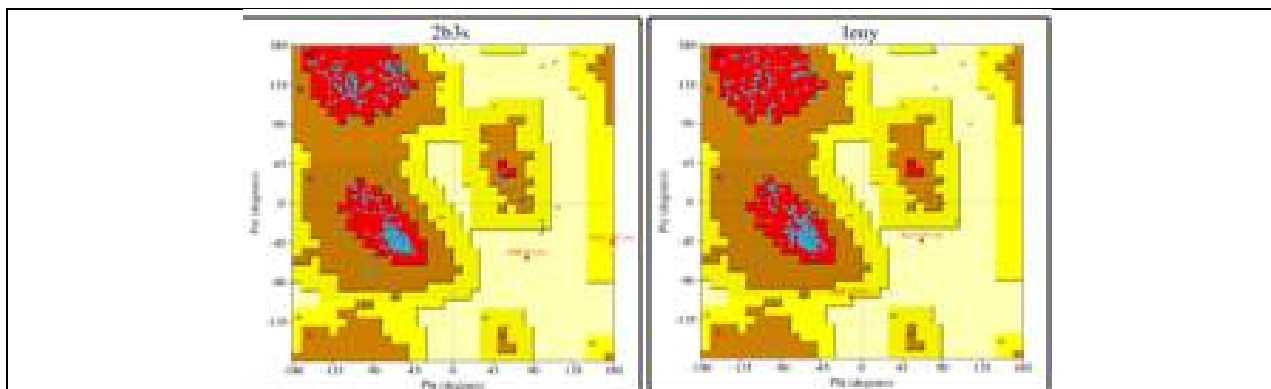


Figure 1 and 2- Ramachandran Plot of PDB ID: 2B3S and 1ENY (Enoyl-ACP Reductase (InhA)).

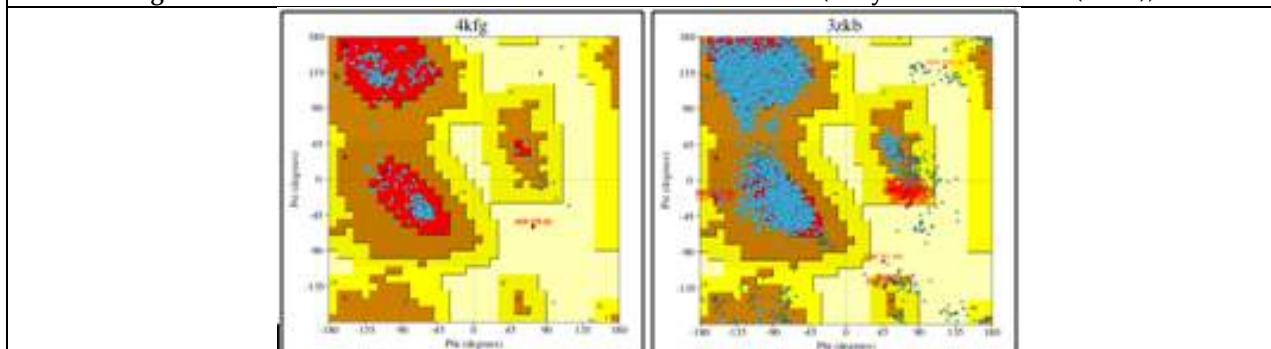


Figure 3 and 4- Ramachandran Plot of PDB ID: 4KFG and 3ZKB (DNA Gyrase Subunit B (GyrB))

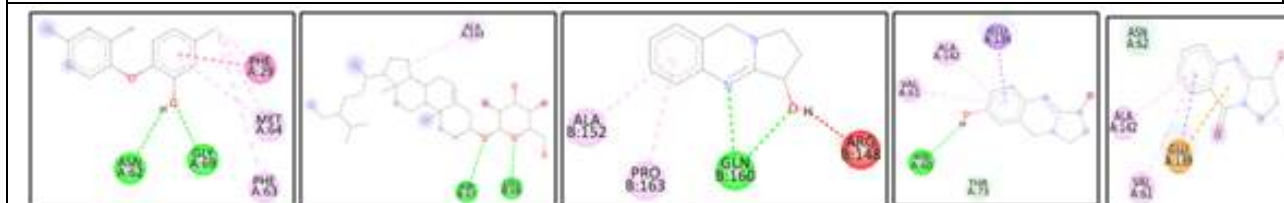


Figure 5-2D interactions of (a) Triclosan, (b) Beta-Sitosterol-Beta-D-Glucoside, (c) Vasicine, (d) Vasicinol, and (e) Vasicinone with Enoyl-ACP Reductase (InhA) on PDB ID: 2B3S.

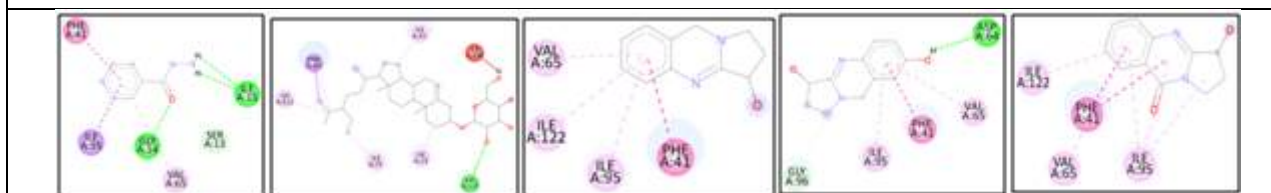


Figure 6-2D interactions of (a) Isoniazid (b) Beta-Sitosterol-Beta-D-Glucoside (c) Vasicine (d) Vasicinol (e) Vasicinone as (Enoyl-ACP Reductase (InhA)) on PDB ID: 1ENY.



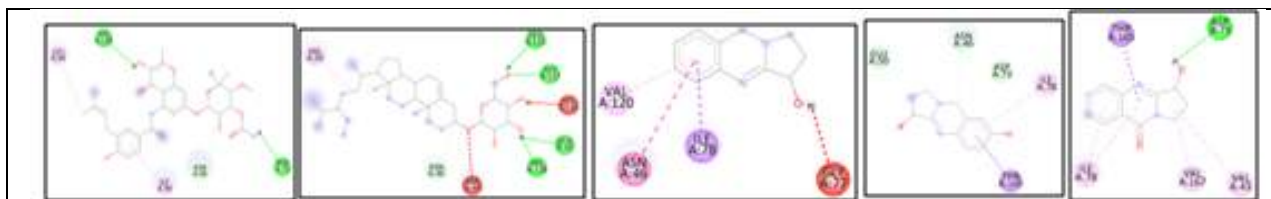
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Figure 7- Two-dimensional Interactions of (a)Novobiocin (b)Beta-Sitosterol-Beta-D-Glucoside (c)Vasicine (d) Vasicinol (e) Vasicinone as (DNA Gyrase Subunit B (GyrB)) on PDB I'd- 4KFG.



Figure 8- Two-dimensional Interactions of (a)Ciprofloxacin (b)Beta-Sitosterol-Beta-D-Glucoside (c)Vasicine (d) Vasicinol (e) Vasicinone as (DNA Gyrase Subunit B (GyrB)) on PDB I'd- 3ZKB.

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RESEARCH ARTICLE

Enumeration of Split 2 – Dominating Sets and Split 2 – Domination Polynomials of Path P_n

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ABSTRACT

Let $G = (V, E)$ be a graph of order n with no isolated vertex. A split dominating set $D \subseteq V(G)$ is said to be split 2 - dominating set if every $v \in V(G) - D$ has at least 2 neighbors in D . Let P_n be the path graph and $D_{s2}(P_n, i)$ be the family of split 2 - dominating sets of a path P_n with cardinality i . Let $d_{s2}(P_n, i) = |D_{s2}(P_n, i)|$. In this paper, we obtain the recursive formula for coefficients of split 2 - domination polynomials of paths. Using the recursive formula, we construct the polynomial $D_{s2}(P_n, x) = \sum_{i=\lfloor \frac{n+1}{2} \rfloor}^n d_{s2}(P_n, i)x^i$, which we call split2- domination polynomial of P_n and also obtain some properties of this polynomial.

Keywords: Split 2 - domination number, Split 2- domination polynomials

INTRODUCTION

In the intricate world of graph theory, where vertices and edges interconnect to form multifaceted networks, it serves as a powerful framework for understanding the intricate structures that underlie real-world networks. Domination theory explores the minimum sets of nodes required to exert control over a graph influencing its structure and





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behavior. The concepts of graph theory pervade various domains and drive innovation, with a particular focus on domination applications. For an undirected graph G can be defined as a pair (V, E) , where V denotes the set of vertices and E represents the set of edges comprising unordered pairs of vertices. A dominating set in a graph G is a subset D of vertices such that every vertex in the graph is either in D or adjacent to a vertex in D . The domination number $\gamma(G)$ represents the minimum cardinality of vertices in a given set. Arocha and Llano analyzed the graphs of domination polynomials. Later, Alikhani and Peng defined the conception of domination polynomials of the graph in their research article [1]. The Idea of k – domination in graph is presented by Fink and Jacobson [3]. Now, in the same way we find the recursive relation for the Split 2 - domination polynomial of paths. A set $D \subseteq V(G)$ is a dominating set if every vertex in $V - D$ is adjacent to at least one vertex in D . The minimum cardinality taken over all the minimal dominating set is called domination number and is denoted $\gamma(G)$. In this study, we refer to the collection $\{1, 2, \dots, n\}$ by $[n]$ and $\lceil x \rceil$ to represent the smallest integer greater than or equal to x .

Construction of Split 2 - Dominating Sets of Paths

Let P_n be a path graph with n vertices. Let $D_{s2}(P_n, i)$ denote the family of all split 2 - dominating sets of P_n with cardinality i . We shall examine the split 2- dominating sets of path P_n and some of its properties.

Definition 2.1. A split dominating set $D \subseteq V(G)$ is said to be split 2 - dominating set if every $v \in V(G) - D$ has at least 2 neighbors in D . The split 2 - domination number denoted by $\gamma_{s2}(G)$ is the minimum cardinality among the split 2- dominating set of .

Lemma 2.2. For $n \geq 3$, $\gamma_{s2}(P_n) = \left\lceil \frac{n+1}{2} \right\rceil$.

Lemma 2.3. Let P_n be a path graph with n vertices. Then $D_{s2}(P_n, i) = \emptyset$ if and only if $i > n$ or $i < \left\lceil \frac{n+1}{2} \right\rceil$.

Proof

Let P_n be the path with n vertices, any member of $D_{s2}(P_n, i)$ contains at most n vertices. Therefore, $D_{s2}(P_n, i) = \emptyset$ for $i > n$. Also, we have the minimum cardinality of split 2- dominating sets of path P_n is $\left\lceil \frac{n+1}{2} \right\rceil$ then cardinality less than $\left\lceil \frac{n+1}{2} \right\rceil$ does not exist for any split 2 - dominating sets. Therefore, $D_{s2}(P_n, i) = \emptyset$ for $i < \left\lceil \frac{n+1}{2} \right\rceil$. Conversely, if $i > n$ or $i < \left\lceil \frac{n+1}{2} \right\rceil$ then by the definition of split 2 - dominating sets of path P_n . We have $D_{s2}(P_n, i) = \emptyset$. Therefore, $D_{s2}(P_n, i) = \emptyset$. Hence, $D_{s2}(P_n, i) = \emptyset$ if and only if $i < \left\lceil \frac{n+1}{2} \right\rceil$.

Observation 2.4. If a graph G contains a path of length $2k - 1$, then every split 2- dominating set of G must contain at least k vertices of G . To find a split 2- domination polynomial of P_n with cardinality i , it is enough to consider $D_{s2}(P_{n-1}, i - 1)$ and $D_{s2}(P_{n-2}, i - 1)$. Thus, we must consider four combinations of whether these two collections are empty or not.

Lemma 2.5. Let $n \geq 3$ and $i > \left\lceil \frac{n+1}{2} \right\rceil$,

- i) If $D_{s2}(P_{n-1}, i - 1) = \emptyset$ and $D_{s2}(P_{n-3}, i - 1) = \emptyset$ then $D_{s2}(P_{n-2}, i - 1) = \emptyset$.
- ii) If $D_{s2}(P_{n-1}, i - 1) \neq \emptyset$ and $D_{s2}(P_{n-3}, i - 1) \neq \emptyset$ then $D_{s2}(P_{n-2}, i - 1) \neq \emptyset$.
- iii) If $D_{s2}(P_{n-1}, i - 1) = \emptyset$ and $D_{s2}(P_{n-2}, i - 1) = \emptyset$ then $D_{s2}(P_n, i) = \emptyset$.
- iv) If $D_{s2}(P_{n-1}, i - 1) \neq \emptyset$ and $D_{s2}(P_{n-2}, i - 1) \neq \emptyset$ then $D_{s2}(P_n, i) \neq \emptyset$.

Proof

From Lemma 2.3, the proof can be derived .

We obtain $D_{s2}(P_n, i)$ for $3 \leq n \leq 16$ and $2 \leq i \leq 16$ as demonstrated in Table 1.

Theorem 2.6. If $D_{s2}(P_n, i)$ be the family of split 2- dominating sets of a path P_n with cardinality i , where $i > \left\lceil \frac{n+1}{2} \right\rceil$ and $D_{s2}(P_n, i) = |D_{s2}(P_n, i)|$.





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Then, $d_{s2}(P_n, i) = d_{s2}(P_{n-1}, i-1) + d_{s2}(P_{n-2}, i-1)$.

Proof:

We prove the theorem by distinguishing the following cases,

- i) If $D_{s2}(P_{n-1}, i-1) = \emptyset$ and $D_{s2}(P_{n-2}, i-1) = \emptyset$ then $D_{s2}(P_n, i) = \emptyset$.
- ii) If $D_{s2}(P_{n-1}, i-1) = \emptyset$, $D_{s2}(P_{n-2}, i-1) \neq \emptyset$, then $D_{s2}(P_n, i) = \{X \mid X \in D_{s2}(P_{n-2}, i-1)\}$.
- iii) If $D_{s2}(P_{n-1}, i-1) \neq \emptyset$, $D_{s2}(P_{n-2}, i-1) = \emptyset$, then $D_{s2}(P_n, i) = \{Y \cup \{n\} \mid Y \in D_{s2}(P_{n-1}, i-1)\}$.
- iv) If $D_{s2}(P_{n-1}, i-1) \neq \emptyset$, $D_{s2}(P_{n-2}, i-1) \neq \emptyset$, then $D_{s2}(P_n, i) = \{X \cup \{n-1\} \mid X \in D_{s2}(P_{n-1}, i-1)\} \cup \{Y \cup \{n\} \mid Y \in D_{s2}(P_{n-2}, i-1)\}$.

By the above construction in every case,

we have, $d_{s2}(P_n, i) = d_{s2}(P_{n-1}, i-1) + d_{s2}(P_{n-2}, i-1)$.

Split 2 - domination polynomials of paths

In this section, the split 2- domination polynomials of paths are introduced and examined.

Definition: 3.1.

Let $D_{s2}(P_n, i)$ be the family of split 2 - dominating sets of path P_n with cardinality i and $d_{s2}(P_n, i) = |D_{s2}(P_n, i)|$. Then, the split 2 - domination polynomials of the path is defined as

$$D_{s2}(P_n, x) = \sum d_{s2}(P_n, i) x^i,$$

where $\gamma_{s2}(P_n)$ is the split 2 –domination number of P_n .

Theorem 3.2. For every $n \geq 5$, $D_{s2}(P_n, x) = x [D_{s2}(P_{n-1}, x) + D_{s2}(P_{n-2}, x)]$ with the initial values, $D_{s2}(P_3, x) = x^2 + x^3$, $D_{s2}(P_4, x) = 2x^3 + x^4$.

Proof

We have, $d_{s2}(P_n, i) = d_{s2}(P_{n-1}, i-1) + d_{s2}(P_{n-2}, i-1)$

Now, $d_{s2}(P_n, i)x^i = d_{s2}(P_{n-1}, i-1)x^i + d_{s2}(P_{n-2}, i-1)x^i$

$$\sum d_{s2}(P_n, i)x^i = \sum_{s2} d_{s2}(P_{n-1}, i-1)x^i + \sum d_{s2}(P_{n-2}, i-1)x^i$$

$$\sum d_{s2}(P_n, i)x^i = x \sum d_{s2}(P_{n-1}, i-1)x^{i-1} + x \sum d_{s2}(P_{n-2}, i-1)x^{i-1}$$

$$D_{s2}(P_n, x) = x D_{s2}(P_{n-1}, x) + x D_{s2}(P_{n-2}, x)$$

Therefore, $D_{s2}(P_n, x) = x [D_{s2}(P_{n-1}, x) + D_{s2}(P_{n-2}, x)]$ with initial values,

$$D_{s2}(P_3, x) = x^2 + x^3,$$

$$D_{s2}(P_4, x) = 2x^3 + x^4.$$

Example 3.3. Consider the path P_{10} with 10 vertices. We construct a Split 2 - dominating polynomial $D_{s2}(P_{10}, x)$ using

Theorem 3.2

Then, the split 2 - dominating polynomial of a path P_{10} is given by

$$D_{s2}(P_{10}, x) = \sum_{i=6}^{10} d_{s2}(P_{10}, i) x^i.$$

From the Table 1, we have, $d_{s2}(P_{10}, 6) = 5$, $d_{s2}(P_{10}, 7) = 20$, $d_{s2}(P_{10}, 8) = 21$, $d_{s2}(P_{10}, 9) = 8$, $d_{s2}(P_{10}, 10) = 1$. Hence, $D_{s2}(P_{10}, x) = 5x^6 + 20x^7 + 21x^8 + 8x^9 + x^{10}$ is a split 2 - domination polynomial of path P_{10} .

Theorem 3.4. The coefficients of $D_{s2}(P_n, x)$ satisfy the following properties:

- i) For every $n \geq 3$, $d_{s2}(P_{2n}, n+1) = n$
- ii) For every $n \geq 3$, $d_{s2}(P_{2n+1}, n+1) = 1$
- iii) For every $n \geq 3$, $d_{s2}(P_n, n) = 1$
- iv) For every $n \geq 4$, $d_{s2}(P_n, n-1) = n-2$
- v) For every $n \geq 4$, $d_{s2}(P_n, n-2) = \frac{1}{2}[n^2 - 7n + 12]$





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vi) For every $n \geq 6$, $d_{s2}(P_n, n-3) = \frac{1}{6}[n^3 - 15n^2 + 74n - 120]$

vii) For every $n \geq 8$, $d_{2s}(P_n, n-4) = \frac{1}{24}[n^4 - 26n^3 + 251n^2 - 1066n + 1680]$

Proof:

It follows from the table of split 2 - dominating sets of paths and we demonstrate using the mathematical induction method on n .

CONCLUSION

This paper discusses several characteristics of split 2 - domination polynomials of paths are obtained and studied. We can speculate this investigation to any power of paths. Future works can be carried out for similar other graphs using this concept.

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Table 1: $d_{s2}(P_n, i)$, the number of split 2 - dominating sets of a path P_n with cardinality i .

$n \backslash i$	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
3	1	1													
4	0	2	1												
5	0	1	3	1											
6	0	0	3	4	1										
7	0	0	1	6	5	1									
8	0	0	0	4	10	6	1								
9	0	0	0	1	10	15	7	1							
10	0	0	0	0	5	20	21	8	1						
11	0	0	0	0	1	15	35	28	9	1					
12	0	0	0	0	0	6	35	56	36	10	1				
13	0	0	0	0	0	1	21	70	84	45	11	1			
14	0	0	0	0	0	0	7	56	126	120	55	12	1		
15	0	0	0	0	0	0	1	28	126	210	165	66	13	1	
16	0	0	0	0	0	0	0	8	84	252	330	220	78	14	1

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RESEARCH ARTICLE

Enhancement of Self-Efficacy Through Experiential Drama : A Mixed Methods Study Among Young Adults

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ABSTRACT

Self-efficacy is defined as a person's belief in their ability to plan and implement actions needed to overcome obstacles. It is a major psychological resource for motivation, emotion regulation, and adaptive behaviour. Theatre-based learning settings could enhance self-efficacy by providing repeated mastery experiences, peer modelling, constructive criticism, and opportunities to regulate performance-related emotional arousal. With a special focus on creative techniques such as anthropomorphic role enactment, the current study investigated whether participation in a three-month theatrical education program was associated with changes in self-efficacy among young adults. A one-group pretest-posttest design was used with 20 undergraduate and postgraduate students enrolled in a Theatre Education Certificate Course conducted by Rangayana Shivamogga in collaboration with Kateel Ashok Pai Memorial College, Shivamogga (December 2021-March 2022). Self-efficacy was assessed using the General Self-Efficacy Scale before and after the intervention. Quantitative data were analysed using descriptive statistics, Shapiro-Wilk normality testing, and a paired-samples t-test, and qualitative reflections were analysed using thematic analysis. Results revealed a significant increase in self-efficacy from pretest ($M = 27.60$, $SD = 5.75$) to posttest ($M = 33.50$, $SD = 4.66$), $t(19) = -3.91$, $p < .001$, with a large effect size ($d = 0.87$). Qualitative



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themes suggested that increased confidence through performance, improved emotional expression, learning through peer observation, and a helpful group environment contributed to participants' perceived growth; anthropomorphic enactment was described as facilitating symbolic emotional expression and expressive freedom. Although causal conclusions are limited by the absence of a control group, evidence indicates that structured theatre education may be associated with enhanced self-efficacy among young adults and supports the use of arts-based experiential training within educational and developmental contexts.

Keywords: self-efficacy; theatre education; drama-based learning; anthropomorphism; young adults; experiential learning

INTRODUCTION

Psychological well-being largely depends on perceptions of how effectively one can manage challenges and function normally. In this belief system, self-efficacy is defined as a person's evaluation of their capacity to plan and execute the activities required to achieve the desired outcomes (Bandura, 1997). A person's ideas, emotions, drive, and conduct all depend on their self-efficacy. Likewise, believers, in their own capacity to act, are more likely to view challenging circumstances as opportunities rather than hazards, to persist even when conditions become difficult, and to recover more rapidly following a setback (Schunk & DiBenedetto, 2021; Usher & Pajares, 2008). Understanding adaptive human behavior requires a solid grasp of self-efficacy, as it is closely linked to motivation, resilience, and emotional regulation. Social cognitive theory holds that mastery experiences, vicarious learning, verbal persuasion, and the interpretation of bodily and emotional states, that is, four main sources, are the means by which self-efficacy develops (Bandura, 1997). Direct achievements, or mastery experiences, are the most powerful since they provide hard evidence of skill. Seeing others succeed in comparable circumstances can increase effectiveness through social modeling. Learning to view emotional arousal (e.g., anxiety or excitement) as acceptable rather than dangerous improves efficacy beliefs; encouragement from teachers and peers supports these convictions through verbal persuasion; furthermore, this action enhances efficacy beliefs (Usher & Pajares, 2008). Therefore, learning environments that combine action, social interaction, feedback, and emotional engagement are particularly conducive to promoting self-efficacy.

Drama and theater offer one such situation (A drama-based programme to develop emotional intelligence in early childhood education, 2024). Because students must interact physically, emotionally, and socially through role-playing, performance, and teamwork, theatre training is essentially hands-on. Through practice and dramatic performance, these activities provide natural, repeated mastery experiences; moreover, they offer opportunities for vicarious learning as participants observe coworkers grow and succeed (Goldstein & Winner, 2012; Lee et al., 2020). Helpful remarks from facilitators and viewers serve as both verbal persuasion and regular exposure to performance-related arousal; participants may perceive anxiety as a manageable and energizing state (Feniger-Schaal & Lotan, 2017). As a result, theoretical ideas outlining how self-efficacy develops align well with theatre teaching. Beyond technical competence, theatre offers a planned forum for emotional inquiry and self-expression. Through role-playing and improvisation, people move beyond familiar patterns of thinking and action and explore alternative perspectives in a supportive setting (Snow et al., 2017). Better emotional awareness, communication abilities, and social confidence have been connected with such physical participation (Goldstein & Winner, 2012; McArdle & Wright, 2014). These mechanisms could help people believe more in their capacity to express themselves, change, and respond appropriately in real-world events.

Imaginative symbolic role-playing, often with anthropomorphic portrayals in which people play non-human or abstract concepts (such as natural objects or social ideas) as characters with human emotions and motivations, is a



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distinctive aspect of theatre training. Within a psychologically safe context, this artistic process allows individuals to externalize inner experiences, indirectly explore challenging emotions, and experiment with novel forms of expression. Although anthropomorphic performance is not considered a single factor, it belongs in the larger creative and physical learning environment that can help to develop emotional flexibility and expressive confidence (Smithner, 2025). The social component of theatre further enhances its developmental potential. Encouragement of group unity and mutual support through theatre activities depends on teamwork, shared storytelling, and group problem-solving (Snow et al., 2017), Ob (McEwan et al., 2017). Hence, while good group comments support perceived competence (Schunk & Di Benedetto, 2021), vicarious experiences help one's sense of potential by overcoming obstacles in serving peers. These group projects could help members, over time, increase their confidence in managing emotionally taxing events, performing, and communicating.

Although drama has long been appreciated for its artistic and creative value, research increasingly demonstrates its psychological benefits, including improved empathy, emotional expression, and self-esteem (Goldstein et al., 2015; Lee et al., 2020). However, rather few studies have examined self-efficacy as a specific, theory-driven outcome of coordinated theatre activities. This difference is important because self-efficacy is strongly associated with mental health, scholastic tenacity, and adaptive functioning across domains of life (Bandura, 1997; Schunk & DiBenedetto, 2021). Young adulthood is a particularly important stage for examining the development of self-efficacy. During this transitional period, individuals manage educational responsibilities, career decisions, and identity exploration, all of which require confidence in their abilities (Arnett, 2015). Experiences that provide mastery, emotional expression, and caring peer engagement may therefore play a valuable part in strengthening efficacy beliefs during this phase. Considering the close theoretical link between theatre training and the processes driving self-efficacy growth, it is crucial to investigate if long-term involvement in a well-organized drama program is linked with quantifiable variations in self-efficacy. The current study examines this question by examining young adults who completed a three-month theatre education course and assessing how confident they felt before and after the course. It also looks at how the participants described their experiences of growth in this creative, group environment.

LITERATURE REVIEW

Self-efficacy influences how people think, feel, and behave in the face of obstacles—that is one basic psychological concept (Bandura, 1997; Schunk & DiBenedetto, 2021). Strong efficacy beliefs help people approach challenging tasks with perseverance, regulate emotional responses under duress, and heal more effectively from failure (Usher & Pajares, 2008). Strong connections between self-efficacy and motivation, resiliency, and well-being have been established across educational, clinical, and social contexts; hence, self-efficacy has been extensively investigated (Artino, 2012). Four main sources—mastery experiences, vicarious learning, spoken persuasion, and interpretation about physical and emotional conditions—according to Bandura's (1997) social cognitive theory, develop self-efficacy. These sources highlight how crucial learning environments providing active participation, social modeling, positive criticism, and opportunities to control emotional arousal are (Usher & Pajares, 2008). Thus, experiential learning environments that combine performance, cooperation, and reflection are especially suited to promoting efficacy beliefs (Schunk & DiBenedetto, 2021). One such experimental setting is drama-based education. Unlike conventional lecture-based education, theatre learning is physically, socially, and emotionally expressive, enabling students to learn through action and engagement (McArdle & Wright, 2014; Lee et al., 2020). Participating in drama calls for practicing performances, conveying emotions, collaborating with others, and delivering performances to audiences—all of which could help individuals achieve mastery experiences and reinterpret performance-related arousal (Feniger-Schaal & Lotan, 2017).

Meta-analytic research indicates that drama-based instruction improves social ability, empathy, and communication skills—results closely related to confidence and perceived competence (Lee et al., 2020). Moreover enhancing emotional awareness and self-identity study are theatrical activities. Role-play and character embodiment enable people to examine feelings and perspectives different from their daily lives (Snow et al., 2017). By creating a



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systematically and psychologically safe environment, this imaginative engagement lets participants externalize interior occurrences, hence reducing criticism, worry, and increasing expressive confidence (Feniger-Schaal & Lotan, 2017). By increasing people's faith in their capacity to manage emotional circumstances, such processes may indirectly help the growth of self-efficacy (Gaiha et al., 2021). And (Creative and healthy through improv: Effects of training improvisational theatre on creative and work-related self-efficacy and self-esteem, 2025). Use of symbolic and creative methods, including anthropomorphic portrayal, is a fundamental component of theatrical training. In these activities, participants could present non-human entities, such as natural items, abstract notions, or environmental forces, as characters with human characteristics. Encouraging this anthropomorphic approach promotes perspective-taking, emotional projection, and imaginative problem-solving, thereby enhancing emotional involvement and widening expressive breadth. People may experience greater self-expression and a stronger sense of personal agency when processing difficult affective topics by adopting symbolic roles (Snow et al., 2017). Although the psychological benefits of drama are increasingly documented, empirical studies directly linking organized theatre instruction to changes in self-efficacy remain sparse. (Manorothkul, n.d.)

Self-discovery, professional and school decisions, and growing societal responsibilities define young adulthood—a time of development (Arnett, 2015). Regularly encountering performance expectations and social assessment during this stage can test people's coping skills and confidence (Schunk & DiBenedetto, 2021). As such, interventions that provide structured mastery experiences, supportive peer interaction, and opportunities for emotional expression may be useful in enhancing self-efficacy during this transition (Bandura, 1997; Usher & Pajares, 2008). While studies on the theoretical concordance between drama-based learning and self-efficacy development have been conducted, targeted research on this relationship in young adults remains scarce. (Impact, practicality, and acceptability of CREATORS: An arts-based pilot intervention to lower mental-health-related stigma among youngsters in Hyderabad, India, 2024). Social cognitive theory holds that self-efficacy grows from four main sources: mastery experiences, vicarious learning, verbal persuasion, and the interpretation of physical and emotional states (Bandura, 1997; Usher & Pajares, 2008). Structured theatre education provides an experiential setting in which performance, collaboration, feedback, and emotional engagement enable these sources to work in concert (Schunk & DiBenedetto, 2021). Drama-based instruction serves as the primary experiential setting within this framework. Rehearsal, role enactment, and public presentation provide regular mastery experiences, therefore enabling participants to achieve success via effort and practice.

While encouragement from facilitators and group members provides verbal reinforcement that strengthens perceptions of competence (Bandura, 1997), observing peers execute and develop inspires vicarious learning. Furthermore, repeated exposure to performance-related anxiety in a supportive environment can help individuals view physiological arousal as controllable, thereby improving their adaptive emotional control (Usher & Pajares, 2008). One unique technique in theatre education is anthropomorphic role-play, in which actors portray characters with human emotions and intentions, such as natural elements, objects, or abstract concepts. Beyond personal identity, this creative process expands expressive possibilities and encourages deeper emotional exploration and perspective-taking. Assuming symbolic roles allows individuals to indirectly access and express their inner experiences, which can reduce self-consciousness and enhance their communication confidence. Anthropomorphic engagement helps improve emotional engagement and creative agency, enrich mastery experiences, and support emotional reinterpretation within performance scenarios. Theatre training is viewed as enhancing self-efficacy through the interplay of these processes, as evidenced by greater confidence in handling difficulties, more expressive emotional expression, and improved performance before audiences. In turn, strengthened self-efficacy is linked with more general adaptive results, including better affective control, social confidence, resilience, and willingness to participate in new experiences (Bandura, 1997; Schunk & DiBenedetto, 2021). The conceptual path underpinning the current study so suggests that theatre-based experiential education, boosted by anthropomorphic imaginative involvement, triggers the key sources of self-efficacy, therefore promoting greater adaptive self-beliefs and psychological development.





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Need for the Study

Self-efficacy is a vital psychological construct that helps individuals operate adaptively across academic, social, and emotional spheres (Bandura, 1997; Schunk & DiBenedetto, 2021). Strengthening efficacy beliefs during young adulthood may help individuals be resilient, motivated, and capable of coping with new life difficulties (Arnett, 2015). Although experiential and arts-based methods are increasingly recognized for fostering whole-person development, empirical research on their influence on core psychological factors, such as self-efficacy, remains limited (Lee et al., 2020). Drama-based education provides a distinctive framework in which mastery experiences, social modeling, affective regulation, and constructive feedback naturally unfold (McArdle & Wright, 2014; Feniger-Schaal & Lotan, 2017). Additionally, creative methods such as anthropomorphic role acting might improve emotional engagement and confidence in expressiveness. Most current research emphasize general results like empathy or communication abilities rather than theory-based assessments of self-efficacy (Schunk & DiBenedetto, 2021). Therefore, a methodical research is needed on whether continuous involvement in organised theatre training correlates with noticeable changes in self-efficacy among young adults. Filling this vacuum will support a more thorough understanding of the cognitive advantages of arts-based educational strategies and inform the design of programs to foster confidence, emotional maturity, and adaptive self-beliefs.

Intervention

The intervention investigated in this research was a planned three-month Theatre Education Certificate Course given by Rangayana Shivamogga in partnership with Kateel Ashok Pai Memorial College, Shivamogga. Designed to foster expressive ability, self-awareness, and group creativity, the program meld classic Indian theatrical conventions with current performance techniques. Training was carried out alongside participants' normal academic timetables in rigorous daily morning and evening sessions. The theoretical teaching was interwoven with hands-on performing activities in the curriculum. Principles drawn from Bharata's *Natyashastra*, including *Angika* (body language), *Vachika* (voice and debate), and *Aharya* (costume and theatrical performance), were presented to students. Body conditioning, voice modulation, stage movement, emotive expression, improvisation, character development, and makeup were all covered in the lessons. The performance of anthropomorphic parts sets the training apart. Encouragement was given to pupils to picture and portray non-human or symbolic beings such as trees, discarded items, or abstract powers—as characters with human emotions, objectives, and voices.

Participants may investigate inner emotions indirectly through symbolic expression using this anthropomorphic approach, thereby broadening their emotional range and imaginative perspective-taking. Participants engaged in creative exploration that facilitated the expression of freedom and emotional processing in a secure, cooperative environment by adopting roles outside their normal identities. In addition to group improvisations and ensemble composition, the program included folk performance features such as *Janapada*, *Geethe* and *Kolata*. Students performed socially relevant street theatre plays addressing topics such as cybercrime and plastic contamination. These public shows offered chances for audience engagement, peer modeling, mastery experiences, and good criticism. Shared circles and reflective group discussions helped participants express personal insights and recognize their own development over the course. Combining physical training, symbolic imagination, affective exploration, group creativity, and live performance produced a holistic experiential setting consistent with processes known to foster the development of self-efficacy (Bandura, 1997; Usher & Pajares, 2008).

METHODOLOGY

Research Design

Changes in self-efficacy following attendance in a structured theatre training program were investigated in the current study using a one-group pretest-posttest quasi-experimental approach. This design enables evaluation of change over time inside the same group when random allocation or a control group is not practical (Creswell & Creswell, 2018; Shadish et al., 2002). Although causal inferences are constrained, this strategy is well-suited to



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assessing experiential educational programs conducted in naturalistic contexts. A mixed-methods strategy was used to provide a fuller understanding of the results. Qualitative data investigated participants' lived experiences of the theatre training process (Creswell & Creswell, 2018), whereas quantitative data measured measurable changes in self-efficacy.

Participants

Twenty young adults enrolled in a three-month Theatre Education Certificate Course held in Shivamogga, Karnataka, comprised the sample. Participants were undergraduate and postgraduate students who attended the instruction alongside their regular academic programs. Because all participants belonged to the same training cohort and met the research inclusion criteria (Etikan et al., 2016), purposive sampling was employed. The ultimate sample size of N = 20 mirrors the entire cohort enrolled in the certificate program during the study period. (Moore et al., 2016)

Inclusion Criteria

- Age between 18 and 25 years
- Enrollment in the three-month theatre training program
- Willingness to participate and provide informed consent
- Ability to comprehend and react to study instruments

Exclusion Criteria

- Severe physical or psychological conditions that could prevent active participation in theatre activities

Young adults were selected because this developmental stage involves self-identity exploration, performance demands, and increasing personal responsibility, all of which make self-efficacy particularly relevant (Arnett, 2015).

Tool General Self-Efficacy Scale (GSE)

Self-efficacy was measured using the General Self-Efficacy Scale developed by Schwarzer and Jerusalem (1995). The GSE is a widely used 10-item self-report instrument designed to assess individuals' general belief in their ability to cope with a variety of challenging situations. Responses are recorded on a Likert-type scale, and higher scores indicate stronger perceived self-efficacy. The GSE has demonstrated good psychometric properties across cultures, with internal consistency coefficients frequently ranging from .76 to .90 (Luszczynska et al., 2005; Schwarzer & Jerusalem, 1995). The scale has been used extensively in research on coping, resilience, and mental health (Schunk & DiBenedetto, 2021).

Procedure

Pre-Intervention Phase

At the beginning of the program, participants completed the GSE to establish baseline self-efficacy levels. The purpose of this phase proved to be to measure participants' perceived capability before exposure to structured theatre training.

Intervention Phase

Participants underwent a three-month structured theatre education program involving daily training sessions conducted in the morning and evening alongside their academic schedules. The program integrated theoretical instruction with practical performance training.

Components included:

- Body and voice training based on principles of **Angika** (physical expression) and **Vachika** (verbal expression) from classical Indian theatre traditions
- Stagecraft and visual presentation (**Aharya**), including costume, makeup, and staging
- Improvisation, role-play, and character development exercises
- Group performance projects and ensemble theatre creation
- Folk forms such as JanapadaGeethe and Kolata
- Public performances, including socially themed street plays



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One unique feature of the intervention was its use of anthropomorphic role-play. Participants were inspired to represent non-human and metaphorical entities, such as trees, discarded objects, or abstract powers, as characters with human emotions, speech, and purpose. Through symbolic expression, this anthropomorphization process allows students to examine internal feelings and points of view covertly. Participants explored emotionally expressive confidence and perspective-taking in a supportive group setting by adopting roles beyond their own identities. Students engaged in reflective group discussions that promoted the sharing of personal experiences and emotional insights and that facilitated the observation of development throughout the training. These sessions provided verbal reinforcement, peer modeling, and emotional processing, experiential aspects of self-efficacy development (Bandura, 1997; Usher & Pajares, 2008).

Post-Intervention Phase

At the conclusion of the three-month program, participants completed the GSE again as a posttest measure. This enabled comparison of self-efficacy scores before and after participation in the theatre training.

Qualitative Component

Qualitative data were collected through:

- Reflective group discussions
- Participant sharing sessions
- Observational notes from facilitators

These data were analyzed using **thematic analysis** following Braun and Clarke's (2006) framework, including familiarization, coding, theme identification, review, and definition. This approach permitted the organized exploration of participants' experiences related to confidence, emotional expression, and self-improvement.

Ethical Issues

Participants provided informed consent prior to participation. Confidentiality was maintained by assigning identification codes rather than names on all data forms. Participation was voluntary, and participants were informed of their right to cease participation at any time without penalty, in accordance with established ethical protocols for human research (American Psychological Association, 2017).

RESULTS

Quantitative Findings

Descriptive statistics were calculated to examine changes in self-efficacy scores from pretest to posttest. Assumptions of normality were assessed before conducting inferential analysis. A paired-samples *t*-test was performed to determine whether participation in the theatre training program was associated with significant changes in self-efficacy.

Data Analysis

Descriptive statistics (M, SD) were computed for pretest and posttest scores. Normality of difference scores was assessed using the Shapiro-Wilk test, appropriate for small samples (Field, 2018). A paired-samples *t*-test evaluated pre-post change. Cohen's *d* was computed to describe effect size (Cohen, 1988). Qualitative data were analyzed using thematic analysis procedures (Braun & Clarke, 2006).

DISCUSSION

The present study examined whether participation in a structured theatre-based training program was associated with changes in self-efficacy among young adults. Quantitative findings showed a statistically significant increase in



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self-efficacy from pretest to posttest, with a large effect size, indicating meaningful improvement in participants' perceived capability to manage challenges. Qualitative findings further supported these results by revealing increased confidence, improved emotional expression, learning through peer observation, and the importance of a helpful group environment. Together, these findings correspond closely with the conceptual framework underlying the study and with established theory on the development of self-efficacy (Bandura, 1997; Schunk & DiBenedetto, 2021). According to the conceptual model proposed for this study, theatre training provides an experiential context that activates the four primary sources of self-efficacy: mastery experiences, vicarious learning, verbal persuasion, and interpretation of emotional arousal (Bandura, 1997; Usher & Pajares, 2008). The significant increase in self-efficacy observed in the quantitative analysis may be understood as the cumulative effect of repeated mastery experiences embedded within the training. Rehearsals, character development, and public performances required participants to engage in challenging tasks, practice skills, and witness their own improvement over time. Successfully navigating performance demands, particularly in front of an audience, likely strengthened participants' beliefs in their ability to handle difficult situations, consistent with the central role of mastery experiences in efficacy development (Bandura, 1997)

The qualitative results on peer learning provide further evidence for the role of vicarious experiences within the conceptual framework. Participants reported that observing others perform, grow, and overcome performance anxiety helped them feel more confident. Such modeling effects are particularly potent when individuals perceive parallels between themselves and others, thereby reinforcing the idea that they, too, might be successful (Schunk & Di Benedetto, 2021). Theatre training's collaborative character appears to have created an environment in which social comparison worked positively, thereby boosting the development of efficacy. Important parts of the training experience also proved to be support and useful input from group members and facilitators. Particularly when combined with obvious progress in performance and expression, these forms of words may have strengthened participants' impressions of competence (Artino, 2012; Bandura, 1997). Participants' favorable group environment probably increased their inclination to engage more completely in expressive tasks and take creative risks, therefore boosting positive efficacy beliefs. The conceptual framework emphasized that the use of anthropomorphic role play was a unique aspect of the intervention. Participants were challenged to show trees, objects, or abstract forces—as characters with human characteristics—as non-human or symbolic creatures. By letting people express emotions indirectly via symbolic roles, this creative process might have increased emotional involvement and lowered self-consciousness. Participants might have had more expressive freedom and perspective-taking by pretending to be people other than who they were on a daily basis. This might have led to a feeling of creative agency and confidence. Anthropomorphic interaction might then have served as a mechanism to enhance mastery experiences and promote more adaptive interpretation of emotional response during performance contexts.

Improved emotional expression and greater comfort with stage-related anxiety that participants noted support the theoretical connection between theatre participation and reinterpretation of physical and emotional states. Regular exposure to performance-related arousal in a supportive environment may have enabled participants to view anxiety as a tolerable or even inspiring experience instead of a sign of disability (Usher & Pajares, 2008). Those changes in emotional interpretation are accompanied by improved self-efficacy beliefs. The evidence points to theatre-based experiential learning, particularly when it combines creative and anthropomorphic elements, as potentially offering several interlinked pathways through which self-efficacy develops. These results build on earlier studies on the psychological advantages of drama instruction, particularly by highlighting self-efficacy as a conceptually grounded outcome (Lee et al., 2020; Snow et al., 2017). Such treatments can help foster confidence, emotional competence, and adaptive functioning in young adulthood, a developmental period characterized by increasing performance demands and the formation of self-identity (Arnett, 2015; Schunk & DiBenedetto, 2021). However, the findings should be interpreted with caution. The absence of a control group limits the ability to attribute changes solely to the intervention (Shadish et al., 2002). Improvements in self-efficacy may also reflect general maturation, increased social familiarity, or other concurrent experiences. Nevertheless, the consistency among quantitative improvements, qualitative themes, and the conceptual framework strengthens confidence in the interpretation that theatre training was meaningfully associated with increased efficacy beliefs.





To summarize, the discussion of findings in relation to the conceptual framework indicates that theatre training, particularly when enriched by anthropomorphic imagination and joint performance, can activate the core psychological processes through which self-efficacy develops. These results support the view that arts-based instructional environments may contribute not only to creative skill development but also to the strengthening of adaptive self-beliefs and psychological toughness.

Applied Implications

According to the results of the current research, organised theatre-based training courses may be useful instruments for promoting psychological development in young people. Theatre education can help develop self-efficacy, a key psychological resource linked to resilience, drive, and adaptive functioning (Bandura, 1997; Schunk & Di Benedetto, 2021), by offering experiential learning environments that combine performance, teamwork, emotional involvement, and reflection. Including theatre-based or drama-integrated courses in undergraduate and graduate programs can help educational institutions foster pupils' social and personal growth as well as their academic success. The development of efficacy beliefs is correlated with role-play, improvisation, and group performance projects, as these activities offer opportunities for mastery experiences, peer modeling, and constructive criticism, all of which help shape them (Usher & Pajares, 2008). Such programs may be notably beneficial for students who experience performance anxiety, low confidence in communication, or difficulty expressing emotions. The study additionally reveals the potential value of anthropomorphic and symbolic role enactment as a pedagogical strategy. Motivating students to portray non-human or conceptual entities allows for indirect emotional expression and creative perspective-taking, which may reduce self-consciousness and enhance expressive confidence. Educators and facilitators can intentionally use these imaginative techniques to create psychologically safe environments in which students become more comfortable exploring emotions and experimenting with new forms of expression.

Theatre-based activities can provide readily accessible and culturally flexible ways to foster emotional competence and social confidence in youth development and community programs. Group performances and socially focused street dramas can help people to believe in their capacity to speak and make a major contribution to their society, therefore encouraging civic involvement and social awareness, and so enhance participants' belief. Young people's engagement and motivation could be raised by a mix of creative expression and social relevance. Drama-based exercises can be used as adjunctive treatments in counseling and psychosocial support contexts to help individuals build self-assurance in emotional communication and interpersonal interaction. The experiential and physical nature of theatre activities may help regulate emotion and reduce avoidance behavior, potentially enhancing adaptive functioning and coping. The findings ultimately reveal the importance of training facilitators in encouraging comments and performance methods. Whether theatre-based treatments work depends not only on the activities themselves but also on establishing a supportive group environment in which participants feel free to try new things. Organized reflection sessions and peer debates can help internalize efficacy-enhancing experiences, thereby enhancing learning and support. Overall, the present findings support the integration of theatre-based experiential learning approaches inside educational and developmental contexts as a means of promoting self-efficacy and related adaptive outcomes in young adults.

Strengths of the Study

This research has several especially great qualities. It first employed a mixed-methods approach, combining quantitative and qualitative data to provide both measurable evidence of change and a thorough understanding of how participants lived their lives. Linking statistical results with empirical activities helped to clarify the meaning of the data. Second, the intervention was ecologically sound and culturally relevant since it took place in a real theatre education program instead of a simulated laboratory environment. This made the findings more relevant to the real world. Third, the study looked at a three-month structured intervention that was sustained, which let researchers see significant changes in development instead of just short-term effects. Ultimately, the inclusion of anthropomorphic and symbolic performance elements offers fresh conceptual originality by presenting a unique expressive device by



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which theatre training may affect psychological development, therefore providing a different viewpoint on studies on self-efficacy and arts-based interventions.

Limitations

The study has certain drawbacks that should be taken into account while evaluating the results even if it has some benefits. A one-group pretest-posttest design without a control group limits the power to reach strong causal judgments regarding the consequences of the theater intervention (Shadish et al., 2002). Enhancements in self-efficacy may have been influenced by factors such as growth, greater peer familiarity, or other concurrent activities over the three-month period. The sample size was rather tiny and taken from a single training cohort, the applicability of the results to other groups or cultural contexts may be limited (Creswell & Creswell, 2018). The study was also largely based on self-report questionnaires, which may be subject to response bias or social desirability effects (Podsakoff et al., 2003). Lastly, self-efficacy was measured only immediately after the intervention; the long-term viability of the observed improvements remains uncertain. Future investigations, including bigger samples, control groups, multi-method evaluations, and long-term follow-up, would help to build the evidence base.

CONCLUSION

Young people who participated in a structured theatre-based training program showed changes in their self-efficacy, according to the current research. Quantitative data showed a notable increase in self-efficacy after the three-month program, whereas qualitative results emphasized experiential components including performance practice, emotional expression, peer learning, and group support as important elements of participants' development. These results support social cognitive theory, which holds that theatre training can activate important sources of self-efficacy, such as mastery experiences, vicarious learning, verbal encouragement, and adaptive interpretation of emotional arousal (Bandura, 1997; Usher & Pajares, 2008). Adding anthropomorphic and symbolic role-playing increased opportunities for emotional exploration and expressive confidence, thereby offering a unique means by which theater can support psychological growth. Although the study design precludes causal inferences, the findings support mounting evidence that arts-based experiential learning environments may foster adaptive self-beliefs and creative talent. The results generally highlight the potential of theatre education as a whole to promote psychological resilience and self-efficacy across young adulthood, a developmental stage characterized by increasing performance demands and exploration of self-identity (Arnett, 2015; Schunk & DiBenedetto, 2021). The long-term effects and fundamental processes of drama-based treatments on self-efficacy and associated outcomes will be clarified by future studies employing controlled, long-term designs.

Authors Declaration

- All authors declare that they have no conflicts of interest for authorship regarding this research and have agreed to publish it in the specified order.
- **Authors' Contribution to this paper**
 - Arunkumar and Dr. Beena G conceptualized the research idea and structure of the paper.
 - Vinay and Gayathri V contributed by collecting the primary resources and data for drafting the paper.
 - Dr. Archana Bhat Kallahalla organized the data and proofread the paper.
- **Declaration on funding**
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Table 1: Descriptive Statistics for Pretest and Posttest Self-Efficacy Scores (N = 20)

Measure	N	M	SD
Pretest self-efficacy	20	27.60	5.75
Posttest self-efficacy	20	33.50	4.66

Note. Higher scores indicate stronger perceived self-efficacy (Bandura, 1997).

Table 2: Shapiro-Wilk Test of Normality for Self-Efficacy Difference Scores

Variable	W	p
Pretest-posttest difference	0.921	.105

Note. Difference scores did not significantly deviate from normality ($p > .05$); parametric testing was appropriate (Field, 2018).





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Table 3: Paired-Samples t Test Comparing Pretest and Posttest Self-Efficacy Scores

Comparison	t	df	p
Pretest vs. posttest	-3.91	19	< .001

A paired-samples t test showed that posttest self-efficacy scores were significantly higher than pretest scores, $t(19) = -3.91$, $p < .001$.

Table 4: Effect Size for Change in Self-Efficacy Scores

Comparison	Cohen's d
Pretest-posttest	0.87

Note. $d \approx 0.87$ indicates a large effect (Cohen, 1988).

Table 5: Qualitative Themes Identified From Participant Reflections

Theme	Description
Increased confidence through performance	Greater confidence speaking, performing, and expressing emotions.
Improved emotional expression	Role-play supported comfort with expressing a range of emotions.
Learning through peer observation	Watching peers improve contributed to belief in one's own capability.
Supportive group environment	Encouragement and collaboration increased psychological safety and willingness to take risks.

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RESEARCH ARTICLE

Techniques for using MATLAB to Estimate the Weibull Distribution's Parameters for Customer Transaction Data

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ABSTRACT

This shape parameter (b) and scale parameter (h) are two techniques for estimating Weibull parameters that we present in this study. For reliability and maintainability analysis in particular, the Weibull distribution is a crucial distribution. The methods that have been given can be divided into two groups: analytical methods and graphical methods. The approaches offered are tested computationally and the results are reported. The usefulness of the Weibull distribution is illustrated using customer transaction data sets. The results show that the Weibull distribution provides a better parametric fit than the competing distributions using MATLAB.

Keywords: Maximum likelihood, Weibull Probability Plotting, predictive analysis.

Mathematics Subject Classification (2020): 00A71, 60G25.

INTRODUCTION

A common The Weibull distribution is frequently used to describe lifetime data and phenomena with monotone failure rates. The Weibull distribution with two parameters, which is frequently used as a model in life testing, In order to estimate the distribution parameters from (i) full data, (ii) singly censored samples, and (iii) progressively (many) censored samples, maximum likelihood equations are generated [1]. For each of these sample types, asymptotic variance-covariance matrices are provided. Included is an example to illustrate the point.



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Maximum likelihood estimators based on different left and right censored data scenarios for the three parameter Weibull distribution. the developed estimation procedure involves the simultaneous solution of two iterative equations for the case of single censoring from the left and progressive censoring from the right. The aforementioned scenario leads to an estimating process with a single iterative equation for the two parameter Weibull distributions [2]. The estimators' asymptotic variance-covariance matrix is provided. There exist pivot functions whose distributions can be utilized for hypothesis testing and estimating confidence intervals. The estimate process using left-censored samples is demonstrated with an example. Examines and contrasts various approaches to estimating the parameters of the two-parameter Weibull distribution using complete, type II, and massively time censored samples. The performance of various estimators is compared in a comprehensive simulation exercise [3].

The goal of [4] to determine the best approach for calculating the wind power density at four stations, Edmonton City Center Awos, Grande Prairie A, Lethbridge A, and Waterton Park Gate located throughout the Canadian state of Alberta. Both daily and monthly scales are used for the evaluations in order to provide a thorough analysis. The findings show that using alternative parameter estimating techniques to derive the k and c parameters alters the accuracy of calculated wind power density values. While the GP approach has poor ability for all stations, the four EMJ, EML, EPF, and ML methods present extremely favorable efficiency. However, because the wind parameters vary from station to station, it is discovered that the more effective way is not the same.

A linear mixture of Fréchet densities can be used to represent the new density function. The model parameters are estimated using the greatest likelihood method. The flexibility of the new distribution is empirically demonstrated by applying it to two real data sets [5]. In many fields, it can be used as a substitute model for other lifespan distributions found in the literature to model positive real data. The Lindley Weibull distribution is a novel three-parameter lifetime model that accounts for a wide range of monotone failure rates as well as unimodal and bathtub failures. Given thorough explanation of several of its mathematical characteristics, such as order statistics, quantile and generating functions, and ordinary and incomplete moments, a linear combination of exponentiated Weibull densities can be used to represent the new density function. The subject distribution's several mathematical characteristics are examined. Quantile function, expansion of density and distribution functions, moments, generating function, incomplete moments, conditional moments, residual life function, mean deviation, inequality measures, Rényi and q -entropies, probability weighted moments, and order statistics are all given general explicit expressions. The maximum likelihood approach is used to estimate the model parameters [6]. Lastly, three actual data sets are used to analyze the suggested distribution's practical significance. It has been determined that the new distribution outperforms the rival models. The model parameters are estimated using the greatest likelihood method [7]. To evaluate the effectiveness of the maximum likelihood estimation, we report simulated results. We provide empirical evidence for the new distribution's significance and adaptability in modeling two data sets. Equations that enable the representative volume to be computed from strength data are generated using the distribution's exact form, without the assumptions that result in its usual exponential form, as long as enough specimens and sizes are examined. The newly derived equations are applied to the analysis of graphene and polysilicon data [8], yielding representative elements that are in good agreement with the observed flaws.

The main objective of this study is to introduce and examine a novel lifetime model called the Exponentiated Generalized Weibull Exponential Distribution [10], which is based on mathematical techniques. Using the EGWD, we assessed consumer transaction data [11]. The main objective of the new model is to introduce a parameter that will allow for greater flexibility in the shape of the density and hazard functions, among many other desired characteristics. In this paper, Based on the mathematical technique, the primary goal of this research is to present and investigate a novel lifetime model known as the Weibull Distribution [9]. We evaluated customer transaction data using the WD [10]. The primary goal of the new model is to provide more flexibility in the shape of the density and hazard functions, along with many other desired qualities, by adding a parameter.





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Weibull distribution

Weibull Probability Plotting

The Weibull distribution density function is given by:

$$f(x) = \frac{\beta}{\eta} \left(\frac{x - \gamma}{\eta} \right)^{\beta-1} e^{-\left(\frac{x - \gamma}{\eta} \right)^{\beta}}, \beta > 0, \eta > 0, x \geq \gamma \geq 0$$

The cumulative Weibull distribution function is given by:

$$F(x) = 1 - e^{-\left(\frac{x - \gamma}{\eta} \right)^{\beta}}$$

Where the form, scale, and position parameters are denoted by β , η , and γ , respectively.

We use the double logarithmic transformation of the CDF to determine the relationship between it and the two parameters (β, η).

Let $\gamma = 0$, we have

$$1 - F(x) = e^{-\left(\frac{x}{\eta} \right)^{\beta}}$$

$$\frac{1}{1 - F(x)} = e^{\left(\frac{x}{\eta} \right)^{\beta}}$$

$$\ln \left[\frac{1}{1 - F(x)} \right] = \left(\frac{x}{\eta} \right)^{\beta}$$

$$\ln \ln \left[\frac{1}{1 - F(x)} \right] = \beta \ln \eta - \beta \ln x$$

The final equation is a straight line equation. The process below is used to plot (x) vs x :

- Rank failure times in ascending order.
- Estimate $F(x_i)$ of the i^{th} failure.
- Plot $F(x_i)$ vs. x in the Weibull probability paper.

To estimate $F(x_i)$ in (2 and 3) above, we may use one of the following methods presented in Table 1 where n is number of data points. Using one of the techniques listed in below Table, where n is the number of data points; we can $F(x_i)$ in the aforementioned equations (2 and 3).

Hazard Plotting Technique

The Weibull parameters can be estimated using the hazard plotting technique. Plotting the cumulative hazard function $H(x)$ versus failure times on a hazard paper or a straightforward log-log paper is how this is accomplished.

The following is the hazard function:

$$h(x) = \frac{\beta}{\eta} \left(\frac{x}{\eta} \right)^{\beta-1}$$

The cumulative hazard function is given below:

$$H(x) = \int h(x) = \left(\frac{x}{\eta} \right)^{\beta}$$

We can transform by taking the logarithm as follows

$$\ln H(x) = \beta \{\ln x - \ln \eta\}$$

From above equation, we can then plot $\ln H(x)$ versus $\ln x$ using the following procedure:

Plotting $\ln H(x)$ against $\ln x$ can then be done by following these steps:

- Rank the failure times in ascending order.
- For each failure, calculate $\Delta H_i = \frac{1}{(n+1)-1}$
- For each failure, calculate $H = \Delta H_1 + \Delta H_2 + \dots + \Delta H_i$





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- Plot $\ln H$ vs. $\ln x$.
- Fit a straight line.

The estimated parameters after the plotting is finished will be as follows:

$$\beta = \frac{x}{y} = \frac{1}{\text{slope}}$$

at $H = 1, \eta = x$

Maximum Likelihood Estimator (MLE)

Due to its very desirable characteristics, the maximum likelihood technique is a frequently employed process. Given a probability density function $f_X(x; \theta)$, where θ is an unknown parameter, let $x_1, x_2, \dots, x_n$ be a random sample of size n . The joint density of the n random variables, which depends on the unknown parameter, is the probability function of this random sample. So

$$L = \prod_{i=1}^n f_{X_i}(x_i, \theta)$$

Is the function of likelihood, the value of θ that maximizes L , or the logarithm of L , is the maximal likelihood estimator (MLE) of θ , let's say $\hat{\theta}$. The MLE of θ is frequently, but not always, a solution of

$$\frac{d \log L}{d\theta} = 0$$

Where neither solutions that are not in the parameter space nor those that are not functions of the sample values $x_1, x_2, \dots, x_n$ are admissible, the shape and scale parameters are the Weibull parameters that we will now estimate using the MLE the likelihood function of the WD will be

$$L(x_1, \dots, x_n; \beta, \eta) = \prod_{i=1}^n \left(\frac{\beta}{\eta} \right) \left(\frac{x_i}{\eta} \right)^{\beta-1} e^{-\left(\frac{x_i}{\eta} \right)^\beta}$$

We derive the estimating equations by first differentiating with regard to β and η , then equating to zero.

$$\frac{\partial \ln L}{\partial \beta} = \frac{n}{\beta} + \sum_{i=1}^n \ln x_i - \frac{1}{\eta} \sum_{i=1}^n x_i^\beta \ln x_i = 0$$

$$\frac{\partial \ln L}{\partial \eta} = \frac{n}{\eta} + \sum_{i=1}^n \ln x_i - \frac{1}{\eta} \sum_{i=1}^n x_i^\beta \ln x_i = 0$$

After simplifying and removing η between these two equations, we have

$$\frac{\sum_{i=1}^n x_i^\beta \ln x_i}{\sum_{i=1}^n x_i^\beta} - \frac{1}{\beta} - \frac{1}{n} \sum_{i=1}^n \ln x_i = 0$$

Whose solution yields the estimate of $\hat{\mu}_k = \beta$. Standard iterative processes, such as the Newton-Raphson method, can be used to achieve this. Using above Equation can be used to estimate η once β has been established.

$$\eta = \frac{\sum_{i=1}^n x_i^\beta}{n}$$

Method of Moments (MOM)

Another popular method in the field of parameter estimate is the method of moments. If a set of data is represented by the numbers $x_1, x_2, \dots, x_n$, then an unbiased estimator for the k^{th} origin moment is

$$\hat{m}_k = \frac{1}{n} \sum_{i=1}^n x_i^k$$

$$\mu_k = \left(\frac{1}{\eta^\beta} \right)^{\frac{-k}{\beta}} \Gamma \left(1 + \frac{k}{\beta} \right)$$





where Γ signifies the gamma function

$$\Gamma(s) = \int_0^{\infty} x^{s-1} e^{-x} dx, (s > 0)$$

we can find the first and the second moment as follows

$$m_1 \& = \mu_k = \left(\frac{1}{\eta}\right)^{\frac{1}{\beta}} \Gamma\left(1 + \frac{1}{\beta}\right) \quad (13)$$

$$m_2 \& = \mu_k^2 + \sigma_k^2 = \left[\frac{1}{\eta}\right]^{\frac{2}{\beta}} \left\{ \Gamma\left(1 + \frac{2}{\beta}\right) - \left[\Gamma\left(1 + \frac{1}{\beta}\right) \right]^2 \right\}$$

The formula that results from dividing m_2 by the square of m_1 , is solely a function of β .

$$\frac{\hat{\sigma}_k^2}{\hat{\mu}_k^2} = \frac{\Gamma\left(1 + \frac{2}{\beta}\right) - \Gamma^2\left(1 + \frac{1}{\beta}\right)}{\Gamma^2\left(1 + \frac{1}{\beta}\right)}$$

we have the coefficient of variation

$$CV = \frac{\sqrt{\Gamma\left(1 + \frac{2}{\beta}\right) - \Gamma^2\left(1 + \frac{1}{\beta}\right)}}{\Gamma\left(1 + \frac{1}{\beta}\right)}$$

The calculated $(\hat{\beta})$ is the equivalent β . The following can then be used to estimate the scaling parameter (n).

$$\hat{\eta} = \{\bar{x} / \Gamma[(1/\hat{\beta}) + 1]\}^{\hat{\beta}}$$

where $\bar{x}$ is the mean of the data.

Least Squares Method (LSM)

We use the method of least squares,

$$\ln \ln \left[\frac{1}{1 - F(x)} \right] = \beta \ln x - \beta \ln \eta$$

$$\bar{x} \& = \frac{1}{n} \sum_{i=1}^n \ln \left\{ \ln \left[\frac{1}{\left(1 - \frac{i}{n+1}\right)} \right] \right\}$$

$$\bar{Y} \& = \frac{1}{n} \sum_{i=1}^n \ln x_i$$

$$\hat{\beta} \& = \frac{n \cdot \sum_{i=1}^n (\ln x_i) \cdot \left(\ln \left\{ \ln \left[\frac{1}{\left(1 - \frac{i}{n+1}\right)} \right] \right\} \right) - \sum_{i=1}^n \ln \left(\ln \left[\frac{1}{\left(1 - \frac{i}{n+1}\right)} \right] \right) \cdot \sum_{i=1}^n \ln x_i}{n \cdot \sum_{i=1}^n (\ln x_i)^2 - \sum_{i=1}^n (\ln x_i)^2}$$

$$\hat{\eta} \& = e^{\left(\bar{Y} - \frac{\bar{x}}{\hat{\beta}} \right)}$$

Real time Data

This section analyzes an actual data set to show the advantages of the Weibull distribution. The model parameters' MLE and associated standard errors (in parenthesis) are obtained. We present the estimated PDF of the Weibull distribution model together with the histogram for every data set. Additionally, the following figures show the respective plots of the PDF, CDF, and Hazard rate of the data set Using MLE's. Further, fitted CDF and empirical CDF of the Weibull distribution and difference of these both are given. The information which was taken from Kaggle.com [10], shows real-time customer transactions on Kaggle.com. The following is the data set: transaction amounts 35.47, 2552.72, 115.97, 11.31, 62.21, 99.14, 145.94, 161.39, 77.73, 142.85, 928.68, 387.78, 142.07, 107.44, 54.31, 79.57, 441.18, 475.82, 106.26, 1468.14, 40.08, 39.87, 151.73, 17.05, 108.3, 366.56, 924.23





RESULTS AND DISCUSSION

A popular method for modeling lifetime data is a flexible version of the Weibull distribution. A larger class of hazard rate and density functions is produced by this extension. The new distribution is treated mathematically, with extensions for the density and cumulative functions. For a broader spectrum of statistical study, we anticipate that the suggested model will be an intriguing alternative paradigm. With the aid of the MATLAB application, we illustrate the outcomes of all the dependability functions of the adjusted distribution using real-time client amount transaction data from kaggle.com [10]. In Section 4, graphical representations of histogram PDF, CDF, Hazard rate for Estimated Weibull distribution are given. Where, shape parameter α is 280.3304 and β is 0.76063. Furthermore, difference of Difference of Empirical CDF and Fitted CDF of Weibull distribution for customer amount transaction data also given. Hence, MLE to estimating the parameters β and α of the Weibull distribution's from the given transaction data. When the transaction values increases, the shape parameter α of WD shows whether the event occurs more frequently. A Most failure rate is indicated by $\alpha > 1$. When $\alpha < 1$, the failure rate is degenerated. A constant failure rate, unique of an exponential distribution, is indicated by $\alpha = 1$. The cumulative and opportunity that the transaction amount will fall below or equal a specific value has been given by the CDF. With an increase in the transaction amount, it rises from 0 to 1. The Hazard Rate offers information on the instantaneous rate at which an event (such as a high-value transaction) occurs at any particular moment. If the shape parameter $\alpha > 1$, the hazard rate is higher for larger transaction amounts, indicating that larger transaction amounts are more likely to occur over time.

CONCLUSION

We have provided both mathematical and graphical approaches for estimating the Weibull distribution parameters in this study. The computational findings have demonstrated that the method of moments provides the best estimations. Following the model's fit to the transaction amount data set, all of the figures show that the proposed model provides a superior fit to the provided data set than any of the competing models.

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Table 1. Methods for estimating $F(x_i)$.

Method	$F(x_i)$
Mean Rank	$\frac{i}{n+1}$
Median Rank	$\frac{i-0.3}{n+0.4}$
Symmetrical CDF	$\frac{i-0.5}{n}$

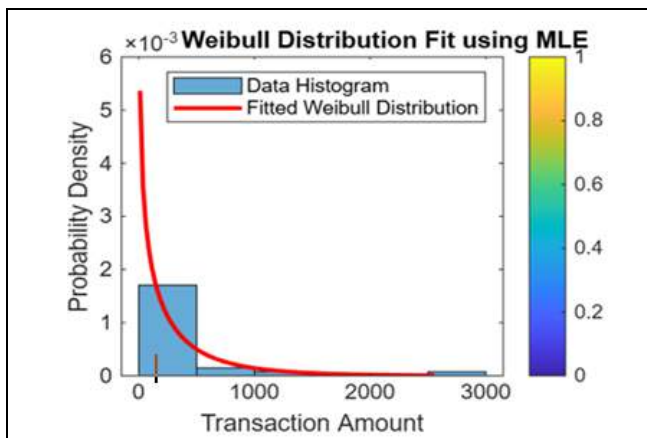


Fig 1: PDF of Weibull distribution.

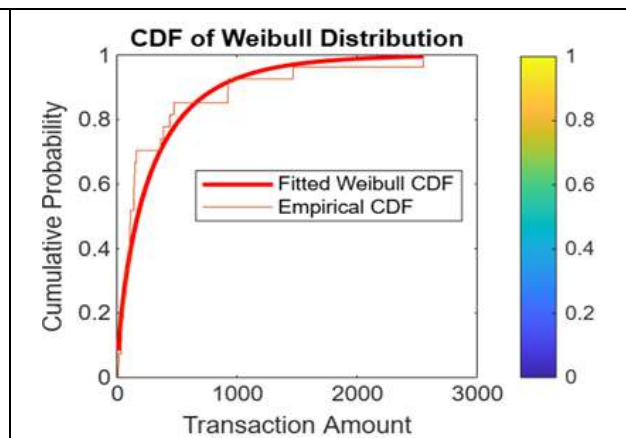


Fig 2: CDF of Weibull distribution for customer amount transaction data.

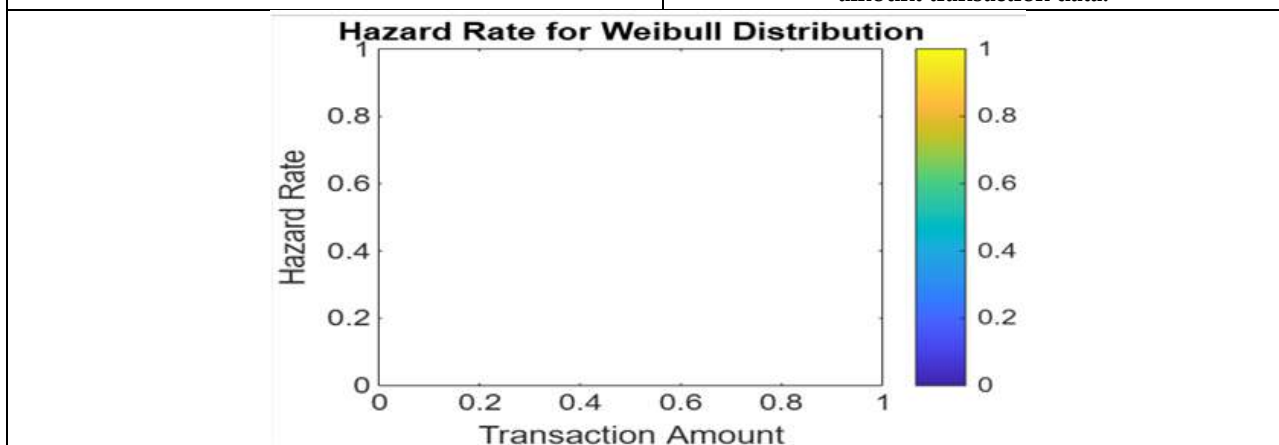


Fig 3: Hazard rate function of Weibull distribution for customer amount transaction data.



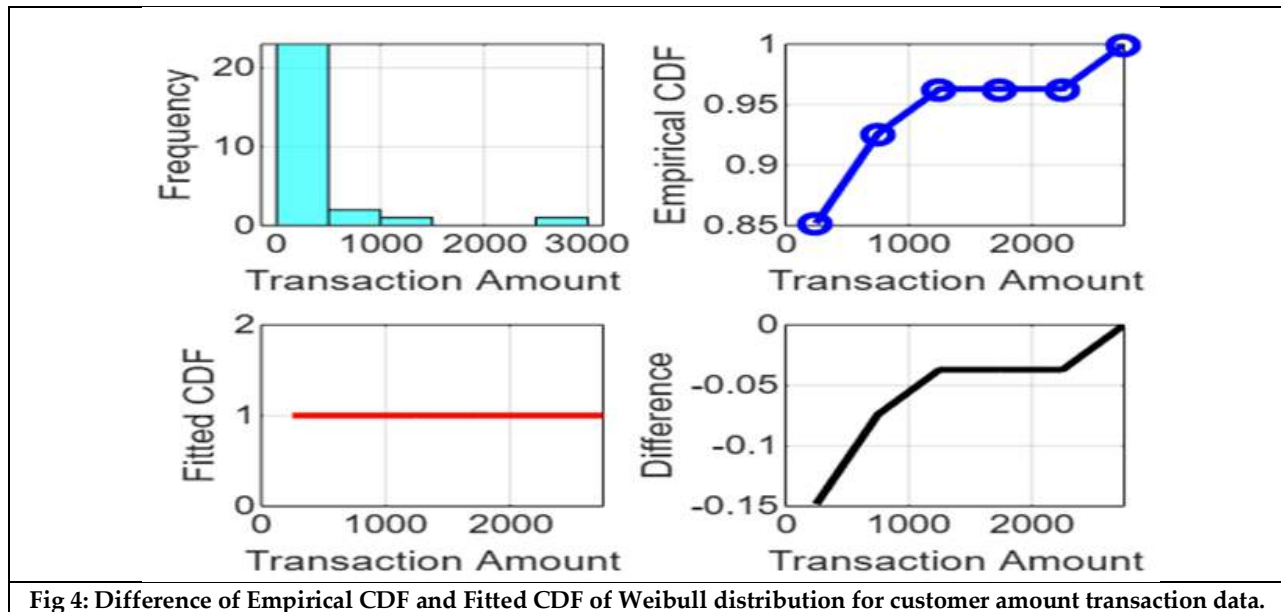


Fig 4: Difference of Empirical CDF and Fitted CDF of Weibull distribution for customer amount transaction data.

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RESEARCH ARTICLE

Determination of Related Compounds by RP - HPLC Method for the Estimation of Metformin and Alogliptin in Bulk and its Dosage Form

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ABSTRACT

A new, simple stability-indicating RP-HPLC and UV method for simultaneous estimation of Metformin and Alogliptin in bulk and dosage form was developed. Chromatography was carried out using Phenomenex Synergi polar column with a flow rate of 1.5mL/minute. The mobile phase consisted of 0.1% Prepare a degassed mixture of buffer, Acetonitrile and methanol in the ratio of 60:28:12 % v/v/v. at 224nm for Alogliptin, 232nm for Metformin. Strict control of impurities is necessary for the manufacturing of drug products. These impurities may be present in the materials, formed as by-products during the process of production or appear as degradation products during storage. Both actual and potential impurities should be studied and detected by a reliable and convenient method. Metformin impurities Related compound A (RCA), Related compound B (RCB) and Related compound C (RCC) are chemically known as 1- Cyanoguanidine (RCA), 1- methyl biguanidine hydrochloride (RCB) and N, N dimethyl (1, 3, 5) triazine 2, 4, 6 triamine (RCC). The impurities of AGLT-BZ studied in this paper were named as compounds RC-01, RC-02, RC-03 & RC-04.

Keywords: Metformin, Alogliptin, RP-HPLC and Related compounds, Impurities

INTRODUCTION

Metformin Hydrochloride is an oral antidiabetic drug in the biguanide class. It is the first-line drug of choice for the treatment of type 2 diabetes, in particular, in overweight and obese people and those with normal kidney function. Its use in gestational diabetes has been limited by safety concerns. It is also used in the treatment of polycystic ovary

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syndrome, and has been investigated for other diseases where insulin resistance may be an important factor. Metformin Hydrochloride works by suppressing glucose production by the liver. Alogliptin works by increasing levels of natural substances called incretins. Incretins help to control blood sugar by increasing release, especially after a meal. They also decrease the amount of sugar your liver makes. Increased concentrations of the incretin hormones such as glucagon-like peptide-1 (GLP-1) and glucose-dependent insulinotropic polypeptide (GIP) are released into the bloodstream from the small intestine in response to meals. These hormones cause insulin release from the pancreatic beta cells in a glucose-dependent manner but are inactivated by the dipeptidyl peptidase-4 (DPP-4) enzyme within minutes.

MATERIALS AND METHODS:**Instrumentation**

All HPLC experiments were carried out on a Waters Alliance 2695 separation module, with waters uv detector in gradient mode using Auto sampler. The analytical column used for the separation was Phenomenex Synergi polar (250× 4.6 mm I.D., 4µm particle size) Analytical balance (contech balance), pH meter (DIGITAL pH METER 802, Systronics), sonicator (SONIC, VIBRA CELL).

Chemicals and reagents

- A working standards Metformin (99.7%) and Alogliptin (99.5%) were procured from HETERO, Hyderabad, India. Acetonitrile (HPLC Grade; MERCK), Sodium dodecyl sulphate SIGMA-ALDRICH (part no 71725-100G), Orthophosphoric acid (88%) (AR Grade, MERCK), HCl (AR Grade, Qualigens), Related compounds metformin hydrochloride and Related compounds Alogliptin are obtained from HETERO Hyderabad, Methanol (HPLC Grade) and milli Q grade water was used for entrained study

Preparation of solutions**Buffer**

Transfer 1mL of orthophosphoric acid into a beaker containing 1000 ml water, add 1g of sodium dodecyl sulfate and dissolve. Filter the solution through 0.45µm membrane filter.

Mobile phase

Prepare a degassed mixture of buffer, Acetonitrile and methanol in the ratio of 60:28:12 % v/v/v.

0.01N HCl

Dilute 0.85 ml of HCl to 1000mL of water and mix.

Diluent

prepare a degassed mixture of 0.01N HCl and Acetonitrile in the ratio of 90:10%v/v

Determination of Related Compounds

Strict control of impurities is necessary for the manufacturing of drug products. These impurities may be present in the materials, formed as by-products during the process of production or appear as degradation products during storage. Both actual and potential impurities should be studied and detected by a reliable and convenient method. Metformin impurities Related compound A (RCA), Related compound B (RCB) and Related compound C (RCC) are chemically known as 1- Cyanoguanidine (RCA), 1- methyl biguanidine hydrochloride (RCB) and N, N dimethyl (1, 3, 5) triazine 2, 4, 6 triamine (RCC). The impurities of AGLT-BZ studied in this paper were named as compounds RC-01, RC-02 & RC-03.



**Radhakrishnaveni Vadlamudi****Preparation of Standard****Solution A**

Metformin: Accurately weigh and transfer about 40mg of Metformin Hydrochloride working standard into 100ml volumetric flask. Add about 60ml of diluent and sonicate to dissolve. Dilute to volume with diluent and mix.

Solution B

Alogliptin: Accurately weigh and transfer about 57mg of Alogliptin benzoate working standard into 100ml volumetric flask. Add about 60ml of diluent and sonicate to dissolve. Dilute to volume with diluent and mix.

Impurity stock solution was prepared by dissolving each 1mg of related compounds (A, B, C) in 100ml of diluents to obtain a solution having a concentration of each related compounds (0.5mg/ml). Resolution solution of Metformin HCL, Alogliptin Benzoate and its related compounds were prepared by adding 5ml of impurity stock solution in 20ml of diluents. Samples of formulated metformin HCL (tablet) were prepared by dissolving a quantity of tablet equivalent to metformin HCL and Alogliptin Benzoate in 100ml of diluents. A portion of sample solution was centrifuged at 3500rpm for 10 minutes. 5ml of supernatant liquid was transferred to 50 ml volumetric flask and add diluents up to the mark in order to detect impurities and degradants which may be present in the samples of Metformin HCL and Alogliptin Benzoate tablets.

CONCLUSION

Only 1 or 2 Related Compounds are determined in literature survey. There is no method to determine all Related Compounds of Metformin HCL and Alogliptin Benzoate. My method was good because All Related Compounds separated within 15 minutes. The RP-HPLC method was proved to be more sensitive, the validated parameters were found to be within the acceptance criteria and hence the developed methods were proved to be precise, accurate and robust. A simple, accurate and precision stability indicating HPLC analytical method was developed and validated for the analysis of Metformin HCL and Alogliptin Benzoate in tablet formulation.

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Conflict of interest

The authors declare that they have no conflict of interest.

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Table 1: Peak 1 Result:

S.No	Name	RT	AREA	% AREA	PURITY ANGLE	PURITY THRESHOLD	PURITY FLAG
1	MFN RC-A	1.31	8823	0.34			
2	SODIUM BENZOATE	4.66	164379	17.44			
3	MFN RC-C	5.17	25433	2.69			
4	METFORMIN	5.56	344675	36.50			
5	MFN RC-B	6.03	55636	5.90			
6	PEAK-5	6.33	7711	0.82			
7	ALO RC-03	7.34	38283	4.06	0.571	1.072	No
8	ALO RC-01	7.67	69216	7.34	1.336	1.316	Yes
9	ALO	10.50	229159	24.31	0.089	0.422	No
Sum			942615				

Table 2: Peak 2 Results

S.No	Name	RT	AREA	% AREA
1	MFN RC-A	2.79	10592	0.73
2	SODIUM BENZOATE	6.24	245443	17.03
3	MFN RC-C	6.68	39784	2.76
4	METFORMIN	6.81	523021	36.29
5	MFN RC-B	7.40	14619	1.01
6	PEAK-5	7.97	90538	6.28
7	ALO RC-03	9.53	59577	4.13
8	ALO RC-01	10.36	107433	7.45
9	ALO	11.61	350380	24.31
Sum			1441385	

Table 3: peak 2 results

S.No	Name	RT	AREA	% AREA
1	MFN RC-A	1.31	8823	0.34
2	SODIUM BENZOATE	4.66	164379	17.44
3	MFN RC-C	5.17	25433	2.69
4	METFORMIN	5.56	344675	36.50
5	MFN RC-B	6.03	55636	5.90
6	PEAK-5	6.33	7711	0.82
7	ALO RC-03	7.34	38283	4.06
8	ALO RC-01	7.67	69216	7.34
9	ALO	10.50	229159	24.31
Sum			942615	





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Table 4: peak 2 results

S.No	Name	RT	AREA	% AREA
1	MFN RC-A	3.10	21855	01.59
2	METFORMIN	5.79	506410	36.94
3	PEAK	6.41	232821	16.98
4	MFN RC-B	7.10		
5	MFN RC-C	7.63		
6	ALO RC-02	8.18	91341	6.66
7	ALO RC-03	9.71	61401	4.48
8	ALO RC-01	10.76	109259	7.97
9	ALO	11.71	229159	25.38
10	ALO RC-04	13.32		
Sum			1370993	

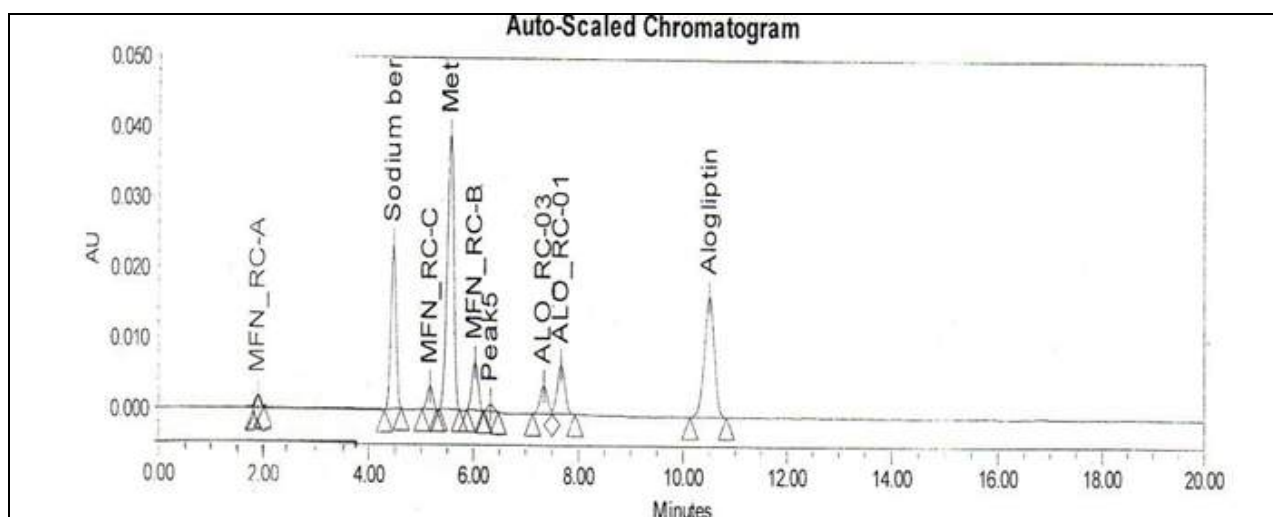


Fig 1: Peak 1

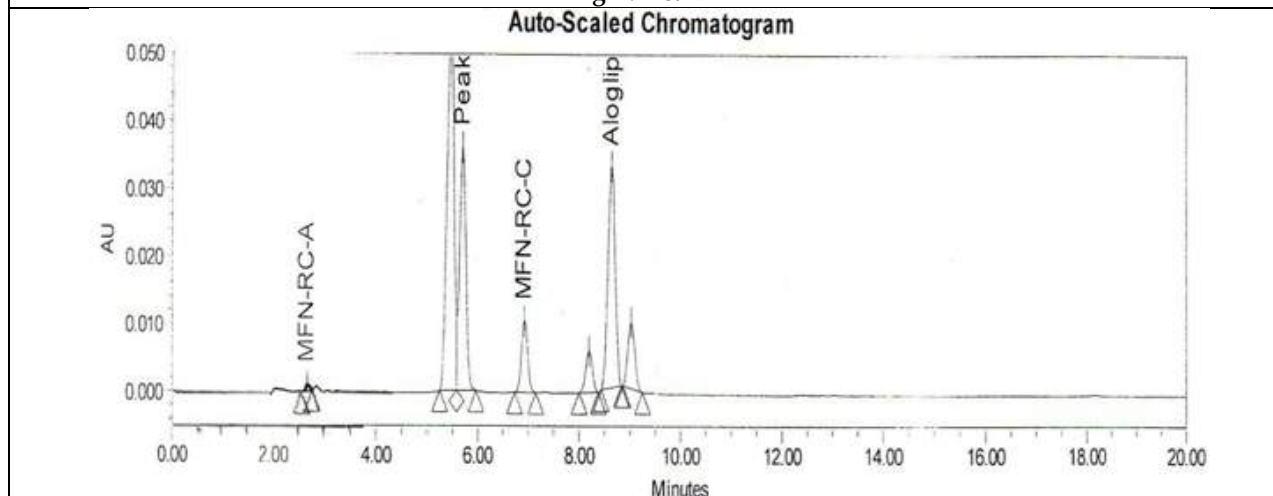
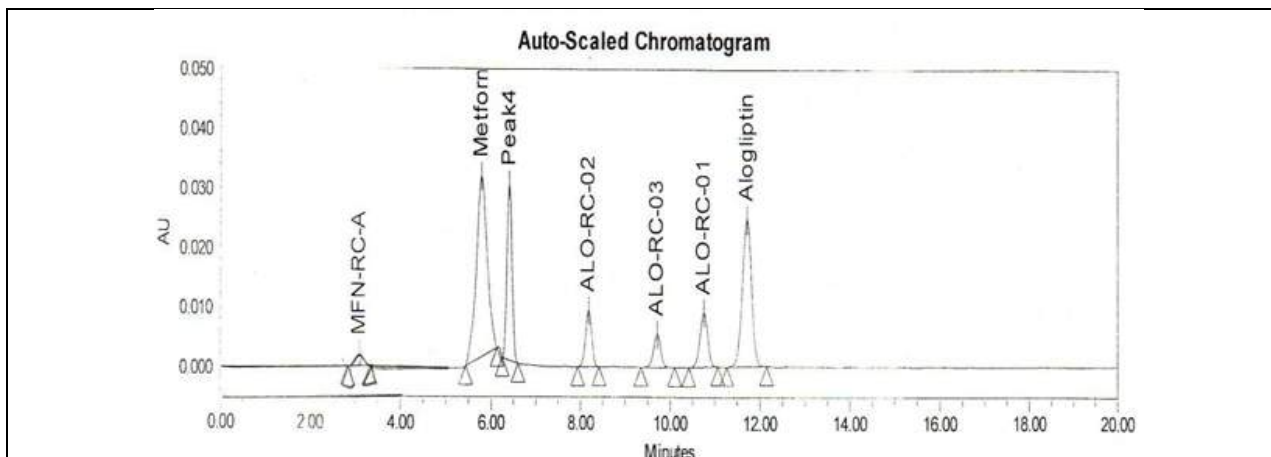
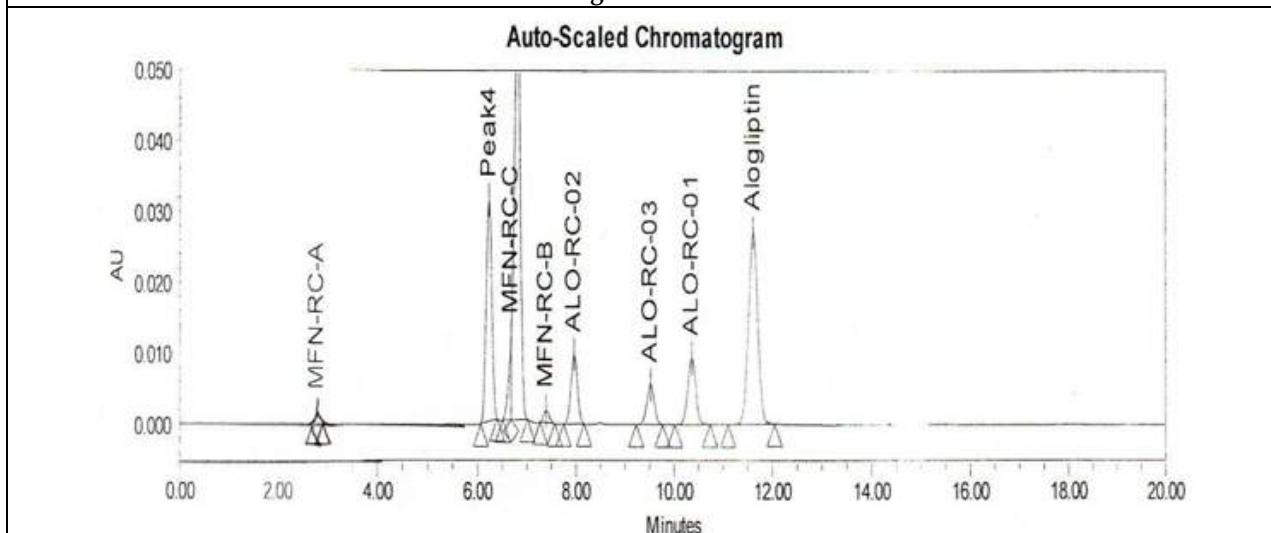


Fig 1: Peak 2



**Radhakrishnaveni Vadlamudi****Fig 1: Peak 3****Fig 1: Peak 4**

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RESEARCH ARTICLE

Fenugreek (*Trigonella foenum graecum*) in the Management of Polycystic Ovarian Syndrome: Nutritional, Biochemical and Therapeutic Perspectives

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ABSTRACT

Polycystic Ovarian Syndrome (PCOS) is a prevalent endocrine and metabolic disorder affecting women of reproductive age, characterized by hyperandrogenism, insulin resistance, and chronic anovulation. It is associated with multiple complications including infertility, obesity, type II diabetes, hormonal imbalance and cardiovascular disorders. Conventional management primarily involves lifestyle modification and pharmacological interventions; however, increasing attention has been directed towards functional foods and herbal therapies as alternative therapy. Fenugreek (*Trigonella foenum graecum*), a widely used medicinal plant, exhibits significant nutritional and therapeutic potential due to its rich composition of dietary fiber, steroidal saponins (diosgenin), alkaloids, and polyphenolic compounds. These bioactive compounds contribute to its hypoglycemic, hypolipidemic, immunomodulatory, and antioxidant properties. Diabetes, one of the most common concerns in PCOS, and Fenugreek aids in diabetes or insulin resistance by delaying carbohydrate absorption and enhancing insulin secretion as well as insulin sensitivity. Further, its effects on lipid metabolism and oxidative stress further support its role in managing associated metabolic disturbances. This review highlights the nutritional composition, biochemical properties, and therapeutic relevance of fenugreek in PCOS management, emphasizing its potential as a functional food and alternate therapy. Further clinical investigations are required to validate its efficacy and establish standardized therapeutic applications.

Keywords: Polycystic Ovarian Syndrome; PCOS; Fenugreek (*Trigonella foenum graecum*); Insulin Resistance; Hyperandrogenism; Functional food; Bioactive compounds; Hypoglycemic effect; Antioxidant activity; Nutritional therapy





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INTRODUCTION

As humans approach puberty, both sexes start producing sex hormones that differentiate them from one another. Females release Progesterone, Estrogen, Follicle Stimulating Hormone, Gonadotropin Releasing Hormone and Luteinizing Hormone. A small amount of male hormone is additionally present in females, called Androgen. When androgen levels in women rise to greater extents, it leads to PCOS, known as Polycystic Ovarian Syndrome [1]. The global prevalence of PCOS ranges between 2.2 to 26%, it is around 2 to 7.5% in Asia. In India, the PCOS affects around 9-22% of all women [2]. Signs and symptoms of PCOS include infertility, chronic anovulation, obesity, and insulin resistance. Common symptoms include hirsutism and acne. However, some cases may exhibit hypermenorrhea (prolonged, heavy menstrual periods) as well as alopecia (thinning or loss of hair) among other symptoms [3]. Nearly 80% of PCOS cases are found in women with obesity, the other 20% are lean, or non- obese women [4]. Diagnosis of PCOS comes with the increased risk of the associated conditions including insulin resistance and type II diabetes, endometrial cancer, depression and anxiety, high blood pressure, dyslipidemia, sleep apnea, patchy skin, fatty liver disease, strokes, miscarriage, and even weight gain [3]. A pelvic ultrasound is a major diagnostic tool for PCOS [5]. The management of PCOS includes changes in lifestyle along with medical treatment..

Fenugreek Seeds:

Botanical Description and Culinary Uses:

Fenugreek, scientifically named *Trigonella foenum graecum*, is a plant belonging to the family of Leguminosae, which is the most famous spice of human food. Fenugreek seeds and leaves are widely used in food and medicinal applications. Flavor and color are increased by adding the leaves and seeds of fenugreek, along with altering the texture of food materials. Seeds have medicinal properties like lactational aid, hypercholesterolemic, gastric stimulant, antibacterial, anti-anorexic, galactagogue and antidiabetic effects. These beneficial effects are due to intrinsic dietary fiber constituent that promises nutraceutical value [6]. Fenugreek is known largely for the taste of its slightly sweet and bitter seeds, which are available in any form, either whole or ground, used to flavor many foods, mostly curry powders, spices and teas. Fenugreek seeds have yellow and hard central embryo surrounded by corneous and comparative large layers of semi-transparent, white endosperm [7].

Chemical Composition and Bioactive Compounds

Diosgenin, present as 0.1-0.9% in fenugreek, is extracted from it commercially. As much as 2% diosgenin was found from plant tissue cultures of fenugreek when grown under optimal conditions. Smaller amounts of gitogenin and trigogenin were found too. Saponin fenugrin B was also found in the seeds. Fenugreek seeds are known to contain several coumarin compounds and numerous alkaloids, such as trigonelline, carpaine and gentianine. Trigonelline, present in large amounts, is degraded to nicotinic acid and pyridines during the process of roasting [8]. Fenugreek's chemical composition shows that the endosperm has the highest saponin (4.63g/100 g) and protein (43.8g/100 g). Husk, however, contains higher total polyphenols. The extracts of the husk and fenugreek seed at about a concentration of 200 mcg exhibited an antioxidant activity of 72%, 64% and 56% respectively, using the method of free radical scavenging [9]. Majority of the bioactive compounds in fenugreek seeds are polyphenols, like isovitexin and rhaponticin [10]. From studies, it was reported that fenugreek seeds are a rich source of protein and dietary fiber. About 4.8% of saponins are found in whole fenugreek seeds. Fenugreek seed saponins are steroidal, type furostanol saponins with diosgenin as the primary steroidal saponin. Alkaloids, including gentianine, trigonelline and carpaine compounds are found in fenugreek seeds. The seeds contain fenugreekine fiber that may have hypoglycaemic activity. Crude fibre is composed of cellulose, a complex carbohydrate made up of glucose molecules. Hemicellulose is related to cellulose, while pectin is a type of hemicellulose. Another form of crude fibre, lignin, is not a carbohydrate but is of plant origin and is indigestible as well. This arrests the rapid uptake of glucose in the small intestine and slows gastric emptying, which in turn retains blood sugar in diabetes patients and may be effective in the treatment of hypercholesterolemia [11]. High proportion of protein between 20 to 30% of amino acids, especially



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4-hydroxy isoleucine are found in fenugreek [12]. From another comparative study, fenugreek protein fraction is comparable with soybean protein because of its richness of lysine [13].

Metabolic and Nutritional Effects:

Glucose can be blunted by the consumption of dietary fiber after the meal and fenugreek does an excellent job at that. Mechanisms for these effects haven't thoroughly been explained. A 45.5% content of dietary fiber ensures that fenugreek works well in that aspect, with 32% insoluble and 13.3% soluble fibre; and the gum being composed of mannose and galactose. These latter compounds are responsible for the reduction in the glycemic effect. Hypoglycemic effect of fenugreek has been documented in animals as well as humans with type 1 and type 2 diabetes mellitus [14]. The digestion is delayed by soluble fibre of fenugreek and absorption of carbohydrate is delayed, which improves the homeostasis of glucose. Researchers accounted for this behavior to gel formation and low viscosity of the gels that result in the small intestine that delay gastric emptying and decrease the transit time of the food mass in the intestine [15]. From studies it has been observed that adding 100 g of fenugreek with 50% dietary fibre for 10 days decreased blood sugar levels among type II diabetes patients by 25% [16]. An investigation of the effects of fenugreek on blood lipids has been carried out too, using rats with diabetes. The rats were induced with streptozotocin and administered by oral intragastric intubation with low, middle and high doses of fenugreek extracts along with metformin HCl for six weeks. When compared to the diabetic rats control group, fenugreek treated rats showed lower levels of triglycerides and total cholesterol and higher levels of HDL cholesterol in a manner dependent on the dosage of the extract [17].

Antioxidant Activity:

Antioxidant activity is exhibited by fenugreek due to the presence of polyphenols and flavonoids [18]. They have also been reported to show protective effects against oxidation induced by hydrogen peroxide by protecting red blood cells from hemolysis and peroxidation of lipids [19]. Studies conducted suggested of fenugreek being powerful as an antioxidant with positive effects on the pancreas as well as liver [20]. It was reported that fenugreek seeds have a radical scavenging activity with ethanol, methanol, acetone, dichloromethane, hexane and ethyl acetate [21]. A positive effect of fenugreek on lipid peroxidation and enzymatic antioxidants [22]. Another report showed the proximate composition of fenugreek seeds having cotyledons and husk with the highest protein and saponin content. Husk contains higher content of total polyphenols [23]. At a concentration of 200 mcg, extracts of husk, seeds and endosperm of fenugreek showed 64%, 72% and 56% antioxidant activity by scavenging activity of free radicals [24].

Immunomodulatory Activity:

An agent by which the immune system or immune responses are diminished is called an immunomodulator, with its effect being known as immunomodulatory effect. Research has studied the immunomodulatory effect of fenugreek on stimulation as seen from relative thymus weight, body weight, quantitative hemolytic assay, hemagglutination titer, cellularity of lymphoid organs, phagocytosis, plaque forming cell assay, hypersensitivity response of late type, increase in phagocytic index and capacity and a lymph proliferation significantly. The research was conducted in aqueous extracts at three doses, namely 200, 100 and 50 mg per kg of body weight. They were done on albino mice's immune system for 10 days [13].

Functional Food Applications:

Fenugreek is also known well for its gum, fibre and other components of chemical importance as well as volatile components. The 25% constitution of dietary fiber in fenugreek seeds changes the texture of foods when used in ample quantity. Use of fenugreek is also done as a dietary stabilizer, emulsifier and adhesive due to the high gum, fibre and protein content. Protein found in fenugreek is considered alkaline and more soluble [13]. Fenugreek is used in many foods throughout different cuisines, especially those of Asian origin. It has established itself as a functional food in recent times due to the high fibre content. Fenugreek gum, a hydrocolloid, gives thickening, appeal, textural, stabilizing, emulsifying, encapsulating and gelling effect to the food item in which it is added. Soluble fiber can thus find its way into many products like nutritional beverages, yogurts, bars and dairy products. Soluble fibre powder





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can be used for mixing with seasonings, spice mixes and for juices. It can be used directly in the form of tablets along with other supplements which are needed. Milk shakes, dressings, candies, soups and sweets can also utilize the same. Fortification of pizza, cake mixes, flour, bagels, breads, muffins, tortilla and noodles is also done with fenugreek. Unwanted fat intake can also be taken care of using fenugreek extract by adding it to fried snacks. It decreases oil absorption by 8-15 % [25]. Urinary sugar and glycosylated Hb were reported to reduce by 13% and 12.2% in an examination of 40 patients after consumption of fenugreek seed for 8 weeks [26].

Traditional Therapeutic Uses:

Cleansing the blood and acting as a diaphoretic are other beneficial effects of fenugreek, which help to detoxify the body by sweating. The pungent aroma of fenugreek is smellable in the underarm and on skin perspiration. Lymphatic cleansing activities are also brought about by fenugreek, and it irrigates the cells with nutrients, removing toxic wastes, trapped proteins and dead cells in the process. Poor circulation of fluid, pain, fluid retention, disease and energy loss are also brought about by the blockages in the lymphatic system. Congestion in the lungs is also cleaned using fenugreek, which in turn helps in the maintenance of mucosal balance in the body. Fenugreek is used as a throat cleaner as well, as it eases the urge to cough. Consumption of water in which fenugreek seeds were soaked helps in dissolving and softening, accumulating and hardening the mass of dead cell's leftovers. Fenugreek is also used in relieving bronchial complaints, asthma, influenza, colds, constipation, catarrh, pleurisy, sinusitis, sore throat, pneumonia, hay fever, emphysema and laryngitis [27].

Fenugreek in PCOS Management:

It was indicated with the study that process viability advantage can be availed by separating fenugreek into seed, husk and endosperm with respect to the selective fractionation of bioactive compounds for the effective isolation of the same. Prophylaxis effect of fenugreek seeds on the renal stone formation was also studied in rats [24]. Calcic urolithiasis patients can be treated with the use of fenugreek also reported an anti-inflammatory potential [28]. Another investigation showed treatment by fenugreek as having inhibitory effect on the growth of breast, prostate and pancreatic cancer; however primary and immortalized cells remained unaffected. Trigonella inhibiting the cell growth in cancer is attributed to the ability to induce phagocytosis, i.e., the death of the cell, while promoting growth stimulating pathways in healthy cells [29]. Women with PCOS, obesity, lipid disorders and insulin resistance as well as infertility can be bettered with the use of fenugreek. Hyperinsulinemia can cause increase in abnormal androgen secretion and follicle development, which leads to dysfunctional ovarian cyclicity and menstrual cycle [30].

The first choice of treatment in such cases is metformin of reproductive disorders that stem from PCOS. It inhibits gluconeogenesis from the liver and has a direct effect on steroid production in the ovaries in granulosa cell structures [31]. Insulin resistance and ovarian hyperandrogenism in women with PCOS can be bettered with the use of metformin [32]. Glucose tolerance curve was significantly improved along with glucose induced insulin response using water extract of the fenugreek seed. According to a study, the hypoglycemic effect may be intermediated by stimulation of synthesis of insulin and secretion from beta cells [33]. From another study, similar results were found, where fenugreek seeds extract showed hypoglycemic effect by inhibition of sucrose, alpha-amylase and two other enzymes involved in metabolism of carbohydrates [34]. It also reduces insulin resistance [35]. From another study, the subgroup that had raised insulin showed less changes [36]. As opposed to the studies metformin was shown to reduce the markers of insulin resistance [37, 38].

CONCLUSION

PCOS (Polycystic Ovarian Syndrome) is an endocrine disorder characterized by hyperandrogenism, insulin resistance, and metabolic dysregulation, contributing to significant metabolic and reproductive complications. The growing prevalence of PCOS highlights the need for exploring therapeutic strategies apart from conventional interventions. Fenugreek (*Trigonella foenum graecum*) is one of the promising functional foods with substantial



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therapeutic and nutraceutical potential in the management of PCOS. The bioactive constituents of fenugreek, including steroidal saponins such as diosgenin, alkaloids like trigonelline, and polyphenolic compounds, contribute to its diverse therapeutic activities. High fibre content in fenugreek has a critical role in modulating glucose metabolism pathways by delaying carbohydrate absorption and enhancing insulin sensitivity. Additionally, fenugreek has hypoglycemic, hypolipidemic, immunomodulatory and antioxidant activity, which in turn has positive impact on metabolic disruptions caused because of PCOS. The hypoglycemic, and enhanced insulin sensitivity action attributed by fenugreek is considered comparable to metformin. Furthermore, its functional food applications enhance its feasibility as a potential dietary intervention agent. While traditional usage highlights its broader therapeutic relevance, modern scientific findings support its role in mitigating insulin resistance and hormonal imbalance in PCOS. Overall, fenugreek represents a viable adjunct in the dietary and therapeutic management of PCOS. However, further clinical studies are required to establish standardized dosages, long-term safety, and mechanistic pathways to fully validate its efficiency in clinical practice.

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RESEARCH ARTICLE

Nanotechnology in Periodontics: Current Advances, Clinical Applications and Future Perspectives

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ABSTRACT

Nanotechnology has emerged as a transformative domain in modern biomedical sciences, significantly influencing the diagnosis, prevention, and treatment of periodontal diseases. Periodontitis is a multifactorial chronic inflammatory disease characterized by progressive destruction of the supporting structures of teeth, driven by complex interactions between pathogenic biofilms and host immune responses. Conventional periodontal therapies, although effective in reducing microbial load, are often limited by inadequate drug delivery, inability to completely eradicate biofilms, and insufficient regenerative outcomes. Nanotechnology, defined as the manipulation of materials at the nanoscale (1–100 nm), provides unique physicochemical properties such as enhanced surface area, improved bioavailability, and superior cellular interaction, which can be harnessed for targeted periodontal therapy. Applications of nanotechnology in periodontics include nanoparticle-based drug delivery systems, antimicrobial nanomaterials, nanodiagnosics, and nanostructured scaffolds for tissue regeneration. These innovations enable site-specific drug delivery, sustained release kinetics, enhanced antimicrobial efficacy, and improved regenerative potential. Despite its promising benefits, challenges such as cytotoxicity, high production costs, and limited clinical validation persist. This review comprehensively discusses the role of nanotechnology in periodontics, emphasizing its applications, biological mechanisms, clinical relevance, and future prospects.

Keywords: nanomaterials, drug delivery systems, Periodontal regeneration, Nano dentistry.



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INTRODUCTION

Periodontal diseases represent one of the most prevalent chronic inflammatory conditions affecting humans and are a major cause of tooth loss worldwide. The disease process is initiated by the accumulation of microbial biofilms on tooth surfaces, which trigger a host-mediated inflammatory response leading to destruction of the periodontal ligament, alveolar bone, and cementum. The complexity of periodontal disease lies in its multifactorial etiology, involving microbial, environmental, genetic, and immunological factors. Although conventional treatment modalities such as scaling and root planing, systemic and local antimicrobial therapy, and surgical interventions are effective in controlling disease progression, they often fail to completely eliminate pathogenic biofilms or achieve predictable regeneration of lost tissues (1,2).

One of the major limitations of traditional periodontal therapy is the inability to deliver therapeutic agents at effective concentrations directly to the site of infection for prolonged periods. Additionally, biofilms exhibit significant resistance to antibiotics due to their structural complexity and protective extracellular matrix. These challenges necessitate the development of advanced therapeutic strategies that can overcome these limitations. Nanotechnology has emerged as a promising solution by enabling precise manipulation of materials at the molecular level, thereby enhancing their interaction with biological systems. The application of nanotechnology in periodontics, often termed nanoperiodontics, has opened new avenues for improving diagnostic accuracy, therapeutic efficacy, and regenerative outcomes (3,4).

Fundamentals of Nanotechnology and Its Biological Relevance

Nanotechnology involves the design, synthesis, and application of materials with dimensions in the range of 1 to 100 nanometers. At this scale, materials exhibit unique properties that differ significantly from their bulk counterparts, including increased surface area-to-volume ratio, enhanced chemical reactivity, and improved mechanical strength. These properties enable nanoparticles to interact with biological molecules such as proteins, nucleic acids, and cell membranes in a highly efficient manner. Nanomaterials used in periodontics can be broadly classified into organic and inorganic nanoparticles. Organic nanoparticles, such as polymeric nanoparticles, liposomes, dendrimers, and nanogels, are widely used for drug delivery due to their biocompatibility and ability to encapsulate therapeutic agents. In contrast, inorganic nanoparticles, including silver, gold, zinc oxide, and titanium dioxide nanoparticles, exhibit strong antimicrobial and anti-inflammatory properties. The ability of these nanomaterials to penetrate biological barriers and deliver therapeutic agents in a controlled manner makes them highly suitable for periodontal applications (5,6).

Role of Nanotechnology in Periodontal Pathogenesis and Therapy

The pathogenesis of periodontal disease involves the formation of complex biofilms composed of diverse microbial communities embedded within an extracellular polymeric matrix. This matrix acts as a barrier, preventing the penetration of antimicrobial agents and protecting bacteria from host immune responses. Nanoparticles can overcome these barriers due to their small size and high surface reactivity, enabling them to penetrate biofilms and exert antimicrobial effects directly at the site of infection. In addition to their antimicrobial properties, nanoparticles can modulate host immune responses by reducing inflammation and promoting tissue healing. For instance, certain nanoparticles have been shown to inhibit the production of pro-inflammatory cytokines and enhance the activity of anti-inflammatory mediators. This dual action of antimicrobial and immunomodulatory effects makes nanotechnology a powerful tool in periodontal therapy (7,8).

Nanoparticle-Based Drug Delivery Systems in Periodontics

One of the most significant advancements in nanotechnology is the development of nanoparticle-based drug delivery systems. These systems are designed to deliver therapeutic agents directly to the periodontal pocket, ensuring high



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local concentrations and sustained release over extended periods. This targeted approach minimizes systemic side effects and improves treatment efficacy. Polymeric nanoparticles are among the most commonly used drug delivery systems due to their biodegradability and ability to provide controlled drug release. Liposomes, which are phospholipid vesicles, can encapsulate both hydrophilic and hydrophobic drugs, enhancing their stability and bioavailability. Dendrimers, with their highly branched structure, offer multiple binding sites for drug molecules, allowing for high drug-loading capacity. Nanogels, which are hydrogel-based nanoparticles, provide a three-dimensional network for drug encapsulation and controlled release (9,10). Clinical studies have demonstrated that nanoparticle-based delivery systems significantly enhance the efficacy of antimicrobial agents such as doxycycline and chlorhexidine in the treatment of periodontal diseases. These systems not only improve drug penetration into biofilms but also maintain therapeutic concentrations for longer durations, reducing the frequency of administration (11,12).

Antimicrobial Applications of Nanotechnology

Nanoparticles possess intrinsic antimicrobial properties that make them highly effective against periodontal pathogens. Silver nanoparticles are the most extensively studied due to their broad-spectrum antimicrobial activity. They exert their effects by disrupting bacterial cell membranes, generating reactive oxygen species, and interfering with DNA replication. Similarly, zinc oxide nanoparticles and titanium dioxide nanoparticles have been shown to exhibit strong antibacterial and anti-inflammatory properties. The use of nanoparticles in periodontal therapy offers several advantages over conventional antibiotics, including reduced risk of resistance, enhanced biofilm penetration, and sustained antimicrobial activity. Furthermore, nanoparticles can be incorporated into various dental materials, such as gels, mouthwashes, and implant coatings, to provide long-term antimicrobial protection (13,14).

Nanodiagnostics in Periodontal Disease

Early detection of periodontal disease is essential for preventing disease progression and improving treatment outcomes. Nanotechnology has facilitated the development of advanced diagnostic tools capable of detecting disease biomarkers with high sensitivity and specificity. Nanosensors, quantum dots, and lab-on-a-chip devices are among the most promising technologies in this field. These diagnostic tools can detect specific biomarkers in saliva and gingival crevicular fluid, such as inflammatory cytokines, enzymes, and microbial components. The use of nanodiagnostics allows for real-time monitoring of disease progression and response to therapy, enabling personalized treatment approaches. This represents a significant advancement over traditional diagnostic methods, which are often limited by low sensitivity and delayed detection (15,16).

Nanotechnology in Periodontal Regeneration

Regeneration of periodontal tissues remains a major challenge in clinical practice. Nanotechnology offers innovative solutions by providing nanostructured scaffolds that mimic the natural extracellular matrix. These scaffolds support cell adhesion, proliferation, and differentiation, thereby promoting tissue regeneration. Nanofibers, hydrogels, and nanocomposites are commonly used as scaffolds in periodontal tissue engineering. These materials can be combined with growth factors and stem cells to enhance their regenerative potential. Studies have shown that nanostructured scaffolds significantly improve bone regeneration and periodontal tissue repair, making them a promising approach for achieving predictable clinical outcomes (17,18).

Nanotechnology in Implant Dentistry

Nanotechnology has significantly improved the success of dental implants by enhancing their surface properties. Nanostructured implant surfaces promote better osseointegration by increasing surface roughness and surface energy, which facilitate protein adsorption and cell adhesion. Additionally, the incorporation of antimicrobial nanoparticles into implant surfaces reduces the risk of peri-implant infections, thereby improving long-term implant success (19,20).





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DISCUSSION

Nanotechnology has emerged as a transformative approach in periodontics, addressing several limitations associated with conventional therapeutic modalities. The complex pathogenesis of periodontal disease, which involves intricate interactions between pathogenic biofilms and host immune responses, necessitates advanced strategies that go beyond mechanical debridement and systemic drug administration. Traditional periodontal therapies often fail to achieve complete eradication of biofilms due to their structural complexity and resistance mechanisms. In this context, nanotechnology offers a promising solution by enabling targeted drug delivery, improved antimicrobial efficacy, and enhanced regenerative potential. The nanoscale size of particles allows for deeper penetration into periodontal pockets and biofilm matrices, thereby increasing the effectiveness of therapeutic agents and improving clinical outcomes (1,5).

One of the most significant contributions of nanotechnology to periodontics lies in the development of nanoparticle-based drug delivery systems. These systems have demonstrated the ability to deliver drugs in a controlled and sustained manner directly to the site of infection, thereby maintaining therapeutic concentrations for extended periods. This localized delivery not only enhances drug efficacy but also minimizes systemic side effects, which are commonly associated with conventional antibiotic therapy. Studies have shown that nanoparticle-based formulations of antimicrobial agents such as doxycycline and chlorhexidine exhibit superior efficacy in reducing periodontal pathogens compared to their conventional counterparts (6,11). Furthermore, the use of biodegradable and biocompatible nanocarriers, such as polymeric nanoparticles and liposomes, has improved the safety profile of these delivery systems, making them suitable for clinical application.

In addition to drug delivery, the intrinsic antimicrobial properties of certain nanoparticles have been extensively explored for periodontal therapy. Silver nanoparticles, for instance, have demonstrated broad-spectrum antibacterial activity against key periodontal pathogens through mechanisms such as disruption of bacterial cell membranes, generation of reactive oxygen species, and interference with DNA replication (13). Similarly, zinc oxide and titanium dioxide nanoparticles have shown promising antibacterial and anti-inflammatory properties. These nanoparticles are particularly effective in disrupting biofilms, which are known to be highly resistant to conventional antimicrobial agents. By targeting both planktonic bacteria and biofilm-associated microorganisms, nanomaterials offer a more comprehensive approach to infection control in periodontics (5,14).

Another important application of nanotechnology in periodontics is in the field of diagnostics. Early detection of periodontal disease is critical for preventing disease progression and improving treatment outcomes. Nanodiagnostic tools, such as nanosensors and lab-on-a-chip devices, have enabled the detection of disease biomarkers with high sensitivity and specificity. These technologies allow for the identification of inflammatory mediators, enzymes, and microbial components in saliva and gingival crevicular fluid, facilitating early diagnosis and real-time monitoring of disease progression (7,16). Compared to traditional diagnostic methods, which are often limited by low sensitivity and delayed detection, nanodiagnostics provide a more accurate and efficient means of disease assessment, thereby supporting personalized treatment approaches. The role of nanotechnology in periodontal regeneration represents another significant advancement in the field. Regeneration of periodontal tissues, including alveolar bone, periodontal ligament, and cementum, remains a major clinical challenge. Nanostructured scaffolds, such as nanofibers and nanocomposites, have been designed to mimic the natural extracellular matrix, thereby providing a conducive environment for cell attachment, proliferation, and differentiation. These scaffolds can be combined with growth factors and stem cells to further enhance their regenerative potential. Studies have demonstrated that nanostructured biomaterials significantly improve bone regeneration and periodontal tissue repair, highlighting their potential in achieving predictable regenerative outcomes (17,18).

Despite these promising advancements, the clinical translation of nanotechnology in periodontics is not without challenges. One of the major concerns is the potential cytotoxicity associated with certain nanoparticles, particularly





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when used in high concentrations or for prolonged periods. The interaction of nanoparticles with biological systems can lead to unintended effects, such as oxidative stress and inflammatory responses, which may compromise tissue health. Therefore, thorough evaluation of the biocompatibility and safety of nanomaterials is essential before their widespread clinical application. Additionally, the high cost of nanotechnology-based materials and the complexity of their manufacturing processes pose significant barriers to their adoption in routine clinical practice (21,22).

Another limitation is the lack of long-term clinical studies evaluating the efficacy and safety of nanotechnology-based therapies in periodontics. While numerous in vitro and animal studies have demonstrated promising results, there is a need for well-designed randomized controlled trials to validate these findings in human populations. Furthermore, regulatory and ethical considerations must be addressed to ensure the safe and effective use of nanotechnology in dentistry. The development of standardized guidelines for the evaluation and approval of nanomaterials is crucial for facilitating their integration into clinical practice (23).

Future research in nanoperiodontics should focus on the development of smart and multifunctional nanocarriers capable of simultaneous diagnosis and therapy, a concept known as nanotheranostics. These advanced systems have the potential to revolutionize periodontal treatment by enabling real-time monitoring of disease and targeted delivery of therapeutic agents. Additionally, the integration of nanotechnology with other emerging fields, such as artificial intelligence and regenerative medicine, may further enhance the precision and effectiveness of periodontal therapy. With continued advancements and rigorous clinical validation, nanotechnology is expected to play a pivotal role in shaping the future of periodontics (24).

CONCLUSION

Nanotechnology has revolutionized the field of periodontics by introducing advanced diagnostic, therapeutic, and regenerative strategies. Its ability to provide targeted drug delivery, enhanced antimicrobial action, and improved tissue regeneration offers significant advantages over conventional approaches. Although challenges remain, ongoing research and technological advancements are expected to further expand the clinical applications of nanotechnology in periodontics. With continued development and validation, nanotechnology holds immense potential to transform periodontal therapy into a more precise, effective, and patient-centered discipline.

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RESEARCH ARTICLE

Structural Discrimination and Mental Health among Migrant and Native Workers in Kerala's Informal Labour Sectors

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ABSTRACT

Discrimination in informal labor markets is a considerable yet underexplored socioeconomic determinant of mental health, particularly in contexts characterized by employment insecurity and weak institutional protections. This study examines the forms, dimensions, and psychological effects of claimed discrimination among migrant and indigenous laborers in the construction and plantation sectors in Idukki District, Kerala. Utilizing a cross-sectional quantitative approach, primary data were collected from 225 informal laborers through standardized questionnaires administered by interviewers. Standardized instruments were utilized to assess perceived discrimination, melancholy, anxiety, stress, self-esteem, psychological well-being, coping strategies, and awareness and utilization of welfare services. Descriptive statistics, Mann-Whitney U tests, Spearman correlation analysis, and exploratory factor analysis were employed to examine the data. The findings indicate that prejudice is multifaceted, impacting employment, social interactions, and access to resources. Migrant workers encounter much higher levels of social and interpersonal bias and exhibit poorer psychological outcomes compared to native workers. Perceived discrimination is positively associated with depression, worry, and tension, but negatively associated with self-esteem and psychological well-being. Despite the frequent documentation of adaptive coping methods such as acceptance and positive reframing, the use of support systems remains limited, particularly among migrant workers. This study improves understanding of how discrimination and migration status affect mental health outcomes by comparing migrant and native informal workers within a single regional labor market. It emphasizes the need for integrated labor, welfare, and psychosocial policy measures in informal employment settings.

Keywords: Discrimination; Migrants; Natives; Informal Employment; Psychological Well-Being; Coping Strategies; Kerala



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INTRODUCTION

Informal work and internal migration have become key components of contemporary labor markets in emerging countries, particularly in India. A significant proportion of individuals in India are employed in the informal sector, characterized by precarious employment, absence of written contracts, restricted access to social security, and inadequate legal protections (National Commission for Enterprises in the Unorganized Sector [NCEUS], 2009; International Labor Organization [ILO], 2023). Informal employment is particularly prevalent in labor-intensive sectors like as construction and agriculture, which depend on manual labor and consistently employ both local and migrant workers. Although these firms are crucial for economic growth and regional development, their workforce remains structurally vulnerable. Kerala possesses a distinctive labor market characterized by an aging population, an increase in individuals attaining higher education, and a declining willingness among local workers to engage in physically strenuous and low-wage manual jobs. India's dependence on labor from adjacent states has increased owing to structural transformations, particularly in the construction and plantation sectors (ILO, 2021; Ministry of Labour and Employment, 2022). A considerable percentage of local workers participates in these firms under informal and precarious conditions marked by employment instability, income fluctuation, and inadequate social protection (Kannan, 2021; Kannan & Papola, 2007). Migrant and native workers both encounter vulnerabilities associated with informality; yet, their labor market experiences are shaped by distinct and intersecting social contexts.

Growing evidence indicates that informal labor markets serve not just as venues for transactions but also as arenas where social inequities and power dynamics persist (Chen & Carré, 2020). Discrimination in informal employment emerges in multiple dimensions, including remuneration, task allocation, work conditions, interpersonal dynamics, and access to social programs and public services. Migrant workers are particularly susceptible to bias concerning language, origin, ethnicity, and cultural identity, often resulting in social marginalization and restricted access to institutional assistance (Srivastava, 2020). Indigenous informal laborers, despite their local integration, face discriminatory practices arising from class hierarchies, contractual instability, and unequal power dynamics between employers and employees (Harriss-White, 2014). Discrimination in informal work sectors is deeply entrenched in socioeconomic disparities. Harriss-White and Gooptu (2021) assert that informality intensifies labor fragmentation, leading to specific vulnerabilities based on worker origin, job role, and industry. Migrant workers frequently occupy the lowest tiers in occupational hierarchies, rendering them more susceptible to exploitative practices and systemic discrimination (Srivastava, 2020). These structural disadvantages are linked to industry-specific traits, especially in the construction and plantation sectors, where labor practices are markedly informal and regulatory oversight is inadequate.

Discrimination is increasingly acknowledged as a crucial social determinant of health within social science and public health domains. A substantial body of empirical research demonstrates that experiences of discrimination are associated with adverse mental health outcomes, including heightened stress, anxiety, depression, and diminished psychological well-being (Kessler et al., 1999; Williams & Mohammed, 2009; Williams et al., 2019). Discrimination functions as a continual stressor that undermines self-esteem, obstructs coping strategies, and results in lasting psychosocial distress. Prejudice exacerbates mental health issues for migrant workers by imposing additional stresses related to cultural adaptation, linguistic barriers, disrupted social networks, and unfamiliarity with institutional frameworks (Berry, 1997; Bhugra et al., 2021). Empirical research demonstrates that migratory workers frequently encounter barriers to healthcare services, social programs, and grievance resolution mechanisms, hence exacerbating psychological vulnerability (ILO, 2023). Indigenous informal workers, despite their understanding of local social and institutional frameworks, experience significant psychosocial distress due to persistent employment instability, income variability, and perceived marginalization within informal labor markets (Benach et al., 2014; Benach et al., 2021). Standing (2021) defines these workers as part of the "precariat," whose daily existence is marked by uncertainty, absence of autonomy, and ongoing psychological suffering. A recent study highlights the importance of coping strategies and institutional support in shaping employees' reactions to prejudice. Adaptive coping strategies,



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such as problem-focused and emotion-focused methods, can mitigate the negative mental health effects of discrimination, but avoidance-oriented coping is often associated with poorer psychological outcomes (Benach et al., 2021). The ability of employees to manage is closely linked to the support provided by social networks and welfare agencies. Despite the existence of legislation designed to assist informal and migrant workers, many are unaware of or do not utilize social services. This is particularly applicable to migrant workers, who encounter difficulties with documentation, complex regulations, and insufficient information (ILO, 2021; Ministry of Labour and Employment, 2022).

This study employs a cross-sectional quantitative technique to examine the dynamics of discrimination in informal labor markets and its effects on the psychological well-being of workers in the construction and plantation sectors of Idukki District, Kerala. It outlines the primary aspects of felt discrimination and assesses whether their prevalence and severity differ between migrant and native workers in the same labor market context. The study also explores the relationships between discrimination and psychological outcomes, including depression, anxiety, stress, self-esteem, and psychological well-being, while also analyzing differences based on migratory status. It examines how individuals confront discrimination and their awareness and utilization of help programs. The study aims to formulate policies and psychosocial interventions for informal workplaces by integrating perspectives from labor and public health.

MATERIALS AND METHODS

Study Design and Setting

This study employed a quantitative, cross-sectional descriptive approach to examine reported discrimination, psychological effects, coping strategies, and access to welfare among informal workers in the construction and plantation industries in Idukki District, Kerala. The district is a labor-intensive region that depends significantly on migrant workers from other states and local informal laborers. This renders it an advantageous location for comparative analysis.

Sample and Sampling Procedure

A total of 225 informal workers participated in the study, including both migrant and native workers from construction sites and plantations. Participants were recruited using convenience sampling, an approach frequently utilized in informal labor research owing to the lack of formal worker registries, significant workforce mobility, and limited employer access (Benach et al., 2016; Chen et al., 2020). To mitigate selection bias, data were collected from many worksites and plantations, with recruitment conducted at various times throughout the day. Eligibility criteria comprised: (i) informal employment within the construction or plantation sectors, and (ii) a minimum of six consecutive months of work experience at the current location, guaranteeing enough exposure to workplace and social contexts. The non-probability sampling method limits generalizability at the population level; yet, it is appropriate for exploratory and analytical research focused on hard-to-reach and structurally vulnerable populations.

Data Collection and Instruments

Structured interviewer-administered schedules were employed to collect data, enabling participation from those with low reading levels. The survey employed the following standardized instruments: the 20-item Discrimination Scale to assess discrimination in occupational, social, and service contexts; the Depression, Anxiety, and Stress Scale (DASS-21); the Rosenberg Self-Esteem Scale; the Psychological Well-Being Scale; and the Brief COPE Inventory to evaluate problem-focused, emotion-focused, and avoidance coping strategies. All instruments demonstrated satisfactory internal consistency, with Cronbach's alpha coefficients ranging from 0.84 to 0.89.



**Jince George and Sheeja B Karalam****Statistical Analysis**

We utilized SPSS version 29 to analyze the data. Descriptive statistics encompassed demographic and occupational characteristics. Due to the non-normality of data distributions, Mann–Whitney U tests were employed to compare groups of migrant and native workers. The Spearman correlation study examined the associations between discrimination and psychological consequences. We employed exploratory factor analysis (EFA) with varimax rotation to identify the fundamental dimensions of discrimination and strategies for addressing it. The criterion for statistical significance was set at $p < 0.05$.

Ethical Considerations

Prior to data collection, ethical approval was obtained. Participation was voluntary, informed consent was secured from all participants, and confidentiality and anonymity were strictly maintained throughout the study.

RESULTS

The study comprised 225 informal workers, of whom 56% were migrant workers and 44% were native workers. Construction workers constituted 49.8% of the sample ($n = 112$), while plantation workers comprised 50.2% ($n = 113$). A majority of participants (73.3%) were aged between 26 and 55, and 93.8% reported having ceased their education. All respondents have been employed in their current field for a minimum of six consecutive months. Migrant workers had significantly higher levels of depression ($M = 18.32$) compared to native workers ($M = 14.21$). Migrant workers exhibited elevated anxiety ratings ($M = 12.45$) compared to native workers ($M = 10.16$) and experienced higher stress levels ($M = 20.18$) than native workers ($M = 15.67$). Migrant workers had significantly lower self-esteem ($M = 19.27$) compared to native workers ($M = 22.44$). Migrant workers ($M = 52.11$) exhibited inferior psychological well-being scores compared to native workers ($M = 61.34$). The Mann–Whitney U tests indicated that the group differences were statistically significant across all psychological variables ($p < 0.01$), hence affirming the poorer mental health outcomes among migrant workers. Descriptive statistics revealed that workplace discrimination was the most often reported form, with 44.9% of respondents indicating restricted leave access, 38.2% reporting limited salary progression, and 26.7% noting inequitable compensation for equivalent labor. Migrant workers indicated markedly elevated occurrences of social discrimination markers, such as disrespect, incivility, and adverse stereotyping. The Mann–Whitney U analysis indicated statistically significant differences in social and interpersonal discrimination indicators between migrant and native workers ($p < 0.01$); however, the differences in workplace discrimination were not statistically significant.

Exploratory factor analysis utilizing varimax rotation revealed three factors with eigenvalues greater than 1.0. Collectively, these elements constituted 72.81% of the overall variance. Discrimination at work accounted for 41.28% of the variance, prejudice based on social standing contributed 19.46%, and discrimination based on service represented 12.07%. All maintained items exhibited a loading exceeding 0.60, indicating robust construct validity. Spearman correlation analysis revealed statistically significant positive associations between perceived discrimination and adverse psychological impacts. Discrimination had a positive connection with depression ($r > 0.40$, $p < 0.01$), anxiety ($r > 0.35$, $p < 0.01$), and stress ($r > 0.45$, $p < 0.01$). Negative correlations were seen between discrimination and self-esteem ($r < -0.30$, $p < 0.01$) as well as between discrimination and psychological well-being ($r < -0.40$, $p < 0.01$). A partial correlation analysis, controlling for age, sector, and education level, confirmed the statistical significance of these correlations, indicating that perceived prejudice independently predicts psychological discomfort. A descriptive analysis of the Brief COPE Inventory indicated a notable prevalence of adaptive coping strategies. The predominant strategies employed were acceptance (72.1%), positive reframing (64.4%), and religious coping (58.7%). Substance use was minimal, at 4.3%. A limited number of respondents indicated the use of avoidance-based coping strategies, and no statistically significant differences were observed between migrant and native workers. Although 58.2% of respondents expressed awareness of welfare services, only 23.5% reported actual



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utilization. Migrant workers exhibited significantly lower usage rates than native workers ($p < 0.05$), primarily due to documentation issues and administrative constraints.

DISCUSSION

The research examined discrimination, psychological impacts, and coping strategies among migrant and native laborers in the construction and plantation sectors in Idukki District, Kerala. The findings highlight the existence and intricacy of bias, its psychological impacts, and the coping strategies employed by employees, thereby corroborating and enhancing prior research. The demographic characteristics of respondents reflect the structural features of informal labor markets in Kerala, where physically strenuous and low-paying positions are increasingly filled by migrant workers. The density of workers within the economically productive age bracket (26–55 years) and the exceedingly low levels of formal education indicate restricted occupational mobility and reduced bargaining power. Prior research consistently identifies inadequate educational attainment and informal employment as primary factors contributing to job precarity, poor working conditions, and heightened susceptibility to exploitation (Benach et al., 2016; Quinlan et al., 2019). The excessive representation of migrant workers in the sample highlights Kerala's growing dependence on inter-state labor, a trend intensified in the post-pandemic period and associated with increased livelihood insecurity and social vulnerability (Bhagat et al., 2020).

Forms and Dimensions of Discrimination

The prevalence of discriminatory behaviors indicates that discrimination in informal labor markets is mostly structural and institutional, rather than occasional or incidental. Restricted leave access, limited salary advancement, and unequal compensation for identical work illustrate structural inequities present in employment relations. These trends correspond with conceptual frameworks that view prejudice as a systemic issue arising from organizational regulations, power disparities, and policy inadequacies (Krieger, 2014). Moreover, service-related discrimination, particularly exclusion from welfare programs, demonstrates that inequality extends beyond the workplace into governmental and administrative systems, maintaining cumulative disadvantage across several facets of workers' lives (Marmot et al., 2020). The very high discrimination ratings among migrant workers highlight migratory status as a vital factor of stratification in informal labor markets.

The increased exposure of migrants to social and interpersonal prejudice demonstrates that adversity includes not only material deprivation but also symbolic devaluation and habitual exclusion. These findings align with acculturation theory, which posits that migrants experience heightened stress when integration is obstructed by language, cultural, and institutional barriers (Berry, 1997). Empirical evidence indicates that perceived discrimination is more common among migrant groups and is significantly associated with diminished well-being (Jasinskaja-Lahti et al., 2006; Schmitt et al., 2014). The exploratory factor analysis empirically validates the conception of discrimination as a multidimensional phenomena that includes workplace, social, and service-related dimensions. The frequency of workplace discrimination in explaining variance underscores the critical significance of job contacts in shaping inequality within informal labor markets. Nevertheless, the emergence of social and service-related factors confirms that discrimination is sustained in several social contexts. This multifaceted paradigm aligns with life-course and ecosocial perspectives, emphasizing the accumulation and interplay of social inequalities across institutional, interpersonal, and structural domains in shaping health outcomes (Gee et al., 2009; Krieger, 2014).

Discrimination and Psychological Outcomes

The relationship between perceived discrimination and adverse psychological effects strongly suggests that discrimination functions as a chronic psychosocial stressor. Positive associations with depression, anxiety, and stress, alongside negative correlations with self-esteem and psychological well-being, correspond with the stress and coping framework, which asserts that persistent social stressors are pivotal factors influencing mental health (Lazarus & Folkman, 1984). The buffering theory asserts that, without adequate social and institutional support, such stresses



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exert direct psychological pressure (Cohen & Wills, 1985). Meta-analytic and longitudinal studies corroborate these findings, demonstrating significant correlations between bias and mental health across diverse populations (Pascoe & Smart Richman, 2009; Schunck et al., 2015). The significant negative psychological impacts encountered by migrant workers indicate a compounded vulnerability arising from the intersection of migration-related stress, job insecurity, and prejudice. Elevated levels of depression, anxiety, and stress among migrants correspond with systematic reviews and empirical studies that demonstrate impaired mental health among migrant workers facing discrimination and unstable employment situations (Chen et al., 2020; Li et al., 2022). Decreased self-esteem and psychological well-being signify the internalization of discriminatory experiences, a phenomena thoroughly established in studies on perceived discrimination and identity threat (Williams & Mohammed, 2009; Schmitt et al., 2014).

Coping Strategies

The widespread use of adaptive coping strategies—such as acceptance, positive reframing, and religious coping—exemplifies resilience among informal workers despite enduring hardship. These strategies align with meaning-making and emotion-focused coping frameworks, which have been effective in reducing distress in situations marked by limited material resources (Park et al., 2020). However, the presence of avoidance-oriented coping among a certain cohort of employees is noteworthy, as avoidance has been linked to detrimental long-term psychological effects when stressors remain unresolved (Thoits, 2011). This suggests that personal coping skills may be insufficient without supportive systemic environments.

Welfare Awareness and Utilization

The considerable gap between awareness and utilization of welfare programs highlights institutional limitations that reduce the effectiveness of social protection initiatives. The significantly low use rates among migrant workers suggest problems with documentation, administrative complexities, and inadequate support, a trend also observed in studies regarding refugee and migrant access to social services (Hynie, 2018). From a stress-buffering perspective, insufficient institutional support may intensify the psychological impacts of discrimination by depriving employees of vital external coping mechanisms (Cohen & Wills, 1985; Marmot et al., 2020).

CONCLUSION

This study demonstrates that discrimination in labor-intensive informal sectors in Idukki District is a complex and systemic problem, stemming from workplace disparities and intensified by pervasive social and institutional exclusion, particularly impacting migrant workers. The findings provide strong evidence that perceived discrimination acts as a chronic psychosocial stressor, significantly impairing mental health by intensifying melancholy, anxiety, and stress, while diminishing self-esteem and psychological well-being. Migrant workers have a compounded disadvantage stemming from their migrant status, employment instability, and limited access to institutional support. Although many workers exhibit resilience through adaptive coping strategies, the persistent limitations on welfare access substantially reduce their protective effectiveness. This study advances existing literature by juxtaposing migrant and native informal workers within a unified regional labor market, elucidating the mechanisms via which bias is sustained throughout occupational, social, and service-related contexts. The findings underscore the necessity for integrated solutions, including improved labor laws, optimized welfare delivery systems, and the integration of mental health services into support structures for informal workers. Future longitudinal studies are crucial for identifying causal pathways and evaluating the effectiveness of policies and psychosocial therapies aimed at reducing discrimination and improving worker well-being in informal labor markets.





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RESEARCH ARTICLE

Adoption Level of Grapevine Cultivation Practices Among the Farmers of Dindigul District of Tamil Nadu

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ABSTRACT

The study was conducted in Athoor block of Dindigul district of Tamil Nadu to study the adoption level of grapevine growers on recommended grapevine cultivation practices. A sample size of 120 farmers was selected based on proportionate random sampling procedure. The study revealed that majority of the respondents (50.84 per cent) had high level of adoption about recommended grapevine cultivation practices whereas, low level of adoption was observed on fertilizer application (52.00 per cent). The correlation analysis showed that the adoption level of grapevine growers was positively influenced by the characteristics namely educational status, experience in grapevine cultivation, extension agency contact, training undergone and market perception.

Keywords: Adoption level, Grapevine growers, Grapevine cultivation, Practices.

INTRODUCTION

Grape (*Vitis vinifera* L.) is one of the finest and the healthiest fruit. It is one of the most important subtropical fruit crops. The crop has wide adaptability and it has been taken up under a wide range of soil types. Grapes can be eaten raw which are primary source of red and white wine. Table grapes, Raisin grapes, Wine grapes are the three categories of grapes. They were also used for the preparation of grape jelly, grape seed extract, jam, grape seed oil, vinegar and bread spread. There are no reliable statistics that break down grape production by variety. It is believed that the most widely planted variety is Sultana, also known as Thompson Seedless, with at least 3,600 km² (880,000 acres) dedicated to it. The second most common variety is Airen. Other popular varieties include Cabernet Sauvignon, Sauvignon blanc, Cabernet Franc, Merlot, Grenache, Tempranillo, Riesling, and Chardonnay.



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(www.fao.org – 2019). Grapes are one of the oldest utilized fruit crops in India. In India, among growing commercial fruit crops grapes are most important. It occupies 1.14 percent of the total area of cultivation with 2.56 percent of the total production of fruits. India's share in the global production of grapes is 2.80 percent. In Tamil Nadu, Pacha-drakshai (Thompson Seedless) is the earliest variety to be grown and occupies the leading position due to its unfailing yields season after season, the adaptability to the region and the easy marketability. Hence an attempt was made to study the adoption level of grapevine growers with the following objectives.

- To findout the adoption level of grapevine growers on recommended grapevine cultivation.
- To study the relationship of socio-personal and psychological characteristics of respondents with their adoption level.

MATERIALS AND METHODS

This study was conducted in Dindigul district of Tamil Nadu. Ex-post facto research design was followed. A sample of 120 respondents was selected by proportionate random sampling procedure. The selected villages were Thoppampatti, Yerumanayaakampatti, Panjampatti, Jadhigoundanpatti and Muthampatti from Athoor block. Data were collected by a well structured and pre-tested interview schedule. A test was administered to test the adoption level of grapevine growers. The collected data were analysed by using cumulative frequency method, percentage analysis, simple correlation and multiple regression analysis.

RESULTS AND DISCUSSIONS

In order to study the extent of adoption of grapevine growers a test was administered. The respondents were classified as low, medium and high using cumulative frequent method. The result on overall knowledge level of grapevine growers are presented in Table 1. It could be observed from the Table 1 that half of the respondents (50.84 per cent) were found to have high level of adoption about recommended cultivation practices followed by medium (40.83 per cent) and low (8.33 percent) level of adoption. In general majority of the respondents had high to medium level of adoption about recommended cultivation practices. This may be due to majority of the respondents had quite knowledge about the cultivation practices and often got advices from the State Horticulture Department. This finding is in agreement with the findings of RS Karangami et. al. (2024).

Practice-Wise Adoption Level of Grapevine Growers

The results on practice-wise adoption level of the respondents are presented in Table 2. It could be observed from the Table 2 that all the respondents (100.00 per cent) were adopted the same variety, recommended manure application, pest management and recommended harvesting. Also it was observed that majority of the respondents were adopted recommended special practices (96.60 per cent), field preparation (95.80), spacing (95.00 per cent), ripening (92.50 per cent) and training practices (91.20 per cent). The high level on adoption rate was due to the respondents had high farming experience in grapevine cultivation and also well training programme conducted by State Horticultural department in recommended cultivation practices. The majority of the respondents were adopted recommended shoot cutting practices (87.50 per cent), pruning (85.80 per cent), herbicide application (84.20 per cent), irrigation practices (80.80 per cent) and disease management (78.30 per cent) respectively. The low level of extent of adoption was on micro-nutrient application (69.70 per cent) and fertilizer application (52.00 per cent) of the respondents. This finding is in accordance with the findings of Jayasankar (2020).

Association and Contribution of Characteristics of Respondents With Their Adoption Level

It could be seen from the Table 3 that out of sixteen variables training attended was found to be significant at one per cent level of probability, whereas the remaining variables such as educational status, experience in grapevine cultivation, innovativeness and market perception had significant at five per cent level of probability. The correlation values for the other variables showed non-significant association with knowledge level of respondents. In order to find out which of the variables explained the variation in extent of adoption and also to know the extent of contribution made by these variables, multiple regression analysis was carried out and the results are presented in Table 3. The results revealed that the extent of adoption of growers could be positively influenced by their





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educational status, experience in grapevine cultivation, extension agency contact, training attended and market perception. All the other variables were found to be non-significant.

CONCLUSION

Majority of the respondents were found to have high level of adoption about the recommended grapevine cultivation practices. To enhance the extent of adoption of recommended cultivation practices, the extension personnel may organize intensive training programmes and adopt innovative teaching methods to enhance the adoption level of grapevine growers on other grapevine cultivation practices. Regarding the characteristics educational status, experience in grapevine cultivation, innovativeness, extension agency contact, training attended and market perception shown positive and significant relationship with extent of adoption of the respondents. Hence these characteristics may be taken into account while formulating extension strategies for dissemination of grapevine technologies at farm level.

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Table 1: Distribution of respondents based on their overall adoption level: (n=120)

Sl. No.	Category	Number	Percent
1.	Low	10	8.33
2.	Medium	49	40.83
3.	High	61	50.84
	Total	120	100.00

Table-2: Practice-wise adoption level of grapevine growers (n=120)

Sl. No	Items	No. of respondents	Per cent
1.	Variety	120	100.00
2.	Field preparation	115	95.80
3.	Shoot cuttings	105	87.50
4.	Spacing	114	95.00
5.	Irrigation	97	80.80
6.	Herbicide application	101	84.20
7.	Manures	120	100.00
8.	Fertilizer application	62	52.00
9.	Micronutrient application	84	69.70
10.	Training	109	91.20





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11.	Pruning	103	85.80
12.	Special practices	116	96.60
13.	Pest management	120	100.00
14.	Disease management	94	78.30
15.	Ripening	111	92.50
16.	Harvesting	120	100.00

Table-3. Zero-order correlation and multiple regression analysis of socio-personal and psychological characteristics of respondents with their knowledge level

Sl. No.	Variables	'r' value	Regression co-efficient	Standard error	't' value
1.	Age	0.233NS	1.712	1.549	1.457NS
2.	Educational status	0.214*	0.496	0.312	2.248**
3.	Occupational status	0.113NS	-0.317	0.876	1.248NS
4.	Annual income	0.105NS	0.474	0.274	1.468NS
5.	Farm size	0.108NS	1.176	0.699	1.876NS
6.	Area under grapevine cultivation	0.083NS	0.818	0.486	1.422NS
7.	Experience in grapevine cultivation	0.355*	0.365	0.115	1.366*
8.	Social participation	0.118NS	-1.116	0.426	1.734NS
9.	Innovativeness	0.382*	0.414	0.564	1.326NS
10.	Extension agency contact	0.108NS	0.382	0.217	2.486**
11.	Scientific orientation	0.048NS	0.848	0.474	1.222NS
12.	Risk orientation	0.093NS	0.794	0.195	1.177NS
13.	Economic motivation	0.088NS	0.954	0.787	1.114NS
14.	Credit orientation	0.072NS	0.725	0.875	1.368NS
15.	Training attended	0.311**	0.903	1.188	1.251*
16.	Market perception	0.219*	0.682	0.368	1.455*

R² = 0.526

F = 7.142**

a = 9.304

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RESEARCH ARTICLE

Ancient Wisdom for Future Trends: The Art of Natural Dyeing Techniques among the Karbi Community of Northeast India

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ABSTRACT

Natural dyes and pigments used in traditional attires enhance the vibrancy and cultural expression of tribal communities, reflecting both ecological harmony and biological richness. The Karbi communities traditionally extract these dyes and apply them to clothes, fabrics and crafts using age-old techniques. Textile serves as a livelihood of many Karbi women living in both rural and urban areas. It was revealed that, 23 dye-yielding plants species belong to various botanical families are used by Karbi tribe as sources of dye. Among these, 5 species are known for their medicinal properties, while 11 are considered edible. Pre and post dyeing treatment adopt to improve the quality of the textile product. Unfortunately, this valuable traditional knowledge of dye sources and techniques is not widely practiced among the younger generation, posing a high risk of its permanent loss in the near future. Additionally, the natural plant sources used for dyeing are increasingly threatened by ongoing massive deforestation. So, in light of these concerns, there is a pressing need to conduct systematic research through qualitative ethnographic methods, including semi-structured interviews with local dyeing experts, traditional herbalists, and community elders. In addition, direct observation was employed to document the complete dyeing process.

Keywords: Natural dye, colour, conservation, Karbi tribe, traditional knowledge

INTRODUCTION

Natural dyes are colorant derived from various biological sources including plants, insects and minerals. Indigenous communities traditionally have been using dye extract from biological sources to impart colour and apply on fabrics,

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clothing, craft etc since time immemorial. Different parts of the plants were used for the extraction of dyes such as leaves, flowers, vegetables, etc.^[1]. Many traditional dyes require traditional mordant prepared from various natural sources to bind the dye to textile fibres and retain colour fastness. The absorption of light depends on the structure or constituents of the colouring pigment/molecules that contain various chromophores present in the dye yielding plant to display the plethora of colours^[2]. Colours obtained from natural dyes depend on the concentration of the chemicals in the plants, the plant part used, the season in which the material was collected, the growth stage of the plant, and the use of mordants^[3]. The plant material that is used in textile dyeing can be fresh, dried or fermented^[4]. Normally, the colour of newly dyed textiles is lighter and not always pure but when mordant is added to make the binding tight and help fix the colours to the fibre and lighten the fabric to produce brighter colours^[5]. The discovery of natural dye and its uses has contributed to the continuation of the age old bond between human kind and nature^[6]. But traditional natural plant dyes for silk, wool and cotton fibres have over time been replaced by synthetic dyes^[7] because they were cheaper, more easily available, of consistent quality, with greater colour fastness and more stable^[8]. Unfortunately, synthetic dyes may have negative side effects for human and environment, including health and safety risks such as cancer, caused by the toxic mordants^[8].

Therefore, recently, interest in the use of natural dyes has been growing rapidly due to the result of stringent environmental standards imposed by many countries in response to toxic and allergic reaction associated with synthetic dyes. As a result with a distinct lowering in synthetic dyestuff costs, the natural dyes were virtually unused at the beginning of twentieth century^[9]. And they are useful for human health because they have antibacterial, insecticidal and healthy properties, which are due to their natural origin^[6]. Natural dyes/colorants derived from flora and fauna are believed to be safe because of its nontoxic, non-carcinogenic and biodegradable in nature^[10]. Natural dyes are now a days in demand not only in textile industry but in cosmetics, leather, food and pharmaceuticals. Organic pigments are large and often complex organic molecules responsible for the different colours of plants and foods. Besides giving the vegetable their characteristics colour, they are also responsible for critical plant functions^[11]. The rich biodiversity of our country has provided us plenty of raw materials, yet sustainable linkage much be developed between cultivation, collection and their use^[12].

Indigenous handloom textile is intrinsically associated with social and cultural life of ethnic groups of Assam. Every community of the state has their own dresses dyed with indigenous herbal dyes. Although, use of herbal dye is no longer practiced but preparation of dye from locally available plants to dye their silk, cotton and woollen yarns and garments was only option in the absence of chemical dyes a decade back^[13]. Karbi Anglong, the largest district of Assam is blessed with gigantic biodiversity. The Karbi tribe has long relied on forest resources for food and medicine. Their knowledge of dye has been acquired through long years of observation, possibly through trial and error^[14]. This Karbi tribe continues to practice traditional dyeing techniques to color fabrics, clothing, and handicrafts. Textile production serves as a vital source of livelihood for many Karbi women in both rural and urban areas. Interestingly, some of the plants used for natural dyes are also known for their edible and medicinal properties. But unfortunately, traditional dye sources and their associated knowledge are being threatened due to massive destruction of forest, changing of life style, the growing generation gap wherein knowledge transmission between the older and the younger folks is threatened. So, the need is felt to undertake scientific research on various biological sources of dye and document for future references. This research made an attempt to bridge the gap between older and younger folks regarding the empirical understanding and practical application of these historically significant dyeing processes, thereby promoting their preservation and potential sustainable integration.

MATERIALS AND METHODS

Study Area

The Karbi communities predominantly living in Karbi Anglong and West Karbi Anglong districts of Assam (Figure 1 & Figure 2), the largest district (before division) with a geographical area of 10,434 Sq Km. A home for tribal



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communities such as Karbi, Dimasa, Rengma, Kuki, Hmar, Tiwa, Bodo, Assamese, Garo, Chakma etc. However, the Karbis are major tribe in this district. The district lies between 25° 33' to 26° 35' North latitude and from 92° 10' to 93° 50' East longitude. The general status of Mikir Hills (Present Karbi Anglong) of wild flora and fauna is quite rich which could well be gauged from the fact that this district is considered one of the mega biodiversity of the north-eastern region ^[15]. The forest area of the hill regions of Assam covers about 34% of the total geographical area of the region against the regulated forest coverage of 60% as fixed by the National Forestry Policy, 1952. So, the Karbi depend on forest product for food, shelter, medicine and clothes. It is believed that, the rich traditional and its practice is highly prevalent among this tribe in the past. Ethnically, they belong to the Indo-Mangoloid race and linguistically to the Tibeto-Burman family of language. The Karbis have distinctive language, culture, identity and tradition. They have their distinct traditional dress and ornaments which vary according to the age of the wearer ^[16]. Numerous traditional attires including, *Poho* (turban), *choi hongthor* (sleeveless jacket), *pilu* (shawl), *jiso* (wrapper at the chest), *pini* (lower garment), *pekok* (upper garment), *vam'kok* (belt), *chepan*, *pesarpi* (shawl) at different occasion by different age group. They spin yarn and weave through conventional method and used natural dye for colouring their clothes and fabric. It is worth mentioning that some Karbi women traditionally tattooed their faces from the forehead to the chin using natural dye—a practice known as *duk kachiduk*, with the tattoo itself called *duk*. Similarly, both men and women have a strong fondness for wearing ornaments.

Interview method

Preliminary information and data were systematically recorded in a research diary, based on inputs collected randomly across different seasons from traditional dye experts, weavers, elders, priests, and forest department personnel.

Field visit method

Frequent visits were made to the local micro textile industry/weaving centre as and when situation warrants. The process involved in dyeing techniques were observed and learned the every step of dyeing process including grinding/crushing/chopping of natural dyes yielding plant leaves/barks, extract preparation, mordant preparation etc. And all the processes both pre and post dyed treatment were recorded in the research diary in serial.

RESULT AND DISCUSSION

The Karbis use 23 plants species along with other biological sources of dye such as insect and mineral for dyeing fabrics and clothes that revealed during the course of study. All these natural dye yielding plants species are tabulated in vernacular name, common name, scientific name, family, habit followed by part of used (Table 1). Out of 23 natural dye yielding plants, 6 species reported medicinal and 11 are edible (Table 2). 19 different families of plants species belong to phyllanthaceae (01), pubanaceae (01), zingiberaceae (01), lynththraceae (01), acanthaceae (02), apocynaceae (01), theaceae (01), amryllidaceae (01), combretaceae (01), malvaceae (01), bixaceae (01), rhamnaceae (01), myrtaceae (02), burseraceae (02), arecaceae (01), bombaceae (01), combretaceae (01), Euphorbiaceae (01), bignoniaceae (01) and asteraceae (1). Natural dye yielding plants produce different colour pigments and the amount of pigment production is varied in different seasons. It has been reported that pigment quality is better during the winter season compared to summer. It is also believed that, exposition of sunlight and orientation of the plant can affect pigment quality. Plants facing north and east tend to produce inferior pigments, likely due to higher water accumulation on those sides. In contrast, plants facing south and west yield pigments with richer and thicker content. Therefore, traditional dye experts always prefer to collect from south and west facing plant parts. Generally, young dye yielding plants (below 40 years) are avoided for pigment extraction. The distribution of pigment within the plant is uneven, with the highest concentration typically found in the nodes of the trunk compared to other parts. The Karbi people extract dyes from various plant parts including leaves, fruits, bark, and seeds using both hot and cold water extraction methods. However, hot extract maintain colour fastness and lustre while cool extract colour become fade very soon. To increase colour fastness they use mordants like salt (NaCl) and Soda (prepare from ash).



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Fermentation is involved only in some dyeing techniques. It has also been reported that besides plants other sources are used as colorant including iron ore, cow dung, mud etc. now and then.

In Malaysia 51 plant species were identified as sources of natural dyes used mostly for body paints by the Orang Ulu, an informal collective name for several ethnic groups on the Island of Borneo ^[17]. In India, nearly 450 plant taxa are known to yield dyes for a variety of purposes including dyeing of textiles ^[18]. Dyes have been widely used by communities for various purposes, such as a compositional ingredient in food, customs or traditional activities and crafts ^[19]. Colour carries valuable information in Karbi society. It gives elegance to garments, garments dyed with specific colours reflect cultural identity, fibres to specific colour are used during religious and certain colours and garments are considered taboo. Several terms reflect the role of dyes in the cultural life of the Karbis such as *amen ki'ir*, *honjeng kekok* (naming ceremony), *melur* (a ritual lamp), *Rongker* (community festival), *ahop* (a natural physiological change in infants characterised by sticky-greenish stool that lasts for a few days), *Duikhrari* (ritual to appease a deity), *Karjong kikur* (a ritual to reunite body and soul), *Jambili athon* (traditional Karbis wood crafts), *Pi sarpi* (elderly women's cloth) and *Pini* (Women's lower garment) ^[14].

Preparation of extracts: The method of extract preparation varies depending on the plant part used. Parameters such as boiling temperature, duration, and technique differ — for example, some parts require decoction (boiling), while others are better suited for cold extraction or fermentation to preserve bioactive compounds.

Bark extract: Dye yielding plants' bark crushed with pestle and boiled for 40-60 min at 100 ° C in an aluminium utensil. Allow the extract to get cool and then filter with the help of thin cloth. Filtrate is ready to use.

Leaves extract: For certain plants, leaves are crushed into a paste using a pestle and then boiled with soda (alkaline solution) at 80–90°C for 40–60 minutes. After boiling, the extract is allowed to cool and is then filtered through a fine cloth to remove solid residues. In contrast, for plants like indigo species (*Strobilanthes cusia*, *Marsdenia tinctoria*), the preparation process differs. The leaves are first chopped, crushed into a paste, and shade-dried. The dried paste is then soaked in soda water and left to ferment for 3–4 days. Following fermentation, the mixture is filtered using a thin cloth to obtain the extract, which is then ready for use. This fermented extract can be reused multiple times over several days, depending on its stability and effectiveness."

Peel extract

Onion peels (*Allium cepa*) are directly boiled in water at 100°C for 40–60 minutes to extract water-soluble compounds. After boiling, the mixture is allowed to cool to room temperature and then filtered through a fine mesh or cloth to obtain the clear extract.

Rhizome extract

Turmeric rhizomes (*Curcuma longa*) are commonly used as a natural dye source. The rhizomes are crushed to increase surface area and then boiled in water at 90–100°C for 40–90 minutes to extract the curcuminoid pigments. This process yields a dye-rich extract suitable for various applications.

Lac extract

Lac resin is boiled in water at 100°C for 40–60 minutes to soften and release the soluble components. After boiling, the mixture is squeezed to separate the extract from solid debris. The clarified extract is then ready for use.

Cow dung/mud extract

Cow dung or mud is thoroughly mixed with water to form uniform slurry. The liquid portion of this mixture is then used as the extract, typically without the need for further processing.



**Ronjit Hanse and Ramie H. Begum****Mordant preparation**

Phelo a traditional mordant used to enhance color fastness in dyeing, is made by burning dried banana sheaths, sesame stalks, or bamboo. About 500 grams of the resulting ash is mixed with 1000 ml of water, then filtered through a traditional bamboo strainer known as the *Phelo bisir* (Figure 3) The resulting filtrate is ready for use as a natural mordant.

Dyeing process

Cotton or eri silk fabrics/clothes are soaked in clean water thoroughly before dyeing and the water squeezed out or material is left to drip off excess water. Cotton or Eri fabrics are boiled in water for 30-40 minutes to remove wax and debris and allow to dry under shade. Sometime, cotton fabrics are boiled in soda to increase absorbing capacity of dye. If not, the fabric is directly soaked in warm water for 30 minutes and squeezed. The wet fabrics and clothes immersed in dye bath for 30-60 min at 80° C and stirred every after 10 min to make dyeing uniform (figure 4). After that fabrics or clothes taken out from the dye bath and dried in the shade with the help of bamboo pole. Again and over again, immersed until achieving the desired level of colouration.

Shade

The attractive colours and fragrance of natural dyes are influenced by several factors, including the concentration of bioactive compounds in the source plants, the specific plant part utilized, the season and stage of plant growth at the time of harvest, and the application of mordants, which can alter dye uptake and colour fastness (figure: 5).

CONCLUSION

Natural dyes are colorants derived from naturally available sources. They have a wide range of applications in textiles, crafts, cosmetics, tattoos, and medicine. Typically, natural dyes are eco-friendly, non-toxic, non-carcinogenic, and biodegradable. As a result, interest in their use has been growing rapidly. This rising demand is further driven by increasingly stringent environmental regulations in many countries, aimed at reducing the toxic and allergic effects linked to synthetic dyes. Moreover, due to their antibacterial, insecticidal, and health-promoting properties, natural dyes gain more attention. It is reported that, textile products that develop through natural dye techniques give beauty results such as lustre, soft and shadow gives much pleasure to the eyes. Some edible natural dye can be applied in food industry for colouring various confectionery food items. The Karbi tribe primarily relies on the forest and its resources for food, medicine, and shelter. They also possess a rich heritage of culture, traditions, customs, and indigenous knowledge. The indigenous Karbi tribe of Karbi Anglong and West Karbi Anglong has been practicing traditional dyeing techniques sustainably for generations to color their fabrics, clothing, and crafts. Notably, they spin natural yarns, primarily cotton and eri silk. However, the use of natural dyes in textiles and crafts is gradually being replaced by synthetic dyes due to cheap and obtainable. Moreover, traditional dyeing technique is being threatened due growing generation gap wherein knowledge transmission between older and younger folks is menaced. Massive destruction of forest in regular mode lead the biological sources of dye to perish day after day and subsequently the laudable traditional knowledge of Karbi tribe may poses risk of its permanent loss in the near future. This research initiative aimed to systematically and facilitate the revitalization of traditional dyeing techniques among the contemporary populations. The objective is to bridge the gap between older and younger folks regarding the empirical understanding and practical application of these historically significant dyeing processes, thereby promoting their preservation and potential sustainable integration.

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Table 1: Biological sources of natural dye

Vernacular name	Common Name	Scientific Name	Family	Habit	Origin	Part of used	Colour Shade	Fabric/garment
Tamsir	Indo-China Alder	<i>Aporosa octandra</i> Buch. Hem.ex D.Don	Phyllanthaceae	Tree	South China to tropica Asia including Queensland and	Leaves	Blue	Cotton, Eri silk and garment




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					New Guinea			
Sugun	Teak	<i>Tectona grandis</i> L.	Perbenaceae	Tree	South and Southeast Asia, India, Myanmar, Laos and Thailand	Shoot	Redish - brown	Cotton, Eri silk
Tharmit	Turmeric	<i>Curcuma longa</i> L.	Zingiberaceae	Herb	Southeast Asia particularly India	Rhizome	Yellow	Cotton, Eri silk
Jetuka	Henna	<i>Lawsonia inermis</i> L.	Lythraceae	Herb	Northern Africa, Asia and Australia	Leaves	Maroon	Cotton, Eri silk
Sibu	Assam indigo or Chinese rain bell	<i>Strobilantes cusia</i> (Nees) Kuntze	Acanthaceae	Herb	South Asia, China and Indochina	Whole part except root	Blue	Cotton, Eri silk, face tattoo and garment
Bujir	Climbing-indigo	<i>Marsdenia tinctoria</i>	Apocynaceae	Creep er	Southeast Asia including India, China and Malaysia	Whole part except root	Blue	Cotton, Eri silk, face tattoo and garment
Sa	Tea	<i>Camellia sinensis</i> L.	Theaceae	Tree	It is native to East Asia and Indian subcontinent	Leaves	Light brown	Cotton, Eri silk
Harsun ke'er	Onion	<i>Allium cepa</i> L.	Amaryllidaceae	Herb	Central Asia basically Northwest India, Afghanistan, Pakistan and Soviet Republic of Tajikistan and Uzbekistan	Peel	Greenish	Cotton, Eri silk




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Siluka	Myrobalan/Harad	<i>Terminallia chebula</i> Retz.	Combretaceae	Tree	South and Southeast Asia	Fruit	Black	Cotton, Eri silk
Hansering	Roselle	<i>Hibiscus sabdariffa</i> L.	Malvaceae	Herb	West Africa, particularly Sudan region.	Fruit	Pink	Cotton, Eri silk
Lipstick tree/Annatto	Annatto	<i>Bixa orellana</i> L.	Bixaceae	Tree	Central and South Africa, specially the area between Mexico and Brazil	Seed	Red	Cotton, Eri silk
Bogori	Jujube	<i>Ziziphus jujube</i> Mill.	Rhamnaceae	Tree	China	Bark	Brown	Cotton, Eri silk
Jangmi	Black berry	<i>Syzygium cumini</i> L.	Myrtaceae	Tree	North America, Europe and part of Asia	Fruits	Pink	Cotton, Eri silk
Timur	Grey Down Balsam Tree	<i>Garuga pinnata</i>	Burseraceae	Tree	Indian subcontinent, southern China and Southeast Asia	Bark	Light brown	Cotton, Eri silk
Soprim	Guava	<i>Psidium guajava</i> L.	Myrtaceae	Tree	Southern Mexico through Central America and northern South America	Bark/Leaves	Black	Cotton, Eri silk
Kove	Betel nut	<i>Areca catechu</i> L.	Arecaceae	Tree	Philippines and other parts of Southeast Asia	Seed	Red	Cotton, Eri silk
Tiji	Garuga	<i>Garuga floribunda</i>	Burseraceae	Tree	Asia including India,	Bark	Red	Cotton, Eri silk




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					Southeast Asia and part of Australia			
Pharkong	Red-silk cotton tree	<i>Bombax ceiba</i> L.	Bombacaceae	Tree	South and Southeast Asia, including India, Sri Lanka and Malaysia	Bark	Red	Cotton, Eri silk
Kuru	Bahera	<i>Terminalia bellirica</i>	Combretaceae	Tree	Indian subcontinent, Sri Lanka and Southeast Asia	Bark	Yellow	Cotton, Eri silk
Nopakban	Indian trumpet tree	<i>Oroxylum indicum</i> L.	Bignoniaceae	Tree	Native to Indian subcontinent basically Himalayan foothills.	Bark	Green	Cotton, Eri silk
So'ik	Climbing croton	<i>Croton caudatus</i>	Euphorbiaceae	Creepers	Asia mostly in China, Indian subcontinent and southeast Asia	Sap of twigs	Black	Teeth
Mirve	Marsh water-willow	<i>Justicia comata</i> (L.) Lam	Acanthaceae	Herb	Tropical America	Leaves and shoots	Pink	Bamboo craft
Bapbongnai	Siam weed or bitter Bush	<i>Chromolaena odorata</i> (L)	Asteraceae	Herb	Native to Americas	Leaves	Light green	Cotton, Eri silk

Table 2: List of edible dye yielding plants

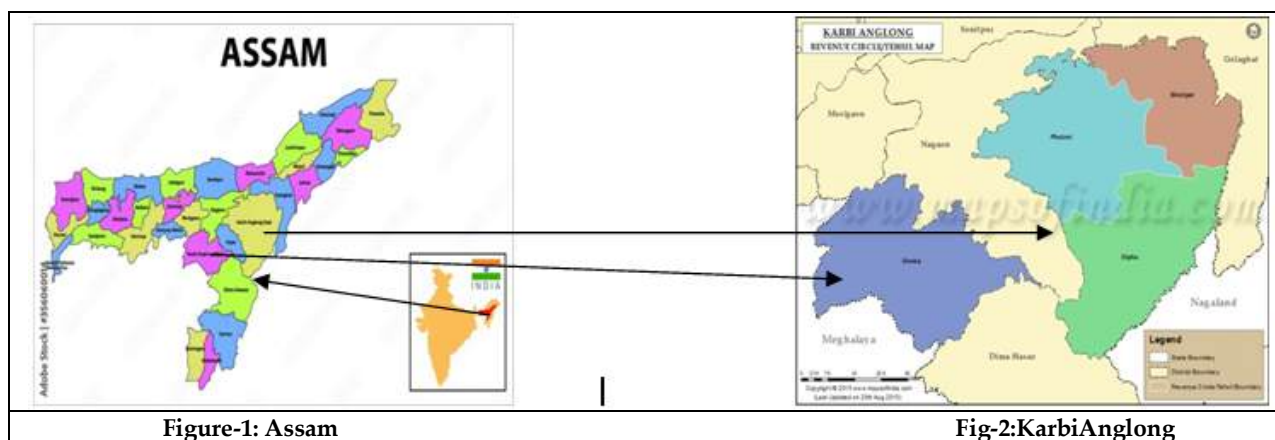
Scientific Name	Part of used	Source of plant material	Mode of preparation
<i>Curcuma longa</i> L.	Rhizome	Cultivated	A paste made from rhizomes, fermented dry fish, salt, and raw chilies is wrapped in banana leaves and placed in hot ash for 30–45 minutes. The cooked mixture is then consumed as chutney. Sometimes, raw rhizomes are crushed and added to boiled curries—especially pork, chicken, or fish—as a spice. Turmeric powder is typically used in





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			vegetable curries or fried dishes.
<i>Camellia sinensis</i> L.	Leaves	Cultivated	Leaves are chopped and dried into sunlight. Dried leaves are boiled and prepare a drink.
<i>Allium cepa</i> L.	Bulb and leaves	Cultivated	Bulb and leaves are chopped and put into different curries as spices. Raw onion also prefers to eat.
<i>Terminallia chebula</i> Retz.	Fruits	Wild	Both raw and dry fruits are used as mouth freshener. It is also used as digestive.
<i>Hibiscus sabdariffa</i> L.	Leaves and fruits	Cultivated	The buds and immature fruits are cooked for 40-60 min with various ingredients including sesame powder, garlic, salt etc. In order to minimise the source taste fermented dry fish put into it.
<i>Ziziphus jujube</i> Mill.	Fruits	Wild	Fruits are consumed. Sometime ripen fruits are dried and prepare pickles for future use.
<i>Syzygium cumini</i> L.	Fruits	Wild	It is one the delicious and popular fruit among the Karbi. Ripe fruits are consumed.
<i>Psidium guajava</i> L.	Fruits	Wild	It is one of the common fruits among the Karbi people, who consume it both raw and ripe. It has been reported that the buds are crushed to prepare a drink used as a remedy for dysentery.
<i>Areca catechu</i> L.	Seed	Cultivated	Areca is consumed with beetle leaves
<i>Terminalia bellirica</i>	Seed	Wild	Seeds are directly consumed after removing the seed coat. The taste is similar to almond.
<i>Oroxylum indicum</i> L	Bud	Wild	The buds are traditionally consumed by baking—wrapped in banana leaves and placed in hot ash. It is also reported that the bark is crushed and mixed with water to prepare a medicinal drink used to treat dysentery





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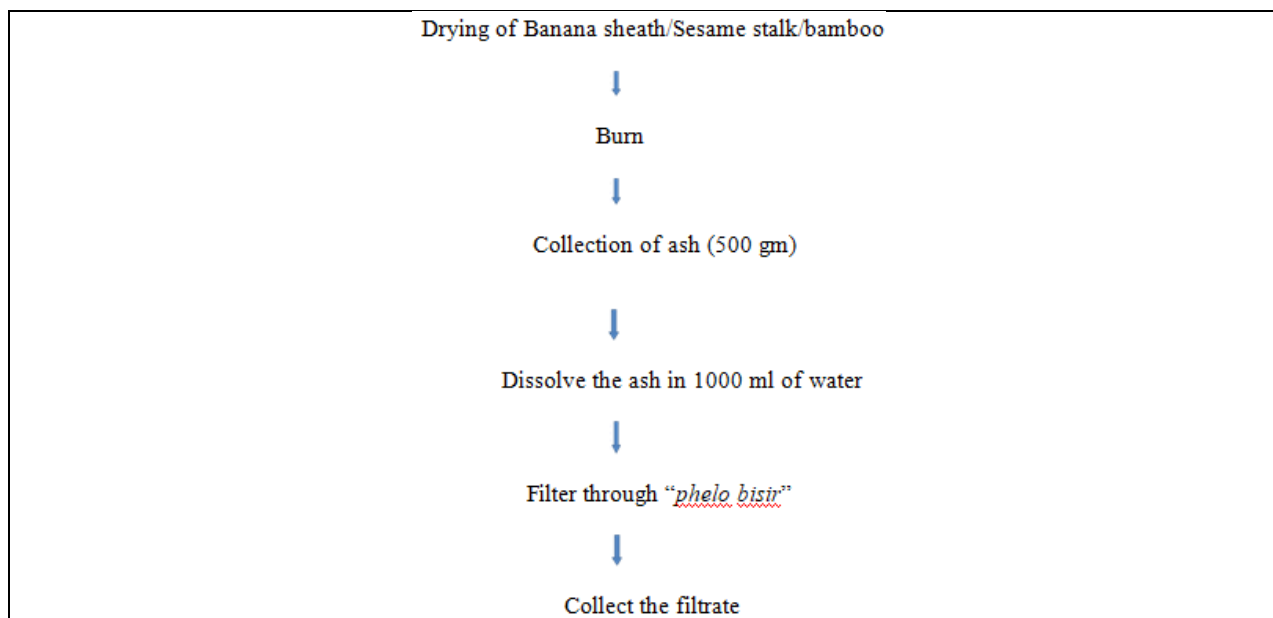


Figure 3: Flowchart of traditional mordant (*phelo*) preparation

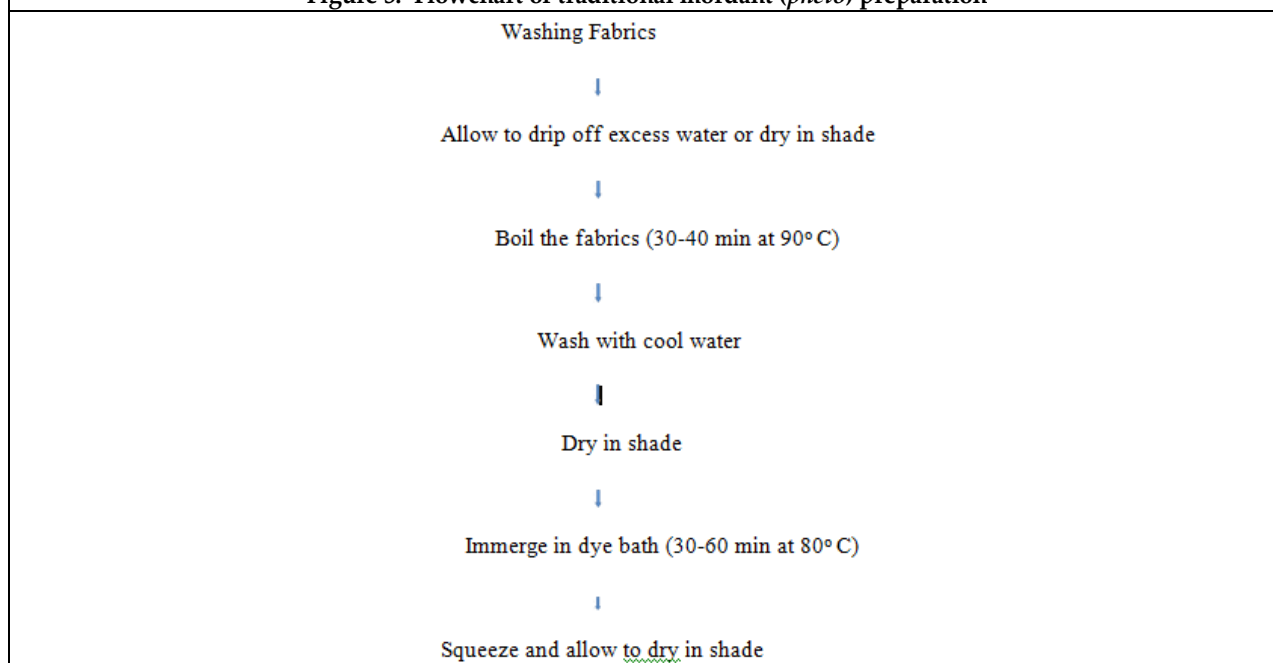


Figure 4: Flow chart of traditional dyeing process



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Plat1: Indigo dye



Plat2: Jammu dye



Plate3: Teadye



Plat 4: Lac dye



Plat 5: Onion peel dye



Plat 6: Termeric dye

Plat 7: *Chromolaena odorata*Plat 8: *Garuga floribunda*plat 9: *Oxoxylum indicum***Figure 5: Dyed fabric with natural dyes**

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RESEARCH ARTICLE

Nutritional Profiling and Consumer Acceptability of A Plant - Based Milk Alternative

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ABSTRACT

Plant-based milk alternative is made from water-soluble extracts of grains, nuts, legumes, oilseeds, and pseudo-cereals, which are crucial constituents in traditional Indian culture. They are known for their unique characteristics. Various reasons, such as environmental sustainability, cholesterol levels, lactose intolerance, and a need for nutrient-rich, locally sourced foods like finger millet and coconut, have led to an increased interest in these plant-based milk alternatives. This study investigated the nutritional profiling, consumer acceptability, physicochemical properties, and microbiological analysis of a milk blend developed using finger millet (*Eleusine coracana*) and coconut (*Cocos nucifera*) milk. Three variations with different ratios of finger millet milk to coconut milk blend were analysed. Most suitable ratio of coconut and water was determined based on sensory attributes for the extraction of coconut milk. FiCo3 mix had the least fat. To improve flavor and cultural value, 2% jaggery was added as a sweetening agent and 0.05% xanthan gum as a stabilizer. Nutritional value per serving is packed with 156.4 kCal, 8.7 g of carbohydrates, 5.2 g of protein, 11.2 g of fat, 3.8 mg of iron, and 292.2 mg of calcium. The milk blend showed a strong nutritional profile due to its calcium content per 100 ml. The findings suggest this milk blend could help improve nutritional security by addressing the shortages of macronutrients and micronutrients in the population and avoid dependency on dairy milk.

Keywords: Plant-based milk alternative; finger millet; coconut milk; nutritional profiling; consumer acceptability





INTRODUCTION

Milk obtained from finger millet serves as an excellent plant-based milk alternative to traditional cow's milk, helps control diabetes and supports bone strength. It contains 112 mg of calcium per 100 g, surpassing cow's milk; enzyme treatment can also boost protein and antioxidant activity. Coconut milk is produced from liquid extraction from matured coconut using a 1:3 (w/ v) ratio. Coconut milk, rich in lauric acid, has an energy content of 135.9 kCal for every 100 ml and is high in fat. It serves as a nutritional and highly digestible source of milk alternative. Its elevated levels of phenols and vitamin C provide numerous health benefits due to their remarkable antioxidant properties. It serves as a nutritious and easily digestible alternative to milk [1]. Finger millet milk rich in fibre, calcium, and protein, is blended with coconut milk, abundant in vitamins and healthy fats, to produce a nutritious plant-based milk. This milk blend enhances taste and nutrition by creating a lactose-free, nutrient-rich beverage that supports bone strength, digestive health, and diabetes control [2]. The present study aimed to develop a milk alternative that is nutritious, tasty, and healthier for mindful consumers, thereby enhancing its nutritional value through the blending of finger millet and coconut milk.

MATERIALS AND METHODS

This study was conducted in the Department of Food Science and Nutrition at Mount Carmel College, Autonomous, Bengaluru, Karnataka, India. Mature coconuts sourced from a dealer in Shanti Nagar, Bengaluru, India, were used to prepare coconut milk. The ML 365 variety of finger millet was procured from the Karnataka State Seed Corporation, Beeja Bhavan, located in Bangalore, Karnataka, India to ensure a better quality. Before germination, finger millet was washed and rinsed to remove any contaminants. Followed by the preliminary processing, it was soaked in water for 12 hours [3]. It was then germinated for approximately 48 hours. During the initial 24 to 48 hours of germination, the enzyme activity in the grain increases while its anti-nutritional factors decrease, thereby improving nutrient availability and digestibility [4]. Following germination, finger millet was dried and roasted at 75–80°C for 10–15 minutes to achieve a moisture content of 10–12%. This process reduces antinutritional factors, imparts a unique roasted flavour, and enhances sensory attributes, digestibility and overall palatability [5]. Then milk was extracted from processed finger millet. Milk obtained after a 48-hour germination period of finger millet, characterized by optimal shoot length and color, yielded a lighter liquid with increased α -amylase activity. The coconut milk extracted was stored in a sealed container, under refrigeration at 4°C for further analysis.

Formulation of milk blend

To enhance the extraction process, the optimal balance of finger millet to water must be determined. Finger millet was roasted and germinated at various finger millet-to-water (w/v) ratios such as 1:1, 1:2, 1:3, 1:4, and 1:5. The suitable ratio of finger millet to water was determined based on the sensory profile of millet milk extracted. The extraction process involved blending finger millet and water for 5 minutes were used to combine the finger millet with water, it was filtered using a double-layer muslin cloth and stored at 4 °C in a sterilised glass jar. Preliminary studies on different coconut-to-water ratios, such as 1:1, 1:2, 1:3, 1:4, 1:5, were conducted to optimize the coconut milk extraction. The most suitable ratio of coconut and water was determined based on sensory attributes for the extraction of coconut milk. Three formulations were then prepared- FiCo1, comprising of 60% finger millet milk and 40% coconut milk; FiCo2, containing 70% finger millet milk and 30% coconut milk and FiCo3, consisting of 80% finger millet milk and 20% coconut milk. Then 0.05% of xanthan gum was added to the blends as a stabilizer. They were then homogenized under high pressure. In semi-batch process using high-pressure chambers, the FiCo3 milk blend was subjected to pressures of 600 – 700 MPa. At medium, moderate, or mild temperatures, processing time lasts between 5 and 30 minutes [6].



**Samiya Mohammedi et al.,****Sensory evaluation**

A 9-point hedonic scale was used to conduct a sensory analysis of the milk blends. The evaluation was carried out by thirty panellists with modest experience. The samples were given three-digit codes to eliminate bias. A structured assessment form was used to assess sensory attributes such as color, aroma, texture, mouthfeel, and overall acceptability.

Product evaluation

The physicochemical characteristics and sensory attributes of food products are critical determinants of their quality, stability, and nutritional value. In this study, a comprehensive physicochemical evaluation was conducted on cow's milk, finger millet milk, coconut milk, and milk blend of finger millet and coconut milk.

Determination of physicochemical parameters

Degrees Brix refers to the total soluble solids (TSS) content, which represents the amounts of dissolved solids in a liquid. TSS is an important parameter in food products such as fruit juices, gravies, and plant-based milk alternatives, where sweetness, texture and flavor strength are inter-related [7]. Using the standard AOAC methods, cow's milk, finger millet milk, coconut milk, and milk blends were examined for ash content and pH [8, 9]. The energy content was determined using the following formula [10]. Food energy = (Crude protein × 4) + (Fat content × 9) + (Carbohydrate × 4).

Macronutrient assessment

Carbohydrate content was determined following anthrone method [11]. The Kjeldahl Digester, and Distillation method, a standard practice used in the food industry, was used to determine the nitrogen levels in the samples. The nitrogen content is calculated with a multiplication factor of 6.25, to transform the nitrogen content into crude protein [12]. The fat content of the sample is measured according to AOAC standards [13].

Micronutrient, and Antioxidant activity

Calcium and iron are essential for healthy bones and anemia prevention; hence the focus of micronutrient estimation was on these two elements. Micronutrient assessment was performed according to the AOAC guidelines. Antioxidant activity was evaluated using the DPPH (2,2-diphenyl-1-picrylhydrazyl) method [14].

Microbial Analysis

Ensuring the safety and stability of food products relies on shelf-life studies through microbial analysis. In this study, the spread plate technique was used, involving serial dilutions, plating samples onto nutrient agar, and counting the colonies after incubation [15].

Statistical analysis

Using IBM SPSS Statistics for Windows, Version 26.0, a statistical evaluation of the data was conducted through an analysis of variance (ANOVA).

RESULTS AND DISCUSSION

The present study comprehensively examines various milk blend ratios and evaluates them to identify the optimal blend that enhances consumer appeal and nutritive value, considering their physical, chemical, sensory, and proximal characteristics.



**Samiya Mohammedi et al.,****Yield analysis**

The findings of the milk yield for both the milk samples are as illustrated in table 1. The highest yield was recorded for both the samples were recorded at 1:5 (w/v) ratio. For finger millet milk it was 455 ± 0.3 ml followed by 310 ± 0.07 ml at a 1:4 rate. Coconut milk it was 525 ± 0.18 mL. Increasing solubilization and extraction effectiveness contribute to the gradual yield rise as water volume grows. Millet germination enhances nutrient availability and increases milk yield. For instance, in a similar study, yield from sprouted kodo millet was reported to be 475 mL, while the yield from raw grains was 400 mL [16]. Oats yielded 320.4 mL under similar conditions; finger millet yielded 96 ml following 8 hours of soaking and 18 hours of sprouting [17].

Sensory evaluation

Results of the sensory evaluation studies are illustrated in table. 2. Both blends exhibited distinct sensory characteristics, including color (8.5 ± 0.3) and aroma (8.3 ± 0.1). These sensory evaluations differ from previous assessments of millet-based milk blends, which generally received a rating of 7.8 or 7.9 overall [18]. The FiCo3 milk blend which contains 80% finger millet and 20% coconut milk, an overall acceptance score of 7.8, which is closest to sensory score of the top-performing combination, T2 reported in previous studies [3].

Determination of physiochemical parameters

The FiCo3 milk blend, due to its unique attributes, showed the highest moisture content 88.6 ± 0.7 and 0.7 ± 0.1 ash content compared to control sample cow's milk which contained 81.3 ± 0.06 moisture content and the lowest ash content 1.9 ± 0.03 (Table. 3). Initially, the pH levels of all samples ranged from 5.59 to 6.84, reflecting a consistent level of acidity. The FiCo3 milk blend exhibited a total soluble solids content of 4.2 ± 0.1 , suggesting increased mineral residue and humidity retention. Finger millet milk displayed a higher total soluble solids (TSS) content of 3 ± 0.42 due to its greater concentration of soluble minerals and carbohydrates compared to barnyard millet milk. Little millet, kodo millet milk, and barnyard millet milk each recorded TSS values of 2 ± 0.06 [19]. In the present study, finger millet milk, displayed a TSS value of 3.1, which is consistent with previous findings. Variation in total soluble solids (TSS) in finger millet milk can arise due to differences in analytical methods, millet varieties, and processing techniques used [20]. Coconut milk and millet displayed significantly different nutritive and physical characteristics ($p < 0.05$). The dilution resulted in a decrease in the moisture content of coconut milk. Previous studies showed similar findings [21].

Determination of macronutrient content

The results of macronutrient analysis are illustrated in Table. 4. Coconut milk is a calorie-dense plant-based milk alternative that surpasses cow's milk in energy and fat content. It contains 272.9 ± 0.01 kCal of energy, 5.6 ± 0.5 g of protein, and 24.9 ± 0.9 g of fat. Containing 46.2 ± 0.04 kCal of energy, 2.3 ± 0.4 g of protein, and 0.3 ± 0.05 g of fat, finger millet milk serves as an excellent low-calorie, low-fat choice. The milk blend, FiCo3, featuring a moderate energy value of 156.4 ± 0.3 kCal, contains a protein content of 5.2 ± 0.8 g and moderate fat content of 11.2 ± 0.3 g. Importantly, these lipids promote heart health as they're mainly unsaturated and free from cholesterol [22]. The coconut milk produced in this present study contained a 5.6g of protein which is similar to the 5.8% protein content reported in domestic coconut milk [23]. However, our results contradict with the findings of Tulasiet al., [2], which reported approximately 135.94 kCal, 14.12% protein, and 2.2% fat in domestic coconut milk. These significant variations highlight considerable diversity, which may be attributed to differences in coconut species or the analysis method used.

Determination of micronutrients, and antioxidant activity

Compared to cow's and coconut milk, the FiCo3 milk blend contained significantly higher levels of calcium 380.3 mg^{-1} and iron 4.6 mg^{-1} (Table 5). These results suggest that finger millet can enhance the mineral content of plant-based milk alternatives, including the FiCo3 milk blend. Although this milk blend exhibited only mild antioxidant activity ($39.4\% \pm 0.02$) due to presence of flavonoids and polyphenols, but it remains favourable. Earlier findings have indicated that increasing the amount of coconut milk in the mixture boosts the overall mineral content [3]. The





highest antioxidant activity of 46.2% was recorded for finger millet milk followed by coconut milk finger millet and coconut milk of (44.4%) as indicated in Table. 6. However, the blend showed an antioxidant activity of 39.4%. Coconut milk is rich in antioxidant proteins and phenolic compounds, which help sustain balanced antioxidant activity by counteracting free radicals and hence shows an activity.

Microbial analysis

The microbial analysis showed that the total plate count (TPC) of finger millet and coconut milk blend varied during storage. On Day 1, the TPC was $2 \times 10^5 \pm 0.09$ CFU- ml^{-1} indicating a minimum initial microbial load. By Day 5, the TPC increased to $33 \times 10^5 \pm 0.05$ CFU- ml^{-1} , followed by a reduction to $3 \times 10^5 \pm 0.1$ CFU- ml^{-1} on Day 10. Throughout the 10-day storage period, no yeast or mold was detected, suggesting that they were either absent or present at levels below the detection threshold (Table. 7). Early microbial growth remained significant although the decline observed on Day 10 suggests a period of stabilization. The consistent rise in TPC by Day 5 highlights the necessity of using preservatives or refrigeration to prevent bacterial growth. Increasing from 1.2×10^3 to 1.5×10^5 CFU- ml^{-1} , the TPC indicates the sensitivity of milk blends to microbial growth. This significant variation in microbial growth of finger millet-based milk, may result from differences in raw materials, processing, storage conditions, or hygiene practices, emphasizes the need for improved processing methods [24].

CONCLUSION

Plant-based milk alternatives are an excellent option for health-conscious individuals avoiding lactose, as they contain lower saturated fat and calorie content compared to dairy milk. The blend developed holds great potential as an alternate to dairy milk and a lactose-free beverage. Future research could focus on its role in supporting weight loss, preventing diabetes, promoting heart health, and strengthening bones. The FiCo3 milk blend is a nutrition-packed, eco-friendly, and culturally significant plant-derived milk substitute with greater consumer approval and market potential.

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Table 1: The milk yield of finger millet milk and coconut milk

Ratios composition	Finger millet milk (mL)	Coconut milk (mL)
1:1 (w/v)	80±0.05	175±0.08
1:2 (w/v)	145±0.04	225±0.17
1:3 (w/v)	270±0.2	330±0.41
1:4 (w/v)	310±0.07	410±0.15
1:5 (w/v)	455±0.3	525±0.18

Mean ± SD; n=3

Table 2: The mean sensory scores of different milks and plant-based milk alternative blends V_o- Cow's milk, VFM-Finger millet milk.VCM-Coconut milk; FiCo1- 60% finger millet milk extract, 40% coconut milk extract; FiCo2- 70% finger millet milk extract, 30% coconut milk extract; FiCo3- 80% finger millet milk extract, 20% coconut milk extract

Parameters	V _o	VFM	VCM	Fico1	FiCo2	FiCo3	p-value
Colour	8.1±0.2	8.1±0.1	8.5±0.3	8.1±0.2	7.8± 0.05	7.9±0.1	<.001**
Aroma	7.9± 0.1	8.3±0.1	8.3±0.05	8.06±0.1	7.7±0.2	7.8±0.05	<.001**
Consistency	8.06±0.2	8.2±0.1	8.2±0.1	7.9±0.2	7.8±0.2	7.8±0.3	<.001**
Taste	8.03±0.2	8.2±0.2	8.4±0.05	8.3±0.2	7.9±0.3	7.9±0.4	<.001**
Mouthfeel	8.1±0.3	8.2±0.1	8.2±0.2	8.3±0.2	7.8±0.05	7.7±0.2	<.001**
Overall acceptability	8.0±0.4	8.2±0.05	8.3±0.1	8.2±0.2	7.8±0.2	7.8±0.3	<.001**

Mean ± SD; n=3 ** significantly different (p<0.01), *significantly different (p<0.05) by ANOVA

Table 3: The mean scores of physicochemical parameters of different milk, and plant-based milk alternative blends V_o-Cow's milk VFM-Finger millet milk.VCM-Coconut milk, FiCo3- 80% finger millet extract, 20% coconut milk extract.

Parameters	V _o	VFM	VCM	FiCo3	p-value
Moisture %	88.6±0.7	81.8±0.05	78.3±0.5	81.3±0.06	<.001**
Ash %	0.7±0.1	1.4±0.3	1.5±0.1	1.9±0.03	<.001**
pH	6.69	6.48	6.56	5.59	0.42*
TSS	13.5±0.04	3.7±0.5	3.1±0.06	4.2±0.1	<.001**

Mean ± SD; n=3 ** significantly different (p<0.01), *significantly different (p<0.05),

Table 4: The mean macronutrient content of different milk and plant-based milk alternative blends V_o-Cow's milk VFM-Finger millet milk. VCM-Coconut milk, FiCo3- 80% finger millet extract, 20% coconut milk extract

Parameters	V _o	VFM	VCM	FiCo3	p-value
Energy (kCal/100ml)	64.2±0.1	46.2±0.04	272.9±0.01	156.4±0.3	<.001**
CHO (g/100ml)	4.2±0.2	8.4±0.9	6.6±0.4	8.7±0.6	<.001**
Protein (g/100ml)	3.3±0.1	2.3±0.4	5.6±0.5	5.2±0.8	<.001**
Fat (g/100ml)	3.8±0.2	0.3±0.05	24.9±0.9	11.2±0.3	<.001**

Mean ± SD; n=3 ** significantly different (p<0.01), *significantly different (p<0.05),





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Table 5: The mean micronutrient Content of different milk and plant-based milk alternative blends V_o-Cow's milk VFM-Finger millet milk. VCM-Coconut milk, FiCo3- 80% finger millet extract, 20% coconut milk extract

Parameters	V _o	VFM	VCM	FiCo3	p-value
Calcium	116±0.8	380±0.3	7±0.2	292.2±0.6	<.001**
Iron	0.05±0.06	4.6±0.9	0.024±0.05	3.81±0.3	<.001**

Mean ± SD; n=3 ** significantly different (p<0.01), *significantly different (p<0.05),

Table 6: The mean antioxidant activity of different milk and plant-based milk alternative blends V_o-Cow's milk VFM-Finger millet milk. VCM-Coconut milk, FiCo3- 80% finger millet extract, 20% coconut milk extract

Parameters	V _o	VFM	VCM	FiCo3	p-value
Antioxidant activity (%)	25.1± 0.09	46.2± 0.5	44.4± 0.1	39.4±0.02	<.001**

Mean ± SD; n=3, ** significantly different (p<0.01), *significantly different (p<0.05),

Table 7: The microbial analysis of blended milk FiCo3

Storage Time	TPC (10 CFU ^{-mL})	Yeast and mold
Day 1	2 ×10 ⁶ ±0.09	ND
Day 5	33 ×10 ⁶ ±0.05	ND
Day 10	3 ×10 ⁶ ±0.1	ND

ND-Not detected, Mean ± SD; n=3

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REVIEW ARTICLE

Review on Engineering Porous Biopolymeric Gels for Regenerative Medicine: Structural Design Strategies for Mechanical Stability and Biological Performance

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ABSTRACT

Porous biopolymeric gels have emerged as sophisticated scaffold systems that incorporate hydration mimicking the extracellular matrix, interconnected porosity and adjustable mechanical properties for regenerative medicine. Their effectiveness is influenced by factors such as polymer composition, pore structure, crosslinking chemistry and fabrication methods, which together control cellular infiltration, nutrient transport, biodegradation and mechanotransduction. This review provides a systematic analysis of the classification of natural, synthetic and hybrid gels; essential design parameters; key crosslinking methods; and fabrication techniques including sol-gel processing, cryogelation, freeze-drying,



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interpenetrating polymer networks, injectable gelation and three-dimensional bioprinting. Sections focused on applications emphasize their usefulness in therapies related to skeletal, osteochondral, dermal, vascular, neural, cardiac and immunomodulation. Recent advancements indicate that the thoughtful engineering of network topology and physicochemical characteristics can resolve the longstanding trade-off between porosity and mechanical strength. Thus, porous biopolymeric gels serve as a strong and clinically applicable platform for the next generation of regenerative therapeutics.

Keywords: Porous biopolymeric gels, regenerative medicine, tissue engineering, crosslinking Strategies, scaffold fabrication, mechanical robustness, biomimetic scaffolds, controlled biodegradation

ABBREVIATIONS

ECM – Extracellular Matrix; PEG – Polyethylene Glycol; PVA – Polyvinyl Alcohol; IPN – Interpenetrating Polymer Network; 3D – Three-Dimensional; FAK – Focal Adhesion Kinase; MAPK – Mitogen-Activated Protein Kinase; YAP – Yes-Associated Protein; TAZ – Transcriptional Co-Activator with PDZ-Binding Motif; DNA – Deoxyribonucleic Acid; RNA – Ribonucleic Acid; AI – Artificial Intelligence; CAD – Computer-Aided Design; MMP – Matrix Metalloproteinase; VEGF – Vascular Endothelial Growth Factor; BMP – Bone Morphogenetic Protein; M1 – Classically Activated Macrophage Phenotype; M2 – Alternatively Activated Macrophage Phenotype; pH – Potential of Hydrogen; UV – Ultraviolet; CaP – Calcium Phosphate; SEM – Scanning Electron Microscopy.

INTRODUCTION

Background and evolution of porous biopolymeric gels

Porous biopolymeric gels have advanced from simple water-saturated polymer networks to highly sophisticated biomaterials that can replicate essential structural and functional aspects of the extracellular matrix [1,2]. Initially, hydrogel systems were primarily recognized for their high hydration and cytocompatibility; however, their dense architecture and limited mechanical properties restricted tissue integration [3]. Subsequent innovations in cryogelation, freeze-drying and sol-gel processing enabled the formation of interconnected pore networks that support cell infiltration, vascularization and effective mass transport [4,5]. Parallel advancements in polymer chemistry introduced controllable crosslinking strategies, allowing for precise regulation of stiffness, degradation and viscoelastic behavior [6]. The integration of natural and synthetic polymers has further enhanced design flexibility by combining biological recognition with structural reproducibility. Consequently, porous biopolymeric gels now serve as a versatile scaffold platform capable of addressing the specific mechanical and biological requirements of both soft and load-bearing tissues in regenerative medicine [2,3].

Importance in regenerative medicine

Porous biopolymeric gels play a crucial role in regenerative medicine as they mimic the physicochemical and biomechanical properties of the natural extracellular matrix [1,3]. Their interconnected macroporous structure promotes cell adhesion, migration, proliferation and lineage-specific differentiation, while also allowing for the convective and diffusive transport of oxygen, nutrients, cytokines and metabolic waste [2,5]. The ability to tune viscoelasticity, degradation rates and bioactive surface chemistry enables precise control over mechanotransduction and cell-matrix signaling [3,6]. Additionally, these scaffolds can concentrate growth factors and therapeutic agents, creating instructive microenvironments that enhance angiogenesis, immunomodulation and tissue remodeling [2,7]. As a result, porous biopolymeric gels act as biomimetic matrices for the functional regeneration of complex tissues that are both structurally and physiologically intricate [1,3].



**Karanam Mithun et al.,****Challenges in balancing porosity and mechanical strength**

The main design challenge in porous biopolymeric gels lies in the inverse relationship between porosity and mechanical integrity [1,3]. While increasing pore volume and interconnectivity promotes cellular infiltration, vascularization and mass transport, it simultaneously decreases the effective load-bearing area and diminishes compressive modulus, tensile strength and fracture resistance [1,5]. On the other hand, a higher crosslink density enhances stiffness and dimensional stability but limits pore accessibility and matrix permeability [3,6]. Therefore, achieving both macroporosity and structural robustness necessitates hierarchical architectures, optimized network topology and energy-dissipating polymer configurations that separate biological functionality from mechanical performance [1,7].

Scope and objectives of the review

This review provides a critical assessment of the choices of materials, pore engineering, crosslinking approaches and the methodologies used in the fabrication of porous biopolymeric gels. Its goal is to establish design principles that merge mechanical durability, controlled biodegradation and biological performance for regenerative scaffolds applicable in a range of tissue engineering scenarios.

Classification of Biopolymeric Gels**Natural polymer-based gels**

Natural polymer-based gels are synthesized from biomacromolecules such as collagen, gelatin, alginate, chitosan, hyaluronic acid, fibrin and cellulose derivatives [1,3]. Their primary advantage is their inherent bioactivity, which includes cell-adhesive motifs, enzymatic degradability and a structural likeness to native extracellular matrix components [1,4]. These materials enable integrin-mediated adhesion, cytoskeletal organization and lineage-specific differentiation in physiologically relevant environments [14,5]. However, their networks often display a low elastic modulus, rapid hydrolytic or enzymatic degradation and variability between batches due to biological sourcing. The mechanical performance is often improved through covalent crosslinking, polymer blending, or the creation of interpenetrating networks, while still maintaining their favorable cytocompatibility and tissue-integrative features [2,6].

Synthetic polymer-based gels

Synthetic polymer-based gels are made from materials like polyethylene glycol, polyvinyl alcohol, polyacrylamide and copolymers derived from polycaprolactone [3]. These systems provide precise control over factors such as molecular weight, crosslink density, network topology and degradation kinetics, allowing for reproducible adjustments of elastic modulus, swelling ratio and mesh size [4,5]. Their chemical consistency reduces batch variability and supports scalable production [2,3]. However, they typically do not possess intrinsic cell-recognition domains, necessitating biofunctionalization with adhesive peptides, polysaccharides, or protein derivatives to promote cellular attachment and signaling. Synthetic gels are especially important when consistent mechanical performance, long-term structural stability and tightly controlled physicochemical properties are critical for the design of regenerative scaffolds [2,7].

Hybrid and composite gel systems

Hybrid and composite gel systems combine natural and synthetic polymers to synergistically merge bioactivity with mechanical reliability [1]. The natural components offer cell-interactive motifs and enzymatically degradable domains, while the synthetic parts provide structural consistency and adjustable viscoelastic properties [2,4]. In composite designs, secondary phases such as ceramics, bioactive glass, or fibrous reinforcements enhance stiffness, fracture resistance and dimensional stability [5,7]. These multiphase networks facilitate independent modulation of degradation behavior, swelling and biomechanical performance [6,8]. By decoupling biological functionality from structural reinforcement, hybrid and composite gels present a versatile platform for creating scaffolds that closely replicate the biochemical and mechanical heterogeneity of native tissues [2,8].



**Karanam Mithun et al.,****Structural categories: hydrogels, cryogels and aerogels**

Hydrogels are networks of polymers that absorb water, noted for their high hydration, nanoscale mesh structures and viscoelasticity akin to that of biological tissues. Their soft and permeable matrices enable the diffusion-driven transport of nutrients and signaling molecules, rendering them suitable for cell encapsulation and soft tissue regeneration. Nevertheless, conventional hydrogels frequently exhibit limited pore interconnectivity and only modest mechanical strength [3,5]. Cryogels are produced by crosslinking in partially frozen conditions, where solvent crystals function as porogens. Upon thawing, they result in highly interconnected macroporous networks with pore sizes typically ranging from tens to hundreds of micrometers. Their sponge-like architecture facilitates rapid fluid perfusion, efficient cellular infiltration and outstanding elastic recovery after compression, making them particularly effective for load-bearing and injectable applications [7,8]. Aerogels are created by removing solvent from wet gels while preserving the three-dimensional network [9,10]. They are known for their ultralow density, extremely high porosity and large specific surface area. These characteristics provide exceptional absorptive capacity and diffusion properties, although their mechanical brittleness may require secondary reinforcement. Collectively, these structural categories present distinct combinations of porosity, stiffness and transport behavior tailored to various regenerative requirements [10,11].

Injectable and in situ forming gels

Injectable and in situ forming gels are delivered as precursor solutions or shear-thinning formulations that gel directly at the defect site [1,3]. The formation of the network is initiated by thermal transitions, ionic interactions, enzymatic reactions, pH changes, or photoactivation [2,5]. This method allows for minimally invasive delivery, uniform cell encapsulation and accurate adaptation to irregular anatomical shapes [3,6]. It is essential to carefully balance gelation kinetics to maintain injectability while avoiding premature leakage [4,5]. These systems are extensively used for localized drug delivery, soft tissue enhancement and regenerative therapies, where conforming architecture, controlled degradation and minimized surgical trauma are vital for therapeutic success [6,7]. Table 1 shows Comparison between different types of biopolymeric gels

Critical Design Parameters

The functional performance of porous biopolymeric gels is governed by a tightly interconnected set of structural, physicochemical and biomechanical parameters. Factors such as pore topology, network mechanics, swelling thermodynamics, degradation kinetics, interfacial bioactivity and mass transport collectively influence cell fate and tissue integration. Thus, effective scaffold engineering requires the simultaneous optimization of these variables to achieve reliable and tissue-specific regenerative results.

Pore architecture and interconnectivity

Pore architecture is essential in regulating the spatial organization of cells and the transport of solutes within the scaffold. Key descriptors include the distribution of pore sizes, tortuosity, connectivity density and anisotropy [2,4]. Macropores promote cellular infiltration and neovascularization, while micropores increase the surface area available for protein adsorption and matrix anchorage [3,5]. High interconnectivity reduces diffusion dead zones and creates continuous pathways for the exchange of oxygen and nutrients [4,6]. Hierarchical architectures that integrate multiple pore scales more accurately replicate the heterogeneity of the native extracellular matrix and enhance biomechanical load transfer [5,7]. However, excessive porosity can lead to a decrease in strut thickness and an increase in stress concentration, making the network prone to mechanical collapse [2,8]. Therefore, pore topology must be designed to maximize biological accessibility while maintaining structural integrity and compressive stability under physiological loading conditions [3,7].



**Karanam Mithun et al.,****Mechanical strength and viscoelastic properties**

The mechanical performance of a scaffold is crucial for its capacity to endure both static and cyclic physiological loads without experiencing plastic deformation or structural failure. Important parameters include elastic modulus, compressive strength, tensile toughness, fracture energy and fatigue resistance [2,4]. Biopolymeric gels demonstrate viscoelastic properties, which are defined by time-dependent stress relaxation, creep compliance and hysteretic energy dissipation due to reversible molecular rearrangements [3,5]. These characteristics influence mechanotransduction by modulating cytoskeletal prestress, focal adhesion maturation and nuclear deformation [5,6]. Matching tissue-specific modulus is vital to avoid stress shielding and to guide lineage commitment through cues provided by matrix stiffness [6,7]. Traditional highly hydrated networks typically show limited toughness due to a low polymer volume fraction and weak intermolecular interactions [3,8]. Mechanical reinforcement can be achieved by increasing crosslink density, utilizing double-network architectures, incorporating sacrificial bonds and employing interpenetrating polymer configurations that dissipate energy through reversible bond rupture [8,9]. The best designs integrate high resilience, quick elastic recovery and resistance to cyclic degradation while ensuring interconnected porosity and biological permissiveness [2,9].

Swelling and water retention behaviour

The swelling behaviour is influenced by the thermodynamic balance between the affinity of the polymer for the solvent and the elastic retractive forces within the crosslinked network. The uptake of water determines the mesh size, diffusivity, osmotic pressure and compliance akin to that of tissue [4]. Sufficient hydration is vital for maintaining a pericellular microenvironment that supports protein mobility, ion transport and biomolecular signalling [3,5]. When swelling is excessive, it can cause pore walls to expand, decrease effective crosslink density and undermine dimensional stability and mechanical stiffness [4,6]. Conversely, inadequate swelling can limit permeability and disrupt metabolite exchange [3,5]. Water retention is affected by the hydrophilicity of the polymer, ionic charge density, crystallinity and the heterogeneity of the network [2]. Furthermore, polyelectrolyte gels also show Donnan swelling due to an imbalance of counterions [7,8]. Thus, it is essential to control equilibrium swelling to maintain scaffold geometry, regulate release kinetics and uphold structural integrity throughout the processes of implantation and tissue remodeling [1,5].

Biodegradation and scaffold longevity

Biodegradation refers to the duration of the scaffold's existence and its ability to offer mechanical support during the process of tissue regeneration. The degradation occurs through mechanisms such as hydrolytic cleavage, enzymatic catalysis, oxidative scission, or the dissociation of reversible crosslinks [2,5]. The kinetics are influenced by factors including polymer chemistry, crystallinity, crosslink density and local biochemical conditions [4,6]. Ideally, the loss of mass and reduction in modulus should coincide with the deposition of the extracellular matrix and the maturation of host tissue [1,7]. If degradation occurs too early, it can result in structural failure, while excessive persistence may hinder remodeling and trigger chronic foreign body reactions [5,8]. The byproducts of degradation must be non-cytotoxic, non-immunogenic and easily metabolized or excreted [4,8]. Thoughtful management of scaffold longevity guarantees a coordinated transfer of load from the biomaterial to the regenerating tissue [1,7].

Surface characteristics and cell–material interactions

The scaffold interface plays a crucial role in regulating the initial adsorption of serum proteins, which subsequently determines cellular responses downstream. Elements such as surface chemistry, charge density, wettability and nanoscale roughness significantly influence integrin engagement, focal adhesion assembly and the activation of signaling pathways including FAK, MAPK and YAP/TAZ [4,6]. While natural polymers often contain intrinsic ligands for receptor-mediated adhesion, synthetic matrices typically require biofunctionalization with peptides or motifs from the extracellular matrix [7,8]. Surfaces that are moderately hydrophilic tend to favor selective protein adsorption and decrease nonspecific denaturation [9,10]. Surface-bound morphogens and matrix-bound cytokines can provide localized instructive cues that steer osteogenic, chondrogenic, angiogenic, or neurogenic differentiation



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[11,12]. Thus, interfacial engineering is vital for controlling cytocompatibility, immunomodulation and the regeneration of tissue specific to its type [8,13].

Nutrient transport and oxygen diffusion

The mass transport within porous gels is controlled by diffusion, convection and partitioning through the hydrated polymer network. Effective transport is dependent on factors such as pore connectivity, tortuosity, permeability and equilibrium water content [2,4]. Oxygen diffusion is especially critical since hypoxic gradients can develop rapidly in thick cellular constructs [5,6]. Interconnected macropores help to decrease transport resistance and ensure a uniform distribution of glucose, amino acids, growth factors and dissolved gases, while also facilitating the removal of metabolic waste [7,8]. Inadequate transport can lead to nutrient depletion, acidosis and the formation of necrotic cores [5,9]. Consequently, scaffold architecture must be designed to minimize diffusional limitations and sustain cellular homeostasis throughout the regenerating tissue volume [4,10].

Integrated optimization of scaffold properties

The design variables that influence porous biopolymeric gels are significantly interrelated and cannot be optimized separately. Increasing the crosslink density typically improves modulus and reduces creep, but it also decreases mesh size, equilibrium swelling and enzymatic accessibility [4,6]. Enhancing porosity facilitates cellular infiltration and mass transport, yet it diminishes the effective load-bearing area and fracture resistance [7,9]. Surface functionalization encourages receptor-mediated adhesion but may change hydrophilicity and degradation behavior [10,11]. Similarly, accelerated biodegradation promotes matrix remodeling but can weaken mechanical support before adequate neo tissue deposition takes place [12,13]. Consequently, effective scaffold engineering depends on a systems-level design approach that harmonizes thermodynamic, kinetic and biomechanical constraints [14,15]. Hierarchical pore structures, gradient crosslinking and multiphase polymer networks allow for independent adjustment of transport, stiffness and degradation [16,17]. Quantitative metrics such as storage modulus, permeability and degradation half-life offer objective benchmarks for optimization [6,18]. Computational modeling, design-of-experiments techniques and multivariate analysis further minimize empirical trial-and-error [15,19]. By integrating parameter control, porous biopolymeric gels can be customized to replicate the structural, mechanical and biological intricacies of native tissues while ensuring strong translational potential [14,20]. In summary, these design parameters establish the structure-property-function relationship of porous biopolymeric gels [3,20]. Their coordinated optimization is crucial for developing biomimetic scaffolds with predictable mechanics, biological responsiveness and long-term regenerative effectiveness [15,18].

Crosslinking Strategies

Crosslinking determines the molecular configuration of biopolymeric gels by creating junctions that influence network density, pore stability, viscoelasticity and degradation kinetics. The mechanism chosen influences scaffold mechanics, injectability and cytocompatibility, thus significantly affecting regenerative performance and clinical application. **Figure 1** shows schematic illustration of major crosslinking strategies used in porous biopolymeric gels and their relative effects on mechanical strength, degradation behavior, injectability and cytocompatibility.

Covalent crosslinking approaches

Covalent crosslinking creates permanent chemical bonds between reactive functional groups like amines, carboxyls, thiols and hydroxyls. This approach results in mechanically strong networks that exhibit high dimensional stability and extended resistance to hydrolytic breakdown [4,5]. The properties of the network are influenced by the functionality of the crosslinker and the stoichiometric ratio [3,6]. While covalent structures offer enhanced modulus and structural durability, an excessive density of crosslinks can hinder pore accessibility and increase brittleness, making it essential to optimize carefully to maintain both mechanical integrity and biological compatibility [7,8].



**Karanam Mithun et al.,****Physical network formation mechanisms**

Physical gelation occurs due to non-covalent interactions such as ionic coordination, hydrogen bonding, hydrophobic association, crystallite formation and supramolecular host-guest recognition. These reversible interactions facilitate gel formation in mild aqueous environments without the need for reactive crosslinking agents [2,4]. Networks that are physically assembled demonstrate shear-thinning, self-healing and stress-relaxation properties, which are beneficial for injectable applications [5,6]. Nonetheless, their junctions are thermodynamically unstable and can dissociate when there are changes in ionic strength, temperature, or pH [1,4]. The mechanical stability can be improved by increasing polymer entanglement or by adding secondary reinforcing domains [5,9].

Enzymemediated gelation

Enzyme-mediated gelation utilizes biocatalysts to form covalent bonds at physiological temperature and pH. This method provides outstanding cytocompatibility and accurate kinetic control while steering clear of harsh reagents [2,4]. The rate of gelation and the density of the network can be adjusted by varying enzyme concentration and substrate availability [3,5]. Since polymerization occurs in aqueous environments, this technique is especially appropriate for cell encapsulation, minimally invasive delivery and the creation of bioresponsive scaffolds [4,6].

Light-triggered crosslinking methods

Light-activated crosslinking depends on photoactivatable functional groups that undergo polymerization when exposed to ultraviolet or visible light. This method provides spatiotemporal control over gelation, facilitating on-demand adjustments of crosslink density, stiffness gradients and microscale patterning [2,4]. Factors such as exposure parameters, photo initiator concentration and oxygen levels affect the efficiency of the reaction and the resulting network structure [3,5]. Systems utilizing visible light are becoming more favored as they minimize phototoxicity and enhance compatibility with living cells, growth factors and delicate biomolecules integrated into the scaffold [6,7].

Dual-network and hybrid crosslinking systems:

Dual-network and hybrid systems incorporate two or more orthogonal crosslinking mechanisms to address the shortcomings of single-mode gelation. Generally, one network offers rigidity and load-bearing capabilities, while a second reversible network dissipates mechanical energy through the rupture and reformation of sacrificial bonds [4,5]. This synergistic design significantly enhances fracture toughness, fatigue resistance and elastic recovery [4,6]. Hybrid systems can integrate covalent, physical, enzymatic and photochemical interactions to independently manage injectability, porosity, degradation and stiffness [3,8]. Such multiscale designs are especially effective in mechanically demanding tissues where both resilience and biological adaptability are essential [6,9].

Influence of crosslinking on mechanical and biological performance

Crosslinking density has a direct effect on mesh size, equilibrium swelling, elastic modulus and degradation rate. An increase in network connectivity usually results in greater stiffness and dimensional stability, but it can also limit cellular infiltration and nutrient transport [2,4]. The chemistry involved in crosslinking further influences protein adsorption, immune recognition and cell-mediated remodeling [6,8]. Thus, it is important to select a crosslinking strategy that balances mechanical strength with permeability, biodegradability and cytocompatibility [9]. Crosslinking serves as the molecular basis for porous biopolymeric gels, combining structural stability with biological functionality [9,10]. The strategic selection and combination of crosslinking mechanisms provide precise control over network architecture, allowing scaffolds to achieve tissue-specific mechanical properties, regulated degradation and regenerative responsiveness, which are essential for effective clinical translation [10,11].

Fabrication Techniques

The fabrication process governs pore morphology, network topology and mechanical anisotropy, thus influencing the structural and biological performance of porous biopolymeric gels in regenerative applications, **Table 2** shows Comparative assessment of fabrication techniques for porous biopolymeric gels



**Karanam Mithun et al.,****Solgel processing**

Sol-gel processing refers to the transformation of polymeric or hybrid precursors from a colloidal sol into a percolated three-dimensional network via hydrolysis, condensation, or crosslinking reactions. This technique allows for molecular-level control over composition, crosslink density and nano structural uniformity [2,4]. Factors such as precursor concentration, solvent polarity, pH, ionic strength and aging time influence gelation kinetics and pore development [3,5]. The subsequent drying process maintains the interconnected network, resulting in highly porous structures with a large specific surface area and adjustable mechanical properties [1,6]. Sol-gel processing is especially beneficial for creating aerogel-like matrices and hybrid systems that require a uniform architecture, controlled porosity and precise adjustments in degradation and mechanical performance [6,7].

Cryogelation

Cryogelation takes place under subzero temperatures, where the partial crystallization of the solvent leads to phase separation and the concentration of polymers within unfrozen microdomains [8,10]. Crosslinking happens around these ice templates and upon thawing, a highly interconnected macroporous network is formed [8,11]. The size of the pores and the thickness of the walls are influenced by the freezing temperature, cooling rate, polymer concentration and gelation kinetics [9,12]. Cryogels are characterized by low flow resistance, quick swelling and remarkable elastic recovery due to their sponge-like structure [10,11]. Their capacity to endure reversible compression without losing structural integrity makes them especially ideal for injectable scaffolds and applications that require load-bearing [11,13]. Cryogelation is extensively utilized when high permeability, mechanical strength and effective cell infiltration are necessary [8,13].

Freezedrying and porogenbased techniques

Freeze-drying creates porous scaffolds by first freezing a hydrogel precursor and then removing the solvent via sublimation under reduced pressure [14,16]. Ice crystals act as sacrificial templates that determine the morphology of the pores [14,17]. Quick freezing results in smaller, more uniform pores, while slower cooling leads to larger and more anisotropic structures [15,17]. Porogen-based techniques utilize removable particulate templates like salts, sugars, or gas-generating agents to form controlled voids [16,18]. Both methods achieve high porosity and interconnected pathways, but they may compromise mechanical strength due to thin pore walls and structural variability [17,19]. Crosslinking after fabrication is frequently used to enhance dimensional stability and resistance to deformation when subjected to physiological loads [18,19].

Interpenetrating polymer network fabrication

Interpenetrating polymer networks are created by either sequentially or simultaneously constructing two distinct yet physically intertwined networks. This design redistributes stress across various phases and improves fracture energy, toughness and fatigue resistance [2,4]. The ability to independently control each network allows for the concurrent adjustment of stiffness, swelling and degradation, rendering IPN fabrication particularly effective for mechanically challenging regenerative scaffolds [3,6].

Injectable and in situ gelation approaches

Injectable systems are provided as low-viscosity precursors that gel within the defect site when exposed to thermal, ionic, enzymatic, or photochemical stimuli. This approach allows for minimally invasive delivery and precise fitting to irregular shapes. Effective formulations necessitate optimized rheological properties, quick gelation and sufficient mechanical stability after implantation [9,11].

Three-dimensional bioprinting and emerging technologies

Three-dimensional bioprinting utilizes a layer-by-layer approach to deposit cell-laden bioinks, forming scaffolds with specific geometries, pore orientations and compositional gradients. The fidelity of the print is influenced by factors such as shear-thinning behavior, yield stress and the kinetics of post-print crosslinking [13,15]. This innovative technology provides spatial control over mechanical heterogeneity and localized biofunctionalization, which aids in the recreation of intricate tissue architectures [14,16]. Newly developed techniques, such as digital light processing,



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microfluidic templating and electrohydrodynamic printing, enhance resolution and structural precision [17,19]. The combination of computer-aided design and computational modeling facilitates predictive optimization of scaffold architecture, allowing for the creation of patient-specific constructs with precisely controlled biomechanical and biological properties [21,22].

Biomedical Applications

The integration of porous biopolymeric gels has enabled the design of application-specific scaffolds that incorporate tissue-matched mechanics, hierarchical porosity and localized bioactivity, which collectively support functional regeneration in a wide array of structurally and physiologically diverse tissues.

Skeletal tissue reconstruction:

Porous gels created for skeletal repair must ensure the presence of osteoconductive microenvironments, exhibit high compressive resilience and possess interconnected macroporosity to facilitate vascular invasion and the deposition of a mineralized matrix. Composite cryogels that are reinforced with calcium phosphate phases are particularly effective as they blend load-bearing capacity with controlled biodegradation [4,6].

Dermal repair and chronic wound management

Cutaneous regeneration requires scaffolds that can sustain a hydrated microenvironment, absorb exudate and shield against microbial contamination, all while facilitating fibroblast infiltration and re-epithelialization. Porous biopolymeric gels made from gelatin, alginate and chitosan demonstrate advantageous oxygen permeability, haemostatic properties and degradation that responds to matrix metalloproteinases. Their high-water content helps prevent desiccation and the interconnected porosity speeds up the formation of granulation tissue and neovascularization. Mechanical compliance reduces shear-induced trauma at the wound interface [3,8].

Guided angiogenesis and microvascular regeneration

The formation of vascularized tissue relies on scaffolds that possess high permeability, interconnected pore channels and the ability to signal pro-angiogenic activity. Porous gels facilitate endothelial sprouting, the creation of lumens and the anastomosis of host vessels by allowing for oxygen transport and matrix remodeling [6].

Localized therapeutic delivery platforms

Porous biopolymeric gels serve as depot systems for proteins, peptides, nucleic acids and small-molecule therapeutics. The release of drugs is influenced by factors such as mesh size, degradation kinetics and interactions between the polymer and the drug, allowing for sustained and localized delivery. Their hydrated structure protects sensitive biomolecules and reduces systemic exposure [23].

Post-surgical tissue reconstruction

After the resection of a tumor or following trauma, biomaterials are needed to fill irregular cavities, prevent the creation of dead space and support quick tissue integration. Porous gels conform to complex anatomical structures and provide temporary structural support while offering haemostatic, antimicrobial, or regenerative cues. Their interconnected pore networks facilitate the infiltration of fibroblasts, endothelial cells and progenitor populations, which speeds up functional restoration and reduces scar formation [24].

Soft tissue augmentation and defect filling

The process of soft tissue restoration requires materials that possess a low elastic modulus, high fidelity in shape retention and a gradual biodegradation capability. Porous gels serve to distribute mechanical loads uniformly and enable the infiltration of host cells, facilitating a progressive replacement by natural adipose or connective tissue. Injectable formulations are particularly useful for contour adjustments and volumetric reconstruction [25].



**Karanam Mithun et al.,****Immunomodulatory and anti-inflammatory applications:**

In addition to providing structural support, porous gels have the ability to modulate both innate and adaptive immune responses by regulating cytokine presentation, macrophage polarization and leukocyte infiltration. Matrix stiffness, degradation products and surface chemistry work together to affect the shift from pro-inflammatory M1 to regenerative M2 phenotypes. This capacity for immunoregulation helps to diminish chronic inflammation and encourages constructive remodeling [26].

Comparative assessment of fabrication methods

Each fabrication technique has its own set of advantages tailored to specific applications. Sol-gel processing enables nanoscale compositional control and extremely high porosity, although it may require longer processing times [2]. Cryogelation results in mechanically durable macroporous scaffolds with excellent permeability. Freeze-drying and porogen leaching are simple to operate and highly versatile, but they often lead to mechanical fragility. The fabrication of interpenetrating polymer networks provides outstanding toughness and fatigue resistance [7,8]. Injectable gelation allows for minimally invasive delivery, while three-dimensional bioprinting facilitates precise spatial patterning and customization for individual patients. The choice of method should be guided by the desired pore architecture, mechanical requirements, degradation profile and translational feasibility [12,14]. The fabrication strategy ultimately dictates the architecture and performance of the scaffold, translating molecular designs into constructs that are clinically relevant, with optimized porosity, mechanical strength and biological functionality.

Future Perspectives

The next generation of porous biopolymeric gels will be defined by the integration of adaptive material chemistry, computational design and precision manufacturing. Future scaffold systems are expected to incorporate dynamic covalent bonds, supramolecular interactions and enzyme-cleavable motifs that enable spatiotemporally regulated remodeling in response to local biochemical and mechanical cues. Such adaptive networks will permit on-demand modulation of stiffness, permeability and degradation, thereby more closely recapitulating the evolving extracellular matrix during tissue repair [4,6]. The use of artificial intelligence in materials discovery and multiphysics modeling will enhance the optimization of polymer composition, pore topology and crosslinking density by forecasting structure–property–function relationships prior to experimental fabrication [7]. Integrating these technologies with three-dimensional bioprinting and patient-specific imaging data will enable the creation of customized scaffolds designed to meet defect geometry, tissue biomechanics and individual regenerative needs [9]. A key area of emphasis is the advancement of immuno-instructive matrices that are capable of steering macrophage polarization, controlling fibrotic responses and facilitating constructive remodeling. Simultaneously, multifunctional gels that merge therapeutic delivery, biosensing and real-time monitoring could revolutionize scaffolds from mere passive substrates to dynamic therapeutic platforms [12]. Despite significant advancements, translation is still limited by factors such as sterilization compatibility, batch reproducibility, long-term *in vivo* safety and regulatory complexities. Consequently, standardized characterization metrics and strong manufacturing protocols will be crucial. The ongoing integration of polymer science, bioengineering and translational medicine is anticipated to produce clinically applicable porous biopolymeric gels with unmatched precision and therapeutic effectiveness [13,14].

CONCLUSION

Porous biopolymeric gels are adaptable biomaterials that integrate hydration resembling the extracellular matrix, interconnected porosity and adjustable mechanical properties within a single scaffold platform. Their functionality is shaped by polymer composition, pore architecture, crosslinking chemistry and fabrication strategies, which together regulate cellular infiltration, nutrient transport, vascularization and tissue-specific mechanotransduction. Natural polymers offer intrinsic bioactivity, synthetic polymers ensure reproducibility and hybrid systems help mitigate the trade-off between porosity and mechanical strength. Applications include bone and cartilage repair, wound healing, angiogenesis and therapeutic delivery. Continued progress in predictive design and scalable manufacturing is expected to speed up their clinical application as next-generation regenerative scaffolds.



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Table 1. Comparison of natural, synthetic and hybrid polymer systems used in porous biopolymeric gels, highlighting representative polymers, key advantages, major limitations and typical regenerative medicine applications

Category	Representative Polymers	Key Advantages	Major Limitations	Typical Applications
Natural [1,14]	Collagen, Gelatin, Alginate, Chitosan	Intrinsic bioactivity	Limited mechanical strength	Wound healing, cartilage
Synthetic [2,4]	PEG, PVA, Polyacrylamide	Reproducible properties	Poor cell adhesion	Drug delivery, load-bearing
Hybrid [5,7]	Gelatin-PEG, Collagen-PVA	Balanced bioactivity and mechanics	More complex fabrication	Multifunctional scaffolds

Table 2. Comparative assessment of fabrication techniques for porous biopolymeric gels, summarizing pore architecture, mechanical performance, injectability and principal advantages of each processing method

Technique	Typical Pore Structure	Mechanical Performance	Injectability	Key Advantages
Sol-Gel Processing [2,7]	Nano-mesoporous	Moderate	No	High surface area
Cryogelation [8,11]	Interconnected macroporous	High elasticity	Yes	Excellent permeability
Freeze-Drying [14,17]	Sponge-like macroporous	Moderate	No	Simple and versatile
IPN Fabrication [3,6]	Controlled hierarchical	Very high	Very high	Superior toughness
In Situ Gelation [9,11]	Variable	Moderate	Yes	Minimally invasive
3D Bioprinting [17,19]	Precisely defined	Tunable	Yes	Patient-specific design





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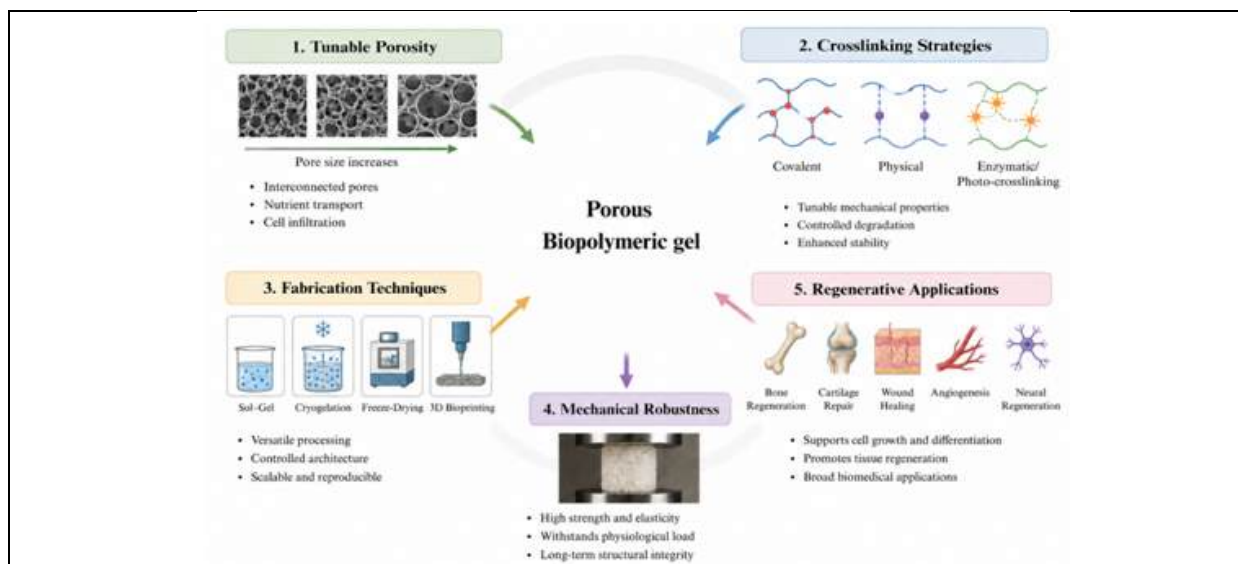


Figure 1. Graphical Abstract

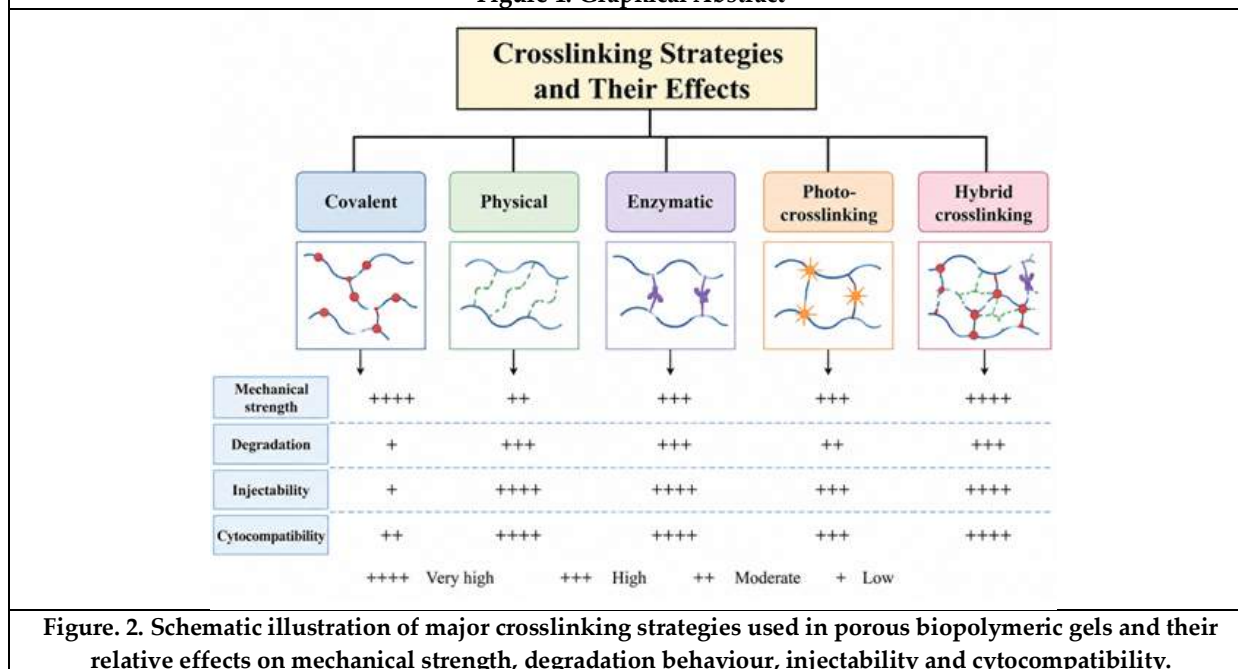


Figure 2. Schematic illustration of major crosslinking strategies used in porous biopolymeric gels and their relative effects on mechanical strength, degradation behaviour, injectability and cytocompatibility.

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RESEARCH ARTICLE

The Bengal Florican (*Houbaropsis bengalensis*) : Its Conservation and Habitat Crisis in Southeast Asian Countries

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ABSTRACT

The Bengal Florican is one of the world's rarest grassland birds and is now facing a severe risk of extinction across India, Nepal, and Cambodia. The article examines the present conservation status of the species, the reasons behind its rapid population decline, and the measures required for its survival. The study shows that fewer than one thousand Bengal Floricans remain globally, with populations becoming increasingly fragmented and isolated. Nepal has experienced drastic declines, including local extinction in several protected areas, while Cambodia is witnessing rapid habitat destruction due to large-scale irrigated rice cultivation and infrastructure projects. India still retains some stable populations, especially in protected areas such as Manas National Park, where scientific grassland management has produced encouraging conservation outcomes. The article identifies habitat loss and habitat mismanagement as the principal threats to the species. Conversion of natural grasslands into agricultural land, invasion of harmful weeds, uncontrolled burning practices, tourism pressure, grazing, pesticide exposure, and collisions with power lines have collectively reduced breeding success and survival rates. The study further explains the ecological requirements of the Bengal Florican, particularly its dependence on a balanced mosaic of short and tall grasslands for feeding, nesting, shelter, and courtship displays. The paper also evaluates several conservation strategies, including controlled grassland management, community participation, nest protection schemes, environmental education, satellite tracking, and cross-border cooperation among South Asian countries. Although captive breeding is discussed as a possible last-resort strategy, the article emphasises that habitat restoration and community-led conservation remain the most effective long-term solutions. The study concludes that the Bengal Florican is not only an endangered bird but also an important indicator of the health of fragile floodplain grassland ecosystems.



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Its disappearance would signal the wider ecological collapse of these habitats and the loss of many associated species.

Keywords: Bengal Florican, Grassland Conservation, Habitat Loss, Endangered Species, Community-Based Conservation, Floodplain Ecosystem

INTRODUCTION

A Global Perspective on a Critically Endangered Bustard

Global Conservation Status and National Legal Protections

The Bengal Florican is a rare bird that is currently in grave danger. It is listed as Critically Endangered, meaning its population is very small and dropping. Today, there are only about 250 to 999 of these birds left across the Indian subcontinent and Southeast Asia. To protect the species from being traded, international laws like CITES place it under strict protection in Appendix I (Poudyal et al., 2008). The bird is also fiercely guarded at the national level. In Nepal, it is one of just nine birds given a special "Protected" status for urgent care. In India, severe penalties exist for harming the bird or its grassland home (Thakur et al., 2024). These laws guide conservation efforts, like Nepal's 2024–2033 action plan, to save the bird from vanishing forever.

Global Taxonomy and Population Fragility

The Bengal Florican is actually divided into two distinct groups based on location. The first group, *H. b. bengalensis*, lives in scattered grasslands in northern India and southern Nepal (Thakur et al., 2024). The second group, *H. b. blandini*, survives mostly in the flooded grasslands of Cambodia, as populations in Vietnam are already gone (Gray et al., 2009). The total numbers remain incredibly low (Poudyal et al., 2008). Roughly 350 to 400 stay in India, fewer than 100 in Nepal, and about 200 in Cambodia. They live in small, isolated pockets separated by human activity (Mahood et al., 2019). In Southeast Asia, survival is even harder because birds leave safe breeding areas for unprotected fields during the year, facing dangers from hunters and farming.

The Overarching Crisis: Habitat Modification and Loss

The biggest crisis facing the Bengal Florican is the rapid destruction of its natural home (Pokharel, 2025). This bird desperately needs open grasslands to survive (Thakur et al., 2024). In Southeast Asia, people are turning grassy areas into dry-season rice fields. In Cambodia, dams and reservoirs caused 28 percent of the bird's habitat to vanish in just 27 months (Packman et al., 2014). In India and Nepal, the problem is slightly different. Open grass is slowly growing into bushes and trees, ruining the clear ground the male birds need (Poudyal et al., 2008; Thakur et al., 2024). Additionally, dangerous foreign weeds are pushing out native plants. Even inside protected nature parks, people mistakenly burn or cut grass at the wrong times, which destroys nests. Human activities like gathering wood and tourism add more stress (Inskipp et al., 2024). Ultimately, the Bengal Florican is an important warning sign. If this bird disappears, it tells us that the floodplains are failing and other wildlife will follow (Pokharel, 2025).

Regional Status and Population Trends

Nepal: A Precipitous Decline Toward Extirpation

In Nepal, the Bengal Florican is Critically Endangered, with fewer than 100 birds left scattered across disconnected protected areas (Inskipp et al., 2024). The population is dropping fast across its national parks. In Shuklaphanta National Park, numbers crashed by 93% between 1982 and early 2024, dropping from 15 birds to just 1, though a wider search later found 5 (Inskipp et al., 2024). Chitwan National Park saw a 75% drop since 1982; despite a brief increase in 2012, no birds were found in the 2024–2025 survey, showing local extinction (Pokharel, 2025). Koshi Tappu Wildlife Reserve holds Nepal's largest remaining group, but numbers still fell 55% from 47 birds in 2012 to 21



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in 2022 (Baral et al., 2013), with 32 counted over a larger area in 2024 (Inskipp et al., 2024). Sadly, the bird is completely gone from Bardia National Park. While there were 9 birds in 1982 and just 1 in 2007 (Poudyal et al., 2008), no birds have been confirmed there since 2010 despite multiple surveys (Inskipp et al., 2024).

India: Success Stories Amidst General Decline

In India, there is still hope for the Bengal Florican, with about 350 to 400 birds surviving in the floodplains and grasslands (Collar et al., 2017; Thakur et al., 2024). Through careful conservation, some areas are seeing success. Manas National Park is a great example of population growth. By burning old grass in February before nesting season, fresh shoots grow back perfectly for the birds. This effort helped numbers rise to 50 territorial males and 17 females by 2021 (Brahma et al., 2009), with 20 males living safely at the community-managed Kokilabari Agriculture Farm (Thakur et al., 2024). D'Ering Wildlife Sanctuary is also a top priority. It is uniquely managed for the bird rather than large grazing animals like rhinos (Mahood et al., 2019). This special focus maintains the perfect mix of short and tall grass needed for the floricans and other important grassland birds (Rahmani et al., 2016b; Mahood et al., 2019).

Cambodia: Industrial-Scale Habitat Loss

The situation in Cambodia is very critical for the Indochinese bird, which is already extinct in Vietnam and southern Cambodia (Collar et al., 2017). Today, these birds only survive in one single area: the seasonally flooded grasslands around Tonle Sap in central Cambodia (Gray et al., 2009). Unfortunately, this important habitat is being destroyed at an industrial scale. The land is shrinking so quickly that experts warn this unique group of birds could completely disappear within the next ten years if the rapid destruction continues (Packman et al., 2014).

Statistical Trends: The Precipitous Decline of Displaying Males

Comprehensive counts made between 2005 and 2012 show how hard the fall has been in Cambodia. In 2012, the number of displaying males was down by 44–64% from what had been recorded in 2005–2007. Where there were once 416 displaying males in 2005, only 216 were counted in 2012 (Packman et al., 2014; Gray et al., 2009). The drop did not stop there. By 2018, the whole population was thought to be about 138 birds, a steady loss of more than ten percent each year (Mahood et al., 2019). The figures are plain, and they tell of a bird slipping away year by year.

The Primary Driver: Industrial-Scale Irrigated Rice Cultivation

The bird faces many pressures, but one stands above the rest. Its biggest threat is the loss of open grasslands because of farming, dams, and human activities (Pokharel, 2025). In Cambodia, many grasslands were changed into rice fields, causing major habitat loss (Packman et al., 2014). In India and Nepal, bushes, trees, and harmful weeds are damaging its habitat (Thakur et al., 2024). Wrong grass cutting and burning also destroy nests (Inskipp et al., 2024). The bird is protected by strict laws, but its future is still at risk.

Ecological Requirements and Breeding Biology**Alluvial Grassland Specialisation**

The Bengal Florican strictly needs lowland river grasslands to survive, or it cannot live at all (Gray et al., 2009). It prefers open areas filled with Siru grass, formally known as *Imperata cylindrica* (Pokharel, 2025). When this specific grass is cut or burned, it grows back short at about ten to fifty centimeters, creating the perfect open space for the birds to find food and for the males to display to the females (Thakur et al., 2024). However, short grass is not enough on its own; the birds also need a mix of tall grass over a meter high to provide shade from the hot sun and safe cover for their nests (Pokharel, 2025). When these important grasslands are ploughed for farming or become overgrown with bushes, the bird population drops quickly and sharply (BirdLife International, 2024).

The "Sward Mosaic" Requirement

The Bengal Florican requires a "sward mosaic," which means a perfect mix of short and tall grasses living right next to each other across the plains. Short grasses are essential for the birds to feed on insects and for the males to perform



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their jumping dances to attract mates. Because the grass is kept short, the black and white males can easily be seen from a distance. Meanwhile, the tall, strong grasses are used by the birds to hide from dangerous predators and the hot midday sun. Females heavily rely on this thick, tall cover to hide their eggs safely on the ground. If land managers cut all the grass to the same height or let wild trees take over, this vital living pattern breaks down.

Breeding Dynamics: The Exploded Lek System

These birds have a unique mating style called an "exploded lek system," where each male claims his own wide, open space roughly a kilometer away from any other males. During the breeding season from mid-March to June, males perform jumping dances up to three meters in the air. While jumping, they puff out their black chests, flash their white wings, and make loud booming and clapping sounds that travel far. The brown females stay quietly hidden in the tall grass most of the time, only briefly coming out to the short grass to watch a male. The males fiercely protect their chosen dancing spots, aggressively fighting off any rivals that come near.

Dietary and Foraging Habits

The Bengal Florican eats both plants and animals, mainly searching for food in the short grass areas during the cool mornings and late afternoons. Its daily diet includes fresh plant shoots, flowers, and many insects like grasshoppers and beetles. During the hottest parts of the day, the bird stops eating and slips deep into the tall grass to rest in the shade. How humans manage the land directly affects their food supply. Burning the grass too late in the year kills off the important insects that the adults and chicks need to eat. However, early burning before the breeding season helps fresh plants grow and keeps the ground perfectly open for feeding.

Critical Threats to Survival**Habitat Conversion and Management Issues**

The Bengal Florican's survival is in extreme danger because its grassy homes are being turned into farms or poorly managed. In Cambodia, building dams to support large dry-season rice farms destroyed a massive amount of grassland very quickly (Packman et al., 2014; Gray et al., 2009). In India and Nepal, farming near places like Chitwan National Park and the Kokilabari Agriculture Farm damages native plants and breaks up the wide areas the birds need to live (Pokharel, 2025; Thakur et al., 2024). Even without farming, open grasslands in places like Bardia National Park are naturally growing into thick bushes and trees, which ruins the clear, open views male birds need to attract mates (Thakur et al., 2024; Poudyal et al., 2008). Harmful foreign weeds are also taking over, crowding out the native plants the birds rely on for food and shelter in areas like Manas National Park (Inskipp et al., 2024; Thakur et al., 2024). Finally, when park managers burn the grass too late in the dry season (March to May), the fires kill nesting birds and chicks; to keep them safe, all burning must be finished before mid-February (Inskipp et al., 2024).

Human Disturbance and Infrastructure

These shy birds are severely stressed by human activities and machines, especially during their breeding season (Inskipp et al., 2024; Pokharel, 2025). Growing tourism in Nepal's Chitwan and Bardia National Parks has brought noisy jeep roads and walking trails straight through their habitats. When locals enter the parks to collect wood or let their cattle graze in places like the Koshi Tappu Wildlife Reserve during the breeding months, the birds are scared away and their nests fail (Inskipp et al., 2024; Pokharel, 2025). Furthermore, deadly power lines are a major threat. When the birds fly up to thirty kilometers outside of protected zones to find food in farmlands, they often crash into these hard-to-see wires and die (Inskipp et al., 2024; Mahood et al., 2019; Pokharel, 2025). This is a severe problem in Cambodia's Stoung-Chikreang Bengal Florican Conservation Area (Mahood et al., 2021). To save the florican, roads must be moved away from their homes and power lines must be made safe (Inskipp et al., 2024).

Biological and Chemical Risks

The Bengal Florican faces natural predators and harmful chemicals. Because they lay their eggs on the ground, their nests are easily eaten by growing numbers of jackals and mongooses in parks like Bardia and Koshi Tappu (Inskipp



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et al., 2024; Poudyal et al., 2008). In Cambodia, pet and stray village dogs are a leading cause of death, easily hunting the birds and destroying nests (Mahood et al., 2021). Crows and other birds also steal eggs from above, especially if late fires burn away hiding spots or humans scare the parents off the nest (Inskipp et al., 2024; Thakur et al., 2024). Additionally, when the birds leave safe areas to feed in farmlands, like India's Kokilabari Agriculture Farm, they are exposed to dangerous farming chemicals (Inskipp et al., 2024; Mahood et al., 2019; Thakur et al., 2024). These pesticides can poison the birds directly or kill off the grasshoppers and beetles they eat, leaving the adults weak and the chicks starving (Inskipp et al., 2024).

Conservation Strategies and Recommendations**Optimised Habitat Management**

To protect the Bengal Florican, grasslands must be managed carefully by cutting and burning grass before the breeding season begins (Inskipp et al., 2024; Mahood et al., 2019; Thakur et al., 2024). In drier areas, this work should be finished by mid-February, while places with taller grass can wait until late February. Burning later, from March to May, destroys nests, kills eggs, and scares away males (Inskipp et al., 2024). It is also highly important to maintain a mix of tall and short grass, leaving some tall patches over a meter high so female birds can hide and safely build nests on the ground (DNPWC, 2024; Inskipp et al., 2024; Thakur et al., 2024). When grass is burned, the leftover ash should stay to nourish the soil and help fresh green shoots grow. Finally, the land must be closely watched to stop dangerous weeds like *Mikania micrantha* and *Parthenium hysterophorus* from taking over the clear ground (Inskipp et al., 2024).

Community-Based Initiatives

Because these birds often move into village fields after breeding, conservation must involve local lands (Jha et al., 2018). Under Promoting Multi-Year Crops for Habitat Stability, farmers near the borders of parks in Nepal and India are encouraged to plant crops that last for several years, such as sugarcane, lemongrass, and mentha (Thakur et al., 2024; Jha et al., 2018). These crops do not require constant ploughing, which reduces machine use and gives the birds a steady, safe place to hide and feed (Inskipp et al., 2024). Additionally, through Incentive-Led Nest Protection Schemes in Cambodia, villagers receive money for finding and protecting nests instead of harming them (Gray et al., 2009; Pokharel, 2025). Using funds from bird-watching tours, locals get one payment for reporting a nest and a bigger reward if the eggs hatch safely. This simple trade stops hunting and prevents nests from being crushed by cattle or tractors, encouraging the community to actively protect the birds (Pal et al., 2024).

Education and Stakeholder Engagement

The Bengal Florican cannot endure on grassland work alone. It must also live in the minds of people. Because most students did not know the Bengal Florican existed or was in danger, conservationists started teaching locals to build deep awareness and care for the bird (Pokharel, 2025).

School-Based Initiatives: Clubs and Creative Arts

Programs in eleven schools created Bengal Florican Clubs. Through fun activities like drawing contests, quizzes, and face painting, more than eighty percent of students successfully learned to recognise the bird and its needs (Pal et al., 2024; Pokharel, 2025).

Community Engagement through Storytelling

Education also moved into the villages. Simple community dramas were performed at local homestays to show the bird's struggles with fires and farming, successfully bringing hundreds of farmers and fishers together to discuss solutions (Pokharel, 2025; Pal et al., 2024).

Educational Materials and Emotional Connection

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To create a lasting emotional bond, children's books, bookmarks, and posters were handed out to locals and guides. Keeping the bird's image visible helps ensure it is remembered and protected by the community (Inskipp et al., 2024; Pal et al., 2024). In such ways, the bird becomes more than a name. It becomes something known. And what is known stands a better chance of being kept.

Ex-Situ Conservation (Captive Breeding)

Captive breeding is considered a risky and expensive last resort to save the Bengal Florican. The goal is to build a safe, captive population that can eventually be returned to the wild (Mahood et al., 2021). However, raising birds in enclosures can artificially change their behavior, physical shape, and genetics over time.

Cambodia: Initiation of Egg Harvesting

Because the Cambodian birds are disappearing so fast, a special program began at the Angkor Centre for Conservation of Biodiversity. Since capturing adult birds is too dangerous, the team focused on collecting eggs instead (Mahood et al., 2021). In 2019, they gathered nine eggs from the wild; five hatched, but two chicks died for unknown reasons (Mahood et al., 2021). Experts warn it could take twenty to thirty years to raise enough birds to release, and by then, their natural grassland homes might be completely gone.

Nepal: Feasibility Evaluation

In Nepal, conservationists are being very cautious. The Bengal Florican Conservation Action Plan for Nepal 2024–2033 recommends closely watching the results of Cambodia's program before trying it themselves (Inskipp et al., 2024; DNPWC, 2024). Experts worry that actively searching for nests to collect eggs will scare and harm the highly sensitive wild birds. For now, Nepal is choosing to focus its efforts on protecting the natural grasslands so the birds can survive in the wild without fences.

Transboundary Research and Monitoring

The survival of the Bengal Florican depends on teamwork between different countries because these birds often fly between safe parks, busy farms, and even across national borders. To protect them properly, countries must work as one and share the important information they learn (Inskipp et al., 2024; Mahood et al., 2019).

The Need for Satellite Tracking and Migration Mapping

For a large part of the year, these birds live outside of their safe breeding zones, so experts need to know exactly where they travel to keep them from being lost (Jha et al., 2018; Mahood et al., 2019). Satellite tracking in Nepal and India shows that after nesting, the birds fly up to thirty kilometers into open village farmlands and even cross the border from Nepal into India (Inskipp et al., 2024; Pokharel, 2025). In Southeast Asia, more tracking work is needed to map how Cambodian birds move into dry forests (Gray et al., 2009; Packman et al., 2014). Mapping these travel paths is extremely important because it helps conservationists find hidden hazards, like deadly low power lines and farming fields heavily sprayed with pesticides, before more birds are harmed.

Species Working Groups and Sharing Best Practices

Instead of keeping knowledge scattered, countries like Nepal, India, and Cambodia need to create dedicated working groups to share their best conservation ideas and track their success. By sharing what works well, they can use successful fire management techniques from India's Manas National Park to help Shuklaphanta and Chitwan National Parks in Nepal, or use farming lessons from one part of Cambodia to save birds in another (Mahood et al., 2019; Thakur et al., 2024). Joining efforts like this saves valuable time and money from being wasted on repeating the same mistakes, ensuring that funds are spent effectively across the bird's entire natural home.

Conclusion: The Indicator of Ecosystem Health

The Bengal Florican is more than a rare bird. It is a sign. Where it stands and displays, the lowland alluvial grassland still holds together. Where it vanishes, the land is already failing. Its presence tells of balance. Its absence tells of loss.





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The forces that drive it down do not stop with one species. They move through the floodplains and They share the floodplains with other species —the Pygmy Hog, the Hispid Hare, the Hog Deer. All depend on the same grass, the same open ground. When that ground is broken, they fall in turn. To steady the future, action must be plain and swift. National Conservation Action Plans, such as Nepal's 2024–2033 strategy, set a course built on habitat restoration and work led by communities. In Southeast Asia, the grasslands must be guarded by stronger law. Bengal Florican Conservation Areas must stand firm under government decree, and the spread of irrigated rice must be checked. Both subspecies—*H. b. bengalensis* in South Asia and *H. b. blandini* in Cambodia—hang in the balance. Their survival calls for work across borders. Countries must share what they know. Satellite tracking must mark the corridors the birds follow. Fire must be managed with care. Farming must bend where it can to spare the grass. If this is not done, the silence that follows the florican's last display will mean more than the loss of a single bustard. It will mark the wider collapse of the fragile grasslands it has long stood to represent.

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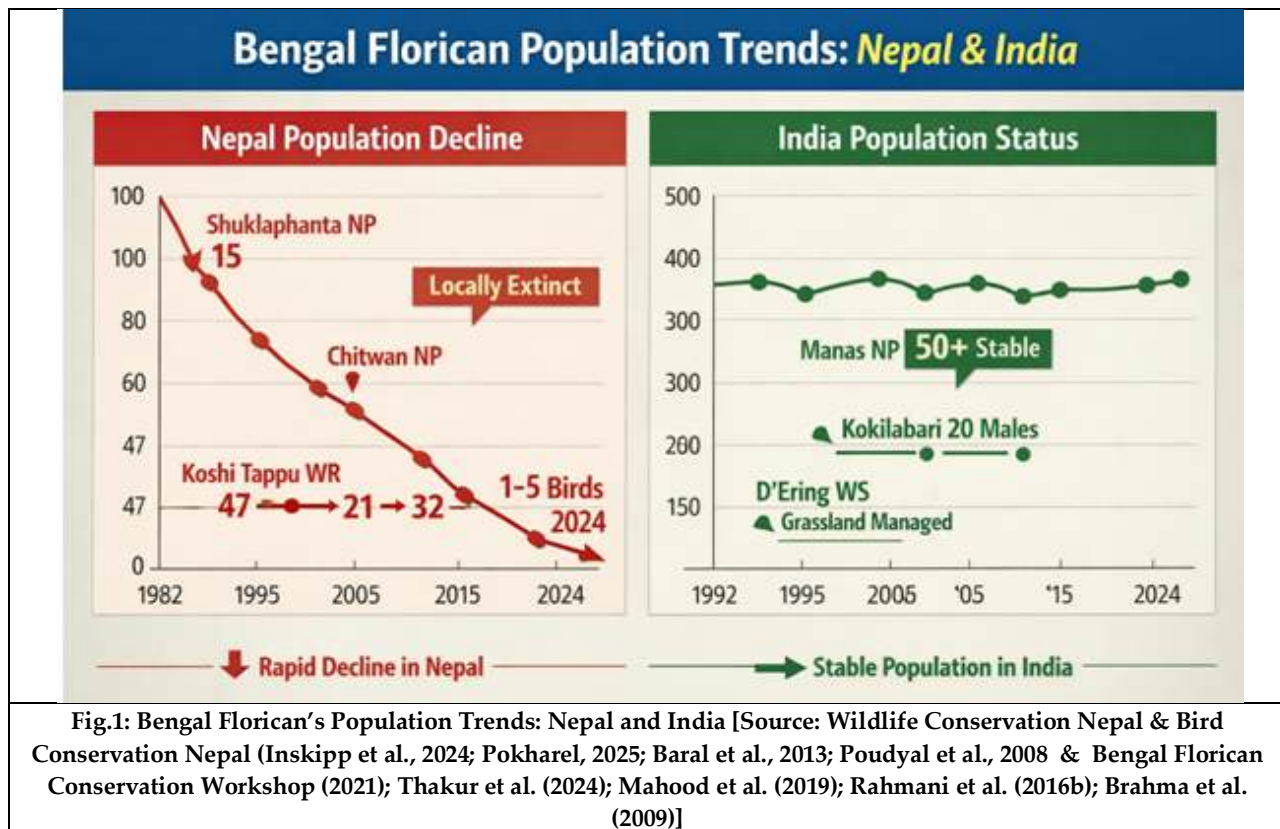
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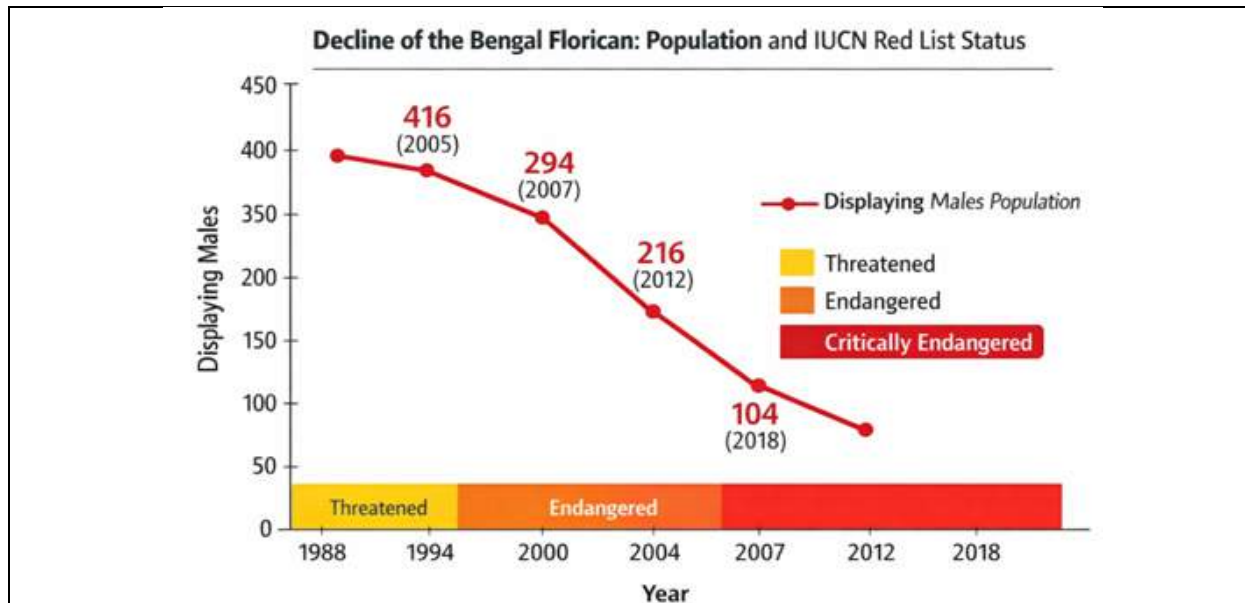
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Fig.2: Bengal Florican's population counts with the IUCN Red List status changes across 1988–2018. (Data from Gray et al. (2009), Packman et al. (2014), Mahood et al. (2019)).

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RESEARCH ARTICLE

Formulation and Evaluation of Antimicrobial Herbal Soap Containing *Chlorophytum Borivilianum* (Safed Musli) Extract

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ABSTRACT

With increasing awareness about the harmful effects of chemical-based soaps, there is a growing demand for natural and skin-friendly alternatives. This study focuses on the formulation and evaluation of a herbal soap using *Chlorophytum borivilianum* (Safed Musli), A well-known medicinal plant in Ayurveda recognized for its rejuvenating and therapeutic properties. The Safed Musli extract was prepared using the Soxhlet extraction method and subjected to phytochemical screening, which confirmed the presence of important bioactive compounds such as saponins, alkaloids, flavonoids, and steroids. These compounds are known for their antimicrobial, antioxidant, and moisturizing effects. The antimicrobial activity of the extract was tested against common skin pathogens like *Escherichia coli* and *Staphylococcus aureus*, showing effective inhibition. The herbal soap was formulated using a stearic acid-based soap matrix along with natural ingredients such as coconut oil, glycerin, and propylene glycol. The prepared soap was evaluated for various parameters including pH, foam stability, Total Fatty Matter (TFM), moisture content, and skin irritation. The results showed that the soap had a near skin-friendly pH, good foaming ability, high TFM (indicating good quality), and no signs of irritation on the skin. Additionally, antimicrobial testing using the thumb impression method confirmed a significant reduction in microbial load after use. Stability studies also indicated that the formulation remained stable over time. In conclusion, the Safed Musli herbal soap proved to be a safe, effective, and natural alternative to synthetic soaps, offering both cleansing and antimicrobial benefits.

Keywords: saponins, alkaloids, flavonoids, and steroids, antimicrobial benefits, natural ingredients,



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INTRODUCTION

In the evolving landscape of natural healthcare, phytomedicine has remained a cornerstone of therapeutic interventions for centuries. While many botanical species are recognized for their systemic benefits, *Chlorophytum borivillianum*, popularly known as Safed Musli, stands out as a high-value medicinal herb native to the tropical wet forests of India. Historically revered in Ayurvedic literature as a "Rasayana" or rejuvenator, this perennial herb is rich in bioactive constituents, primarily steroidal saponins, polysaccharides, alkaloids, and proteins. Recent pharmacological investigations have highlighted its diverse profile, ranging from immunomodulatory and antioxidant activities to potential applications in managing skin-related oxidative stress and cellular regeneration [1].

Morphology

Safed musli is a tiny annual herb that grows well in tropical and sub-tropical climates with altitudes upto 1500m. It grows to a maximum height of 1.5 ft. Tubers can grow upto a depth of 10 inches.

Root

Roots pale brown to white colour with characteristic odour and are tasteless in nature. Root tubers are fleshy, fascicled and directly originate from the stem disc devoid of any fibrous structure and distinguished it from other species of *Chlorophytum* genus. The shape of tubers were cylindrical, the thickness being on the average 0.9 cm and the length 8cm. The number of tubers varies from plant to plant and on an average 5-30 tubers/ plant are observed and slightly tapering towards lower side look like pestle.

Leaf

It has 6 -13 radical leaves spirally imbricate at the base, sessile in nature, lanceolate and linear or ovate with acute apex and slightly narrowed at the base and less than 30cm long. The leaves spread horizontally, with smooth surfaces, wavy margins and parallel venation.

Flowers and fruit:

Flowers of *C. borivillianum* (Figure No.1) are small, white, bracteate, pedicellate, zygomorphic usually arranged in alternate clusters, each cluster comprising of 3 flowers. The flower clusters are dense on the upper part of the scape; bracts are linear, papery and purplish, 1.0 - 10.5cms long; pedicel whitish and 6 -10 mm long. It bears green to yellow coloured fruit which is almost equal in length and breadth. The seed is very small, black and enclosed in the holes.

The integrity of the skin barrier is frequently compromised by environmental stressors, leading to infections, inflammatory rashes, and chronic irritation. In this context, herbal soaps formulated with bioactive plant extracts offer a synergistic approach to skin health, providing antimicrobial protection alongside deep nourishment. Unlike conventional synthetic cleansers, herbal formulations leverage the natural mucilage and saponin content of plants like *C. borivillianum* to soothe sensitive and dry skin types. However, the commercial market is often saturated with soaps that utilize harsh surfactants and maintain high alkalinity, which disrupts the skin's natural acid mantle, leading to xerosis, pruritus, and contact dermatitis [2]. This study aims to bridge the gap between traditional ethnobotany and modern dermo-cosmetics by evaluating the comparative efficacy of available commercial soaps against a specialized Safed Musli-based herbal formulation. A primary focus of this research is the development of a soap with a neutral pH, ensuring that the cleansing process does not strip the skin of essential lipids. By optimizing pH neutralization and harnessing the moisturizing properties of *Chlorophytum borivillianum*, this formulation intends to provide a therapeutic alternative that promotes long-term dermatological health and prevents common integumentary diseases [3, 4].



**Hitesh A. Patil et al.,****Objective of Work**

- **Extraction of Bioactive Compounds:** To perform extraction of *Chlorophytum borivilianum* using the Soxhlet method in order to obtain a concentrated extract rich in saponins and other active constituents
- **Formulation Development:** To develop a potent, nutrient-rich herbal soap by integrating the bioactive saponins of Safed Musli with essential oils, ensuring an eco-friendly formulation that provides both effective cleansing and skin-nourishing benefits.
- **Antimicrobial Assessment:** To evaluate the efficacy of the formulated soap against common skin pathogens (bacteria and fungi) present in the environment, ensuring its potency in preventing infectious diseases and maintaining skin barrier integrity.
- **Physicochemical Evaluation:** To standardize the formulation by assessing parameters such as pH neutrality, foaming height, moisture content.
- **Ensure Safety and Skin Compatibility of the Formulation:** To assess the formulated herbal soap for skin irritation and ensure that it is safe for regular use without causing any harmful effects.
- **To study the stability of the formulated herbal soap:** To evaluate the stability of the soap under different storage conditions to ensure its quality, effectiveness, and shelf-life over time.
- **To compare herbal soap with conventional soaps:** To analyze and highlight the advantages of the Safed Musli herbal soap over synthetic soaps in terms of safety, effectiveness, and skin-friendliness.

MATERIALS AND METHODS**Plan of Work**

- **Collection and Authentication**
 - Procurement of high-quality roots (tubers) of *Chlorophytum borivilianum*.
 - Authentication of the plant material by a certified botanist or recognized herbarium.
- **Extraction and Phytochemical Screening**
 - **Processing:** Cleaning, drying, and grinding of the tubers to obtain a fine crude drug powder.
 - **Extraction:** Cold maceration or **Soxhlet extraction** using solvents of varying polarity (e.g., Ethanol, Methanol, and Aqueous) to ensure maximum recovery of saponins.
 - **Phytochemical Testing:** Qualitative screening of the extracts for alkaloids, glycosides, flavonoids, and specifically **saponins (Foam test)**.
 - **Antimicrobial Evaluation:** Determining the **Zone of Inhibition (ZOI)** against common skin pathogens like *Staphylococcus aureus* (Bacteria) and *Candida albicans* (Fungi).
- **Formulation and Development**
 - Selection of an optimized soap base (Stearic acid-based) and natural emollients.
 - Incorporation of *Chlorophytum borivilianum* extract into the formulation at varying concentrations.
 - Addition of essential oils for aroma and synergistic antimicrobial effects.
 - Finalizing the cold-process or melt-and-pour methodology to ensure heat-sensitive bioactives remain intact.
- **Evaluation Parameters of Formulated Herbal Soap**

To ensure the safety and efficacy of the Safed Musli soap, the following parameters will be evaluated:

 - **Physical Parameters:** Organoleptic properties (color, odor, clarity) and texture.
 - **Chemical Analysis:**
 - Determination of pH (aiming for skin-neutrality).
 - Total Fatty Matter (TFM) determination.





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- Percentage of Free Alkali and Alcohol insoluble matter.
- Saponification Value and Moisture content.
- **Performance Tests:**
 - Foam formation and Foam retention time.
 - Dirt dispersion and cleansing efficiency.
- **Biological & Safety Tests:**
 - Skin Irritation Test (Patch test on volunteers or animal models as per ethics).
 - Thumb Impression Method (to check for microbial load reduction).
- **Stability Studies:** Accelerated stability studies as per ICH guidelines (monitoring changes in pH and physical state at varying temperatures).

Extraction and Extract Tests

- **Extraction Of *Chlorophytum borivilianum*:**

The tubers of *Chlorophytum borivilianum* were sourced from an authenticated supplier, washed, shade-dried, and pulverized into a coarse powder. The extraction was carried out using the **Soxhlet** extraction method. The crude drug powder was packed into a thimble and extracted using Ethanol as the solvent in a ratio of 1:10 [drug (g) : solvent (ml)]. The process was continued for 10-12 cycles to ensure complete recovery of bioactive saponins. The resulting extract was filtered and concentrated using a rotary evaporator [5].

- **Phytochemical Testing**

Phytochemical screening of the *Chlorophytum borivilianum* extract was performed using different solvents (Water, Ethanol, and n-hexane) to identify the following bioactive constituents [5, 6]:

➤ **Test for Saponins (Foam Test):** 0.5 mL of the extract was shaken vigorously with 2 mL of distilled water. Formation of a stable, honeycomb-like froth persistent for 15 minutes confirmed the presence of saponins.

➤ **Test for Carbohydrates (Molisch's Test):**

0.5 mL of crude extract was mixed with 2 mL of Molisch's reagent. 2 mL of concentrated H_2SO_4 was added carefully along the side of the test tube. A violet ring at the junction indicates carbohydrates.

➤ **Test for Flavonoids (NH_3 Test):** 2 mL of extract was mixed with 5 mL of dilute ammonia solution, followed by 1 mL of concentrated H_2SO_4 . A yellow coloration was observed.

➤ **Test for Tannins:**

2 mL of diluted extract was mixed with 3-4 drops of 10% FeCl_3 solution. A brownish-green precipitate was noted.

➤ **Test for Glycosides (Keller-Kilani Test):**

0.5 mL of extract, 2 mL of glacial acetic acid with 2-3 drops of 2% FeCl_3 , and 2 mL of concentrated H_2SO_4 were added. A brown ring at the interface indicates glycosides.

➤ **Test for Alkaloids (Mayer's Test):**

2 mL extract was mixed with 1 mL of Mayer's reagent. Formation of a cream-colored precipitate indicates alkaloids.

➤ **Test for Phenols:**

1 mL of crude extract was mixed with 2 mL of alcohol and 2-3 drops of ferric chloride solution.

➤ **Test for Terpenoids:**

2 mL of extract was added to 2 mL chloroform and evaporated to dryness; 2 mL of concentrated H_2SO_4 was added and heated for 2 minutes.

➤ **Test for Steroids:**

2 mL of chloroform and 2 mL of extract were mixed with 2 mL of concentrated H_2SO_4 and acetic acid. A color change indicates the presence of steroidal saponins.

➤ **Test for Proteins (Ninhydrin Test):**

2 mL of crude extract was mixed with 2 mL of 0.2% solution of Ninhydrin. A violet/purple color confirms proteins.



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Antimicrobial Test (Zone of Inhibition)

The antimicrobial study of the ethanolic extract of *Chlorophytum borivillianum* was performed using the Agar Well Diffusion technique. Mueller-Hinton Agar (for bacteria) and Sabouraud Dextrose Agar (for fungi) were used for plate preparation. The plates were inoculated and incubated for 24 hours at 37°C. The results showed significant antimicrobial potency due to the presence of steroidal saponins. The Zone of Inhibition (ZOI) against *Staphylococcus aureus* and *Escherichia coli* was found to be 8 mm and 7 mm respectively [7, 8].

Herbal Soap Formulation

The formulation of herbal soap involves the saponification of triglycerides with a strong alkali, resulting in the formation of carboxylate salts (soap) and glycerol. In this study, *Chlorophytum borivillianum* extract was integrated into a transparent soap base to leverage its saponin-rich profile for skin nourishment and antimicrobial protection. The batch size for the formulation was standardized to approximately 130 g [8, 9].

Formulation Procedure

- **Preparation of Solution A (Alkali Phase):** 9 g of Sodium Hydroxide (NaOH) was dissolved in 40 mL of distilled water. The exothermic reaction was allowed to stabilize, and the solution was left undisturbed for 30 minutes to reach room temperature.
- **Preparation of Solution B (Oil Phase):** 98 mL of Coconut oil and 30 g of Stearic acid were heated in a water bath until a homogenous molten mixture was formed. Stearic acid was utilized specifically to ensure the structural hardness of the final bar.
- **Saponification:** Solution A was added to Solution B gradually with continuous stirring. The mixture was cooked for 10 minutes at a controlled temperature to initiate the saponification reaction.
- **Clarification and Humectants:** 59.5 mL of Glycerin (humectant) and 74 mL of Ethanol (solubilizer for transparency) were added. The vessel was covered for 5 minutes to prevent solvent evaporation. Subsequently, 28.8 mL of Propylene glycol was added to enhance the skin-conditioning properties.
- **Incorporation of Active Ingredient:** Once the soap base preparation was complete and the temperature slightly reduced, 2 mL of *Chlorophytum borivillianum* ethanolic extract was added. This was followed by the addition of 1 mL of Apple cinnamon perfume for fragrance.
- **Molding:** The final liquid mixture was homogenized using an electric blender and poured into suitable molds to solidify [10].

Evaluation Parameters of Formulated Herbal Soap

Organoleptic Properties

The formulated Safed Musli herbal soap was evaluated for its sensory characteristics. The soap exhibited a creamy off-white to pale-yellowish hue (characteristic of the root extract) with a smooth texture. The dimensions were standardized as: Length (8 cm), Breadth (6 cm), and Thickness (5 cm) [3].

pH Determination

The pH of the formulated soap was measured to ensure skin compatibility. 10 g of the soap was dissolved in 100 mL of distilled water, and the pH was recorded using a digital pH meter. The formulation aimed for a near-neutral pH (range 7.0–8.5) to prevent disruption of the skin's acid mantle [3, 8]. [Figno.8]

Foam Formation and Foam Retention

To examine the surfactant activity, 1 g of soap was dissolved in 50 mL of distilled water in a measuring cylinder and shaken vigorously for 2 minutes. The high saponin content of *Chlorophytum borivillianum* contributed to a stable and dense lather. The foam height was recorded at intervals of 0, 5, 10, and 15 minutes to assess retention stability [3].



**Skin Irritation Test (Patch Test)**

The safety of the Safed Musli soap was assessed on 3 to 4 healthy human volunteers. The soap was applied to a small area of the skin to observe any redness, edema, or irritation. No adverse reactions were reported, indicating the formulation is dermatologically safe [3].

Thumb Impression Method (Antimicrobial Assay)

To evaluate the in-vivo antimicrobial efficacy, the thumb impression method was used.

- A thumb impression of an unwashed hand (exposed to the environment) was taken on sterile Nutrient Agar/Sabouraud Dextrose Agar.
- The same hand was then washed with the formulated Safed Musli herbal soap for 30 seconds and dried.
- A second thumb impression was placed on the same agar plate.

After incubation for 24 hours at 37°C, a significant reduction in microbial colony forming units (CFU) was observed in the washed thumbprint compared to the unwashed one, validating the antimicrobial potential of Safed Musli [9].

Determination Of Percentage Free Alkali

Free alkali can cause skin dryness. 5 g of soap was dissolved in neutralized alcohol and refluxed for 30 minutes. After cooling, 1 mL of phenolphthalein was added and titrated against 0.1M HCl.

Formula: % Free Alkali = $(V \times N \times 4) / W$, Where, V = volume of standard HCL in mL, N = Normality of standard HCL, W = Weight of soap sample in grams, 4 = Equivalent weight factor for NaOH.

Alcohol Insoluble Matter

5 g of soap was dissolved in warm ethanol and filtered through a tared filter paper. The paper was dried at 105°C. The absence of significant residue indicates high purity and proper saponification [6].

Formula: Alcohol Insoluble Matter (%) = $(W_2 - W_1) / W \times 100$

Where,

W_1 = Initial weight of filter paper (g)

W_2 = Final weight of filter paper + residue (g)

W = Weight of soap sample (g)

Determination Of Total Fatty Matter (Tfm)

TFM is a crucial indicator of soap quality. 10 g of soap was dissolved in hot water and reacted with 15% Sulfuric Acid. Bee wax (7 g) was added to solidify the fatty acids.

Formula: % TFM = $((A - X) \times 100) / W$

Where,

A = wt. of wax cake,

X = wt. of beeswax,

W = wt. of soap.

High TFM (Grade 1) ensures better moisturizing effects [11].

Dirt Dispersion Test

A 1% soap solution was treated with two drops of ink. After shaking, the distribution of ink was observed. Minimal ink in the foam portion and maximum dispersion in the water section indicates superior cleansing quality [3].

“The dirt dispersion test indicates the ability of soap to prevent redeposition of dirt. Maximum dispersion of ink in water and minimal presence in foam confirms superior cleansing performance.”

Saponification Value

2 g of the sample was refluxed with 0.5M KOH. Titration was performed with 0.5M HCl using phenolphthalein.



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Formula: Saponification Value = (Mass of KOH / Mass of soap) × 1000 [13, 12].

Moisture Content

5 g of soap was heated at 105°C in a hot air oven for 2 hours.

Formula: % Moisture Content = (W₁ - W₂) × 100 / W₁

Where,

W₁ = Initial weight of sample (before drying)

W₂ = Final weight of sample (after drying) [12].

Accelerated Stability Studies

Following ICH guidelines, the soap was stored at 30°C (ambient) and 4±2°C (refrigerated) for one month. The formulation remained stable with no significant changes in physical appearance, pH, or cleaning efficacy [3,11].

RESULTS AND DISCUSSIONS

A rejuvenating herbal soap was formulated using a transparent soap base containing sodium hydroxide, coconut oil, stearic acid, glycerin, ethanol, and propylene glycol, enriched with an optimized concentration of *Chlorophytum borivilianum* extract.

Phytochemical and Antimicrobial Screening

The pre-formulation study of the ethanolic root extract of Safed Musli showed highly positive results for Saponins, Steroids, and Alkaloids, which are the primary bioactive compounds responsible for its medicinal value. Unlike grass extracts, Safed Musli showed strong positive results for Steroids (Saponins are steroidal glycosides). These constituents are essential for the soap's emollient and antimicrobial properties [3]. The antimicrobial assay revealed a promising Zone of Inhibition (ZOI) of 8 mm for *E. coli* and 7 mm for *S. aureus*. The higher ZOI compared to conventional herbs is attributed to the membrane-disrupting properties of steroidal saponins present in the roots [3, 5].

Physicochemical Evaluation

The formulated soap exhibited a pH of 8.95, which is slightly lower (better) than conventional soaps, aligning well with skin safety standards. The foam formation was instantaneous, and the foam height of 4.8 cm remained stable for over 15 minutes due to the natural foaming nature of Safed Musli saponins [11]. Skin irritation tests on volunteers confirmed zero signs of erythema or irritation, validating the "Rasayana" (rejuvenating) nature of the drug [10]. The Thumb Impression Method showed a drastic reduction in microbial colonies after washing, proving the soap's efficacy as a daily-use antiseptic cleanser [8]. The Total Fatty Matter (TFM) was found to be 76.15%, classifying it as a Grade-1 soap, which provides superior moisturizing effects. The moisture content (3.12%) and free alkali (0.05%) were within the permissible limits of BIS standards [6, 11]. Stability studies confirmed that the formulation remains physically and chemically intact under accelerated conditions [3].

CONCLUSION

The present study successfully formulated and evaluated a therapeutic herbal soap integrated with *Chlorophytum borivilianum* (Safed Musli) root extract. The phytochemical screening of the extract confirmed a high concentration of steroidal saponins, alkaloids, and flavonoids, which are pivotal for its potent antimicrobial and skin-rejuvenating properties. The extract demonstrated superior antibacterial efficacy with inhibition zones of 8 mm against *E. coli* and 7 mm against *S. aureus*, significantly outperforming many common herbal alternatives. The physicochemical evaluation of the formulated soap revealed a pH of 8.95, ensuring it is mild and skin-friendly. The natural surfactant properties of Safed Musli saponins resulted in excellent foam stability (lasting over 15 minutes) and a rich lather.

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With a Total Fatty Matter (TFM) of 76.15%, the formulation meets the criteria for Grade-1 toilet soap, offering enhanced moisturizing benefits. The safety profile was validated through volunteer skin irritation tests and the thumb impression method, which showed zero adverse reactions and effective microbial reduction. In conclusion, the *C. borivilianum* herbal soap stands as a promising, safe, and effective natural alternative to synthetic antimicrobial soaps.

Future Scope

The successful development of this formulation opens several avenues for future research and commercial application:

- **Advanced Clinical Trials:** Future studies can focus on long-term dermatological effects and its efficacy against specific skin conditions like eczema or fungal infections.
- **Synergistic Formulations:** Exploring the combination of Safed Musli with other high-value herbs (e.g., Ashwagandha or Aloe Vera) to create a multi-functional "Rasayana" skincare range.
- **Product Diversification:** The antimicrobial and emollient properties of *C. borivilianum* can be utilized to develop a complete skincare line, including liquid body washes, medicated shampoos, and moisturizing lotions.
- **Nanotechnology Integration:** Future research could involve the use of nano-emulsions of Safed Musli extract to enhance the penetration of bioactive saponins into deeper skin layers for better therapeutic outcomes.
- **Personalized Skincare:** Developing customized soap variants where the concentration of Safed Musli extract is adjusted based on individual skin types (oily, dry, or sensitive) or specific antimicrobial requirements.

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Table 1: Antimicrobial Test (Zone Of Inhibition)

Ingredients	Quantity	Category
Sodium Hydroxide	9 g	Saponifying Agent
Coconut oil	98 mL	Lathering Agent
Stearic acid	30 g	Hardening Agent
Glycerin	59.5 mL	Humectant / Emollient
Ethanol (95%)	74 mL	Clarifying Agent (Transparency)
Propylene glycol	28.8 mL	Humectant / Solvent
Distilled water	40 mL	Vehicle
Apple cinnamon perfume	1 mL	Fragrance
Safed Musli Extract	2 mL	Active Ingredient (Antimicrobial)

Table 2: Results of Phytochemical Testing (*C. borivilianum*)

Tests	Water	Ethanol	n-Hexane
Saponins (Foam Test)	++	++	--
Steroids	++	++	+
Carbohydrates	--	++	++
Flavonoids	++	++	+
Alkaloids	--	++	--
Proteins	++	++	--
Tannins/Phenols	--	++	--





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Table 3: Antimicrobial Activity (Zone of Inhibition)

Microorganism	Zone of Inhibition (mm)
<i>Escherichia coli</i>	8 mm
<i>Staphylococcus aureus</i>	7 mm

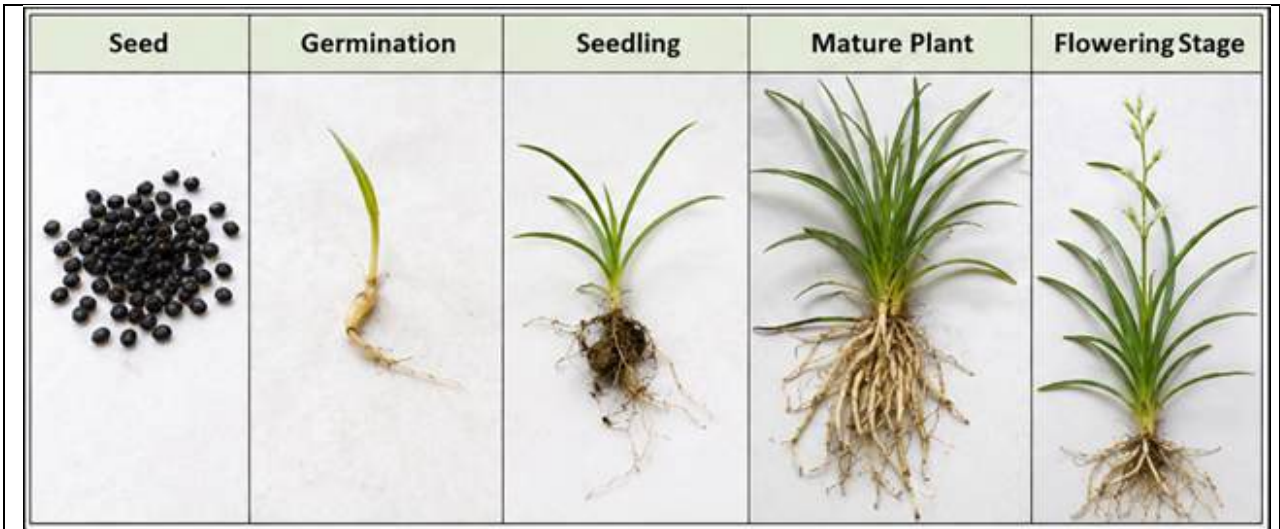
Table 4 Result of Stability And Stability Studies

Parameter	Initial Reading	After 1 Month
Colour /Odour	Pale Creamy / Aromatic	No Change
PH	8.95	8.92
Foam Height(0 min)	4.8 cm	4.6 cm
TFM (%)	76.15%	76.10%
Skin Irritation	None	None

**Fig no.1: Plant Of Chlorophytum Borivilianum (Safed Musli)****Figure No.2: Whole Plant of Safed Musli****Figure No.3: Crude Drug****Figure No.4: Roots Of Safe Musli**



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FigureNo.5: Different stages of safed musli plant.



FigureNo.6:Soxhlet Extraction OfC. Borivilianum

Figure No. 7 Prepared *Chlorophytum Borivilianum* (SafedMusli) Herbal Soap.



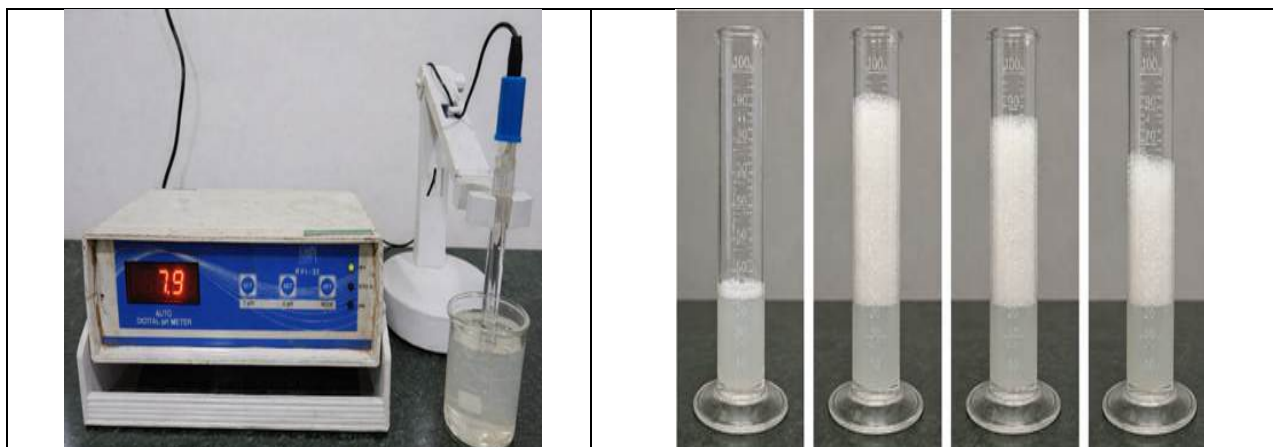
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Figure no. 8: Result of PH Determination Test.

Figure No. 9 Result Of Foam Formation And Foam Retention



Before

Washing

After Wash Wash

Figure No.10 Result of Skin Irritation Test



Figure No.11 Result of Thumb Impression Method (Antimicrobial Assay)

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RESEARCH ARTICLE

Antimicrobial, Antioxidant and Anti-Inflammatory Activities of the Siddha Polyherbal Formulation Megarajanga Kirutham

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ABSTRACT

Infectious diseases continue to be a leading cause of illness and death worldwide. Antimicrobials are used to manage them. However, microbial resistance to these medicines is becoming more prevalent. Disease conditions are also accompanied by inflammation and oxidative stress. In order to combat oxidative stress, inflammation and microorganisms, newer drugs are required. Therefore, biomaterials like herbal medicines with strong antibacterial, anti inflammatory and antioxidant properties can take the place of current antibiotic medications. Megarajanga Kirutham (MRK) is frequently used by Siddha physicians as a traditional cure for a variety of ailments, including inflammation, infections, and improving overall health. It was prepared using the method outlined in the classical Siddha treatise "Sigicha rathna deepam". Hence, the purpose of this study was to investigate the anti microbial, anti-inflammatory and antioxidant properties of Megarajanga kirutham. The disc diffusion method, albumin denaturation assay and 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay, nitric oxide radical scavenging assay and 2,2'-azino-bis-3-ethylbenzothiazoline-6-sulphonic acid (ABTS) assay were used to evaluate the antimicrobial, anti-inflammatory, and antioxidant properties. All of the bacteria showed different levels of sensitivity to the various extracts. MRK showed effective anti microbial activity against *Trichomonas Vaginalis*, *Staphylococcus aureus*, *E-Coli*, *Candida albicans* and not active against *Aspergillus niger* It had a



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significant scavenging impact on hydroxyl and DPPH radicals as well as a robust reduction potential. The anti-inflammatory and antioxidant properties exhibited substantial efficacy at higher doses and were dose-dependent.

Keywords: Megarajanga Kirutham, anti microbial, anti inflammatory, anti oxidant, invitro, Siddha.

INTRODUCTION

Infectious diseases, particularly bacterial, are a major cause of death worldwide, with developing nations experiencing the highest mortality rates. Approximately 13.7 million people died from diseases in 2019 alone, with bacteria being responsible for 7.7 million of these deaths [1]. Antibiotics have been widely used to treat bacterial infections and increase the average survival rate of those who have been affected [2]. Antibiotics also significantly lower the rates of illness and mortality, especially in underdeveloped nations with limited or nonexistent medical services [3]. But repeated, careless use and misuse of antibiotics has led to a rise in microbial agent resistance [4]. Nowadays, one of the most important issues at the moment is antibiotic resistance, which is a natural phenomenon that involves adaptive mechanisms [5]. The lack of good alternative treatment options to treating infections caused by multidrug-resistant organisms is hugely tasking endeavor [6]. Globally, antibiotic resistance has emerged as a serious threat to human population health, which has led to a strong search for substitute sources of antimicrobial drugs [7]. Antimicrobial agents also have a number of negative effects especially raising the body's reactive oxygen species (ROS). ROS contribute to the development of cancer and are extremely harmful to human health and well being [8,9]. Oxidative stress is the primary cause for the pathogenesis of a variety of diseases, including cancer, diabetes mellitus, cardiovascular, neurodegenerative, and inflammatory disorders [10, 11]. Oxidative damage can cause cytokine release and the start of enzymes like lipoxygenases from cellular effectors, which can lead to cellular infiltration and the propagation of inflammation [12].

Inflammation is an active defensive response to counter mechanical injuries, burns, infections, or other toxic stressors. It is meant to be beneficial, but it could also be harmful, especially over time [13]. Chronic conditions such as cardiovascular, neurological, or inflammatory bowel disorders may arise from ongoing inflammatory reactions [14]. Oxidative stress may be reduced with synthetic phenolic antioxidants including butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), or propyl gallate (PG) might have harmful hepatotoxic and carcinogenic consequences [15]. So it is a need of the hour to find safer, more accessible, and more effective substitutes, like traditional herbal medicine. It is thought that medicinal plants represent a safer, more accessible, and less expensive alternative treatment for microbial infections and/or the treatment of oxidative stress-related illnesses, such as inflammatory processes [16]. Megarajanga Kirutham (MRK) is the Siddha polyherbal formulation frequently used as a traditional cure for a variety of ailments, including inflammation, infections, and improving overall health. It was prepared using the method outlined in the classical Siddha treatise "Sigicha rathna deepam". It has the specific indication for menorrhagia, dysuria, leucorrhoea, anemia and emaciation [17]. Hence, the purpose of this study was to investigate the anti microbial, anti-inflammatory and antioxidant properties of Megarajanga kirutham.

MATERIALS AND METHODS

Collection of raw materials

All of the raw drugs needed to prepare the test drug were bought from a reputable raw drug seller, Tambaram and the Medicinal botanist in National Institute of Siddha, Chennai, provided their authentication. After appropriate purification, the trial medication was manufactured in the Gunapadam Lab, National Institute of Siddha, Chennai.

Purification of raw drugs

All the herbal drugs are purified as per the classical Siddha text *Gunapadam Mooligai Vaguppu* ^[18].



**Kopperundevi et al.,****Method of preparation**

The ingredients of Megarajanga Kirutham were mentioned in the Table 1. The drug was prepared as per the Siddha classical text "Sigicha rathna deepam". 350grams of aththi pattai (*Ficus racemosa*), Naaval pattai (*Syzygium cumini*), othiyampattai (*Lannea coromandelica*) were crushed and to prepare the kudineer (decoction) 8 liters of water was added and reduced to 1 liter. Then juices of karumbu juice (*Saccharum officinarum*), nellikai juice (*Embllica officinalis*), lemon juice (*Citrus limon*), gingelly oil (*Sesamum indicum*) and cow's ghee were added into the decoction and boiled well. Each 26.25 grams powder of thalisapathiri (*Abies spectabilis*), elam (*Elettaria cardamomum*), kirambu (*Syzygium aromaticum*), jadhikkai (*Myristica fragrans*), chitrarathai (*Alpinia officinarum*), athimathuram (*Glycyrrhiza glabra*) and nilappanai kizhangu (*Curculigo orchioides*) were ground with the milk of three coconuts (*Cocos nucifera*). This kalkam was added to the decoction mixture and boiled until the ghee consistency.

Antimicrobial activity

The antimicrobial activities of the samples were appraised by disc diffusion method[19]. Antibacterial test was carried out on five species such as *E. Coli*, *Staphylococcus aureus*, *Trichomonas vaginalis*, *Candida albicans* and *Aspergillus niger*. The disc diffusion method was used to test the sample MRK's antimicrobial properties. The test chemicals were employed at doses of 500, 1000, and 2000 µg. Mueller-Hinton broth (MHB) was used to cultivate the target microorganisms. The suspensions were brought to standard subculture dilution after a 24-hour period. A diluted bacterial strain was cultivated in Petri dishes that contained Muller Hinton Agar (MHA) medium. *Trichomonas vaginalis* is incubated in Diamond's medium. A 6 mm diameter Whatman No. 1 disc was kept in an aseptic chamber after being pre-sterilized. The sterile disc papers were injected with each concentration. The discs that had been produced were then put on the culture medium. As a positive reference standard, the standard medications fluconazole (25µg), metronidazole (5µg) for *Trichomonas vaginalis*, and ciprofloxacin (5µg) to determine the sensitivity of each microbial species tested. After that, the inoculation plates were incubated for 24 hours (for bacteria) or 72 hours (for fungi) at 37°C. The anti-microbial property of the disc was determined by measuring and expressing the diameter of the clear zone surrounding it in millimeters.

DPPH (2, 2-Diphenyl 1-2 picrylhydrazyl) Assay for antioxidant activity

A free radical scavenging assay called 2,2-diphenyl 1-2 picrylhydrazyl (DPPH) was used to measure the antioxidant activity of test drug MRK[20]. The stock solution was prepared by mixing sample MRK with 95% methanol at the desired concentration (10 mg/100 ml or 100µg/ml). Five test tubes containing 1 ml, 2 ml, 4 ml, 6 ml, 8 ml, and 10 ml of the stock solution were used. The final volume of each test tube was increased to 10 ml by serial dilution with the same solvent, resulting in concentrations of 10µg/ml, 20µg/ml, 40µg/ml, 60µg/ml, 80µg/ml, and 100µg/ml, respectively. As a standard, ascorbic acid was made with methanol as a solvent at the same concentration as the sample extract. 2.5 ml of sample solution of varying concentrations was mixed with 1 ml of 0.3mM DPPH methanol solution to create the final reaction mixture, which was then left to react at room temperature. After 15 minutes of incubation at 37°C, absorbance was measured in the presence of test sample MRK at various concentrations (10µg, 20µg, 40µg, 60µg, 80µg, and 100µg/ml). Absorbance was read out at 517 nm utilizing double-beam U.V Spectrophotometer by using methanol as blank.

% scavenging = [Absorbance of control - Absorbance of test sample/Absorbance of control] X 100

Nitric Oxide Radical Scavenging Assay for antioxidant activity

The concentrations of test sample MRK are made into serial dilution from 10–100 µg/mL and the standard gallic acid. Griess reagent was prepared by mixing equal amounts of 1% sulphanilamide in 2.5% phosphoric acid and 0.1% naphthyl ethylene diamine dihydrochloride in 2.5% phosphoric acid immediately before use. A volume of 0.5 mL of 10 mM sodium nitroprusside in phosphate buffered saline was mixed with 1 mL of the different concentrations of the test drug (10–100 µg/mL) and incubated at 25°C for 180 mins. The test drug MRK was mixed with an equal volume of freshly prepared Griess reagent. Control samples without the test drug but with an equal volume of buffer were prepared in a similar manner as was done for the test samples. The absorbance was measured at 546 nm using a Spectra Max Plus UV-Vis microplate reader (Molecular Devices, GA, USA). Gallic acid was used as the positive





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control. The percentage inhibition of the test drug MRK and standard was calculated and recorded. The percentage nitrite radical scavenging activity of the test drug MRK and gallic acid were calculated using the following formula [21]:

percentage nitrite radical scavenging activity:

$$\text{nitric oxide scavenged (\%)} = \frac{A_{\text{control}} - A_{\text{test}}}{A_{\text{control}}} \times 100,$$

where A_{control} = absorbance of control sample and A_{test} = absorbance in the presence of the samples extracts or standards.

ABTS Assay for anti oxidant activity

This assay carried out for the purpose of evaluating the anti-oxidant potential of test drug MRK against 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) or ABTS radicals^[22]. The ABTS radical cation method was modified to evaluate the free radical-scavenging effect of one hundred pure chemical compounds. The ABTS reagent was prepared by mixing 5mL of 7mM ABTS with 88μL of 140mM potassium persulfate. The mixture was then kept in the dark at room temperature for 16 h to allow free radical generation and was then diluted with water (1 : 44, v/v). To determine the scavenging activity, 100μL ABTS reagent was mixed with 100μL of test sample (10-100μg/ml) and was incubated at room temperature for 6 min. After incubation, the absorbance was measured 734 nm. 100% methanol was used as a control. Gallic acid with same concentrations of test drug MRK was measured following the same procedures described above and was used as positive controls. The antioxidant activity of the test sample MRK was calculated using the following equation: The ABTS scavenging effect was measured using the following formula:

Radical scavenging (%)

$$= \left[\frac{(A)_{\text{control}} - (A)_{\text{sample}}}{(A)_{\text{control}}} \right] \times 100.$$

Albumin denaturation assay for anti inflammatory activity

In-vitro anti-inflammatory activity of Megarajanga kritham (MRK) was investigated utilizing the albumin denaturation method^[23, 24]. The reaction mixture included standard diclofenac sodium at a concentration of 100 mcg/ml of final volume, test sample MRK at different concentrations ranging from 100 to 500 mcg/ml, and bovine serum albumin (5% aqueous solution). Using a tiny quantity of 1N hydrochloric acid, the pH was changed. The samples were heated for three minutes at 57°C after being incubated for twenty minutes at 37°C. 2.5 ml of phosphate buffer solution was added to each test tube once the material had cooled. Spectrophotometric measurements of the generated turbidity were made at 660 nm. Distilled water was utilized as a control sample, and bovine serum albumin was absent from product control tests. The experiment was carried out in triplicate.

The Percentage protection from denaturation is calculated by using the formulae

$$\left[\frac{(A)_{\text{control}} - (A)_{\text{sample}}}{(A)_{\text{control}}} \right] \times 100.$$

Statistical analysis:

Results are expressed as Mean ± SD. The difference between experimental groups was compared by One-Way Analysis Of Variance (ANOVA) followed by Dunnet Multiple comparison test.





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RESULTS

Megarajanga Kirutham is the polyherbal formulation comprises 16 herbal compounds. Bioactive compounds present in the herbs are responsible for the pharmacological and therapeutic action of the formulation [25]. The investigation of antimicrobial activity of Siddha poly herbal extracts against human pathogens such as *E. Coli*, *Staphylococcus aureus*, *Trichomonas vaginalis*, *Candida albicans* and *Aspergillus niger* done by disc diffusion method which was shown in Figures 1-5 and Table 1. The antimicrobial activity of Siddha polyherbal formulation MRK possess strong antimicrobial activity against human pathogens such as *E. Coli*, *Staphylococcus aureus*, *Trichomonas vaginalis*, *Candida albicans* while low activity against *Aspergillus niger*. The antimicrobial activity of MRK's main ingredient *ficus racemosa* also revealed the significant bactericidal activity against *E.coli*, *S. aureus*, *S. typhi*, *K. pnem* at concentration and low activity against the *A. niger*[26]. Many of the herbals present in the MRK also possess the antimicrobial activity [27-31]. The inhibition zone is maximum in larger area in all the organisms except *Aspergillus niger*. The antimicrobial activity of liquorice revealed against *Staphylococcus aureus*, *Mycobacterium tuberculosis* and *Pseudomonas aeruginosa*[32,33]. *Syzygium aromaticum* extract was the most active against multi drug resistant and gram negative uropathogens[34].

Anti inflammatory activity

The result obtained from the present clearly indicates that the test drug MRK was effective in inhibiting heat induced albumin denaturation. Protein denaturation is a complex process that involves changes to hydrophobic, disulfide, and electrostatic hydrogen bonds [35]. Protein denaturation results in the generation of autoantigens in inflammatory diseases such diabetes, cancer, and rheumatic arthritis. Hence, inflammatory activity can be reduced by blocking protein denaturation[36]. Diclofenac, Non steroidal anti inflammatory drug is used as the reference drug in this study. Maximum percentage inhibition of about 69.54 % was observed at 500 µg/ml when compare to that of the Diclofenac sodium, a standard anti-inflammatory agent with the maximum inhibition 89.22 % at the concentration of 100 µg/ml. The anti inflammatory activity of MRK mentioned in the Table 2 and 3. In this study, MRK produced a dose-dependent anti-inflammatory activity which may be the first description in this particular species. The higher the concentration, the greater the inhibitory effect of the extracts and fractions on the serum albumin. Several studies had reported on anti-inflammatory effect of ingredient of this formulation. According to phytochemical research, *Ficus racemosa* contains biologically active components such as flavonoids, tannins, phenolic compounds, and phytosterols. It is hypothesized that one or more of these constituents, or their combination, is what produces the analgesic and anti-inflammatory effects [37]. The glabridin in liquorice exhibits the great anti inflammatory activity [38]. The petroleum ether extract of nutmeg showed activities similar to non-steroidal anti-inflammatory drugs [39]. The anti inflammatory and analgesic activity of cardamom demonstrated by using the carrageenan-induced rat paw edema and p-benzoquinone induced writhing method. Studies reveal that antispasmodic action of cardamom is produced through muscarinic receptor blockage [40].

Anti oxidant activity

The study formulation MRK was tested for its radical scavenging capacity against DPPH and ABTS, and the results were compared to those of ascorbic and gallic acid. The inhibition percentage against the corresponding radical was represented at the same dose (10-100µg/ml). In Table 4, The MRK formulation showed significant quenching of the DPPH radical, with inhibition percentages ranging from 7.778 ± 2.222% to 41.85 ± 3.395% when compared to the standard ascorbic acid, which had inhibition percentages ranging from 38.15 ± 3.395% to 88.15 ± 0.6415%. The IC₅₀ values for the MRK and standard ascorbic acid were determined to be 121 ± 12.15µg/ml and 23.55 ± 10.9µg/ml, respectively shown in Table 5. The formulation MRK demonstrates a noteworthy scavenging ability against the ABTS radical, reaching a maximum value of 55.86 ± 3.772%. This value is lower than the 88.45 ± 1.24% exhibited by the standard gallic acid (Table 6). In Table 7, the IC₅₀ values for the MRK and standard gallic acid were determined to be 42.48 ± 1.45µg/ml and 89.18 ± 2.81µg/ml respectively. The MRK formulation exhibited notable suppression of the NO radical, with inhibition percentages ranging from 6.069 ± 2.168% to 55.03 ± 7.536% in comparison to the standard ascorbic acid, which had inhibition percentages



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ranging from $31.07 \pm 2.621\%$ to $82.81 \pm 0.6014\%$ (Table 8). The IC₅₀ values for the MRK and standard ascorbic acid were measured to be $93.74 \pm 16.24\mu\text{g/ml}$ and $40.41 \pm 2.46\mu\text{g/ml}$ respectively, as shown in Table 9. The methanolic extract of nutmeg seed showed good antioxidant activity by methods of 2,2-diphenyl-1-picrylhydrazyl (DPPH) and ferric reducing antioxidant power (FRAP) due to high content of tannins, flavonoids, and terpenoids^[41]. Cardamom oil has potent antioxidant activity through increase the levels of glutathione^[42]. Clove is having a potential antioxidant property tested by using 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid), oxygen radical absorbance capacity, ferric-reducing antioxidant power, xanthine oxidase, and 2-deoxyguanosine^[43].

CONCLUSION

MRK is the Siddha polyherbal formulation which is widely used for reproductive diseases. The pharmacological activity of each ingredient of the MRK is responsible for the therapeutic effect of the formulation.. The pharmacological activities of MRK were analyzed, and the results showed promising antibacterial, antioxidant, and anti-inflammatory properties that were dose dependent. This formulation had strong antibacterial activity but weak antifungal efficacy. Further, clinical studies should be conducted on this popular and potent formulation to validate its antioxidant, anti-inflammatory and anti-microbial activity. Thus, there is a scope for further research on its properties and mode of action.

Conflict of Interest:

The authors declare that there are no conflicts of interest.

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Table 1: Zone of Inhibition data of Anti-Microbial activity

Sample Code	<i>E-Coli</i>			<i>Staphylococcus aureus</i>			<i>Trichomonas Vaginalis</i>			<i>Candida albicans</i>			<i>Aspergillus niger</i>		
Concentration	500 µg	1000 µg	2000 µg	500 µg	1000 µg	2000 µg	500 µg	1000 µg	2000 µg	500 µg	1000 µg	2000 µg	500 µg	1000 µg	2000 µg
MRK	-	2	4	-	4	8	-	3	6	-	-	3	-	-	-
Ciprofloxacin (10µg)	24			19			NA			NA			NA		
Metronidazole (5µg)	NA			NA			22			NA			NA		
Fluconazole (25µg)	NA			NA			NA			20			17		

- = Not active

NA = Not Applicable



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Concentration in $\mu\text{g/ml}$	Absorbance
Control	0.917 ± 0.020
MRK 100	0.61 ± 0.098
MRK 200	0.503 ± 0.076
MRK 300	0.406 ± 0.040
MRK 400	0.296 ± 0.080
MRK 500	0.203 ± 0.045
Diclofenac sodium (100 μg)	0.023 ± 0.011

Each value represents the mean $\pm$ SD. N=3**Table 3: Anti inflammatory activity of MRK**

Concentration in $\mu\text{g/ml}$	Percentage Inhibition of Protein Denaturation
MRK 100	25.18 ± 13.2
MRK 200	36.89 ± 8.97
MRK 300	47.46 ± 4.49
MRK 400	59.34 ± 10.9
MRK 500	69.54 ± 7.22
Diclofenac sodium (100 μg)	89.22 ± 2.83

Each value represents the mean $\pm$ SD. N=3**Table 4: Percentage inhibition of test drug MRK on DPPH radical scavenging assay**

Concentration ($\mu\text{g/ml}$)	% Inhibition of Ascorbic Acid	% Inhibition of MRK
10 $\mu\text{g/ml}$	38.15 ± 3.395	7.778 ± 2.222
20 $\mu\text{g/ml}$	50.37 ± 7.398	16.67 ± 1.925
40 $\mu\text{g/ml}$	61.11 ± 6.186	23.7 ± 1.697
60 $\mu\text{g/ml}$	70.74 ± 9.45	29.63 ± 3.395
80 $\mu\text{g/ml}$	80.37 ± 2.313	35.56 ± 1.925
100 $\mu\text{g/ml}$	88.15 ± 0.6415	41.85 ± 3.395

Data are given as Mean $\pm$ SD (n=3)**Table5: IC50 Values for DPPH radical scavenging Assay by MRK and standard.**

Test Drug / Standard	IC50 Value DPPH Assay $\pm$ SD ($\mu\text{g/ml}$)
ASCORBIC ACID	23.55 ± 10.9
MRK	121 ± 12.15

Data are given as Mean $\pm$ SD (n=3)**Table 6: Percentage inhibition of test drug MRK on Nitric Oxide radical scavenging assay**

Concentration ($\mu\text{g/ml}$)	% Inhibition of MRK	% Inhibition of Gallic Acid
10 $\mu\text{g/ml}$	13.97 ± 3.772	22.57 ± 3.772
20 $\mu\text{g/ml}$	20.78 ± 3.281	37.6 ± 4.341
40 $\mu\text{g/ml}$	27.58 ± 3.873	46.56 ± 5.298
60 $\mu\text{g/ml}$	36.89 ± 1.24	66.96 ± 2.236





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80 µg/ml	44.76 ± 1.86	77.35 ± 3.281
100 µg/ml	55.86 ± 3.772	88.45 ± 1.24

Data are given as Mean ± SD (n=3)

Table 7: IC50 Values for Nitric Oxide radical scavenging assay by MRK and standard

Test Drug / Standard	IC50 Value ABTS Assay ± SD (µg /ml)
MRK	42.48 ± 1.45
GALLIC ACID	89.18 ± 2.81

Data are given as Mean ± SD (n=3)

Table 8: Percentage inhibition of test drug MRK on ABTS radical scavenging assay

Concentration (µg/ml)	% Inhibition of MRK	% Inhibition of Gallic Acid
10 µg/ml	6.069 ± 2.168	31.07 ± 2.621
20 µg/ml	19.61 ± 3.658	41.14 ± 0.6014
40 µg/ml	26.9 ± 4.21	52.94 ± 1.203
60 µg/ml	32.46 ± 6.831	60.58 ± 1.804
80 µg/ml	43.22 ± 9.679	67.18 ± 7.678
100 µg/ml	55.03 ± 7.536	82.81 ± 0.6014

Data are given as Mean ± SD (n=3)

Table 9: IC50 Values for ABTS radical scavenging assay by MRK and standard

Test Drug / Standard	IC50 Value NO Assay ± SD (µg /ml)
MRK	40.41 ± 2.46
GALLIC ACID	93.74 ± 16.24



Figure 1: Anti- Microbial Effect of MRK against *Staphylococcus aureus*

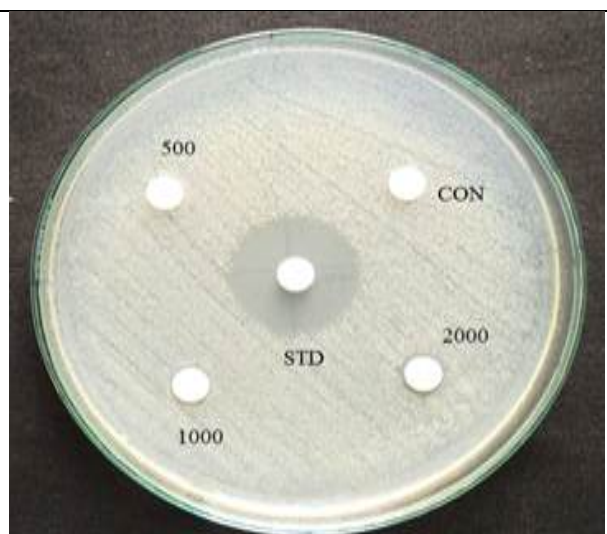


Figure 2: Anti- Microbial Effect of MRK against *E-Coli*





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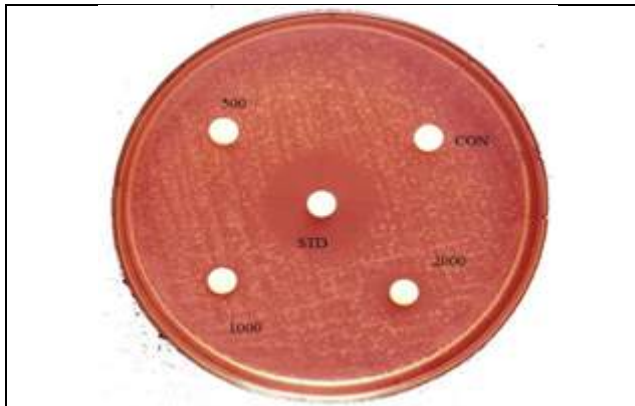


Figure 3: Anti- Microbial Effect of MRK against *Trichomonas Vaginalis*



Figure 4: Anti- Microbial Effect of MRK against *Candida albicans*



Figure 5: Anti- Microbial Effect of MRK against *Aspergillus niger*

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RESEARCH ARTICLE

The Use of Digital Marketing Strategies Impact on Consumer Purchase Intent and Brand Loyalty

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ABSTRACT

The influence of digital marketing tactics on customer purchase intent and brand loyalty is the focus of this study. Marketing has completely changed in the digital era, moving from conventional tactics to innovative digital ideas. This study investigates how customer purchase intent and long-term brand loyalty are affected by digital marketing tactics such as influencer relationships, email campaigns, content marketing, SEO, and social media marketing. In order to comprehend the factors influencing online customer behavior, this thesis employs a mixed-method approach, combining quantitative data from consumer surveys with qualitative interviews with marketing experts. For the quantitative survey, 300 respondents in total were chosen. This figure is enough to carry out reliable statistical analysis, such as regression and correlation, with sufficient power to find important connections between digital marketing tactics and customer purchase intent and brand loyalty. According to the results, digital marketing strategies that are tailored, interesting, and value-driven have a big impact on customers' initial intent to buy as well as their continued loyalty. The report offers useful suggestions for marketers to create successful digital strategies that promote stronger customer bonds and brand loyalty. Thus, the effect of digital marketing tactics on customer purchase intent and brand loyalty is determined. Understanding how internet marketing tools affect customer behavior and long-term brand connections is crucial for businesses due to the marketplace's fast digital transition.

Keywords: Digital Marketing, Consumer, Purchase Intent, Brand Loyalty.



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INTRODUCTION

The way companies engage with customers has changed as a result of the digital revolution. Digital marketing tactics that make use of the internet, mobile devices, social media platforms, search engines, and other digital channels have greatly eclipsed traditional marketing approaches, even if they are still relevant. These platforms enable marketers to more efficiently measure customer interaction, tailor content, and reach a wider audience. Customers are continuously exposed to targeted advertisements, influencer content, email campaigns, and tailored product suggestions in today's fiercely competitive and information-rich world. These digital marketing tactics seek to promote long-term brand loyalty in addition to increasing purchase intent. Businesses must constantly modify their digital strategies to remain relevant and competitive as customer tastes change quickly. Even while digital marketing is becoming more and more important, research on how it really affects customer behavior specifically, buy intent and brand loyalty is still ongoing. For marketers looking to create more successful campaigns and sustain a solid brand-consumer relationship, it is essential to comprehend this relationship.

Digital Marketing

Digital marketing is the deliberate use of digital platforms and internet-based technology to sell goods, services, or brands to specific people. In order to engage clients, foster connections, and increase conversions, it entails utilizing channels including websites, social media, email, search engines, and mobile applications (Chaffey & Ellis-Chadwick, 2019). Due to the quick expansion of social media, mobile connection, and internet usage, digital marketing is becoming a crucial part of contemporary corporate plans. Digital marketing allows for two-way, interactive, and real-time customer involvement, in contrast to traditional marketing, which frequently entails one-way communication through print or broadcast media. In addition to increasing brand awareness, this enables highly customized and targeted messages. Pineiro-Otero and Martínez-Rolan (2016) assert that including a website component and using the internet as a platform for diverse strategic actions are two ways to implement effective and efficient digital marketing strategies. Digital public relations, internet-based advertising, improving search engine visibility (SEO), using search engine marketing (SEM) for promotion, using social media as a marketing tool (SMM), using email as a marketing channel, electronic newsletters, affiliate marketing, content-driven promotional strategies, and many other approaches are just a few examples of the diverse range of derivative activities that fall under this category (Kannan and Li, 2017; Rizvanovic et al., 2023).

A website is a network of linked webpages maintained on a server that allows people, organizations, or groups to share information. Websites are often hosted on web servers that are reachable via networks such as local area networks or the internet, as indicated by Uniform Resource Locators (URLs) Berendt and Spiliopoulou (2000). Websites are an affordable marketing tool for businesses. The literature highlights how crucial it is to integrate a well-designed website into an organization's marketing initiatives, whether they include promoting goods or services. Consumers favor businesses with attractive websites (Gibson, 2018).

Digital Marketing Capabilities

According to Trainor et al. (2011), digital marketing capabilities include an organization's ability to use online and digital technology to create meaningful interactions with customers. According to Herhausen et al. (2020), businesses obtain important insights on their clientele through these exchanges, and customers may access corporate resources and information. Additionally, define digital marketing skills as the organization's ability to effectively plan and implement digital marketing campaigns.

There are seven criteria used to evaluate a digital marketing capacity, which are listed below:

- **Planning:** Developing a comprehensive plan to incorporate digital marketing across all organizational strategies.
- **Reach:** Enhancing awareness and attracting Increasing the number of website visitors through successful marketing communication
- **Action:** Engaging with customers on internet to generate leads and foster meaningful interactions.



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- **Conversion:** Enhancing the effectiveness of sales channels such as email, website, and targeting to successfully convert leads into purchases.
- **Engage:** Enhancing customer retention and encouraging repeat purchases by putting in place methods and procedures that foster consumer loyalty and support.
- **Brand:** Forming an emotional bond with clients by utilizing more frequent interaction and communication through internet channels that emphasize the company's distinctive value offer.
- **Governance:** Executing digital transformation strategies that smoothly incorporate digital media, technology, and data into the company. This requires the strategic alignment of appropriate staff, procedures, marketing tools, and data to efficiently conduct digital marketing initiatives.

Importance of Digital Marketing in Modern Business

Digital marketing has become a key component of contemporary corporate strategy in today's increasingly linked society. Consumer behavior has drastically changed from conventional to digital channels due to the quick growth of cellphones, social media, and internet access. Due to this change, companies of all sizes are now forced to use digital marketing techniques as an essential part of their marketing campaigns rather than just as a supplemental tool. Businesses may operate beyond geographic borders thanks to digital marketing. Digital platforms enable firms to instantaneously access worldwide consumers, in contrast to conventional techniques that are constrained by geography and distribution. Businesses may interact with customers all around the world through search engines, social media, email, and mobile applications, frequently at a cheaper cost than traditional advertising. Digital marketing is more cost-effective and scalable than traditional advertising (such as TV, print, and billboards). Businesses may precisely analyze return on investment (ROI), target certain demographics, and manage budgets using pay-per-click (PPC) advertising, social media advertisements, and content marketing initiatives. Businesses and customers may communicate in both directions thanks to digital marketing. Businesses may engage with consumers, get feedback, and develop connections using social media platforms, blogs, chatbots, and email marketing. In addition to raising consumer pleasure, this interaction fosters the development of devoted brand ambassadors. Before making a purchase, consumers now use a variety of channels and gadgets. An omnichannel presence is supported by digital marketing, which guarantees consumer satisfaction and brand coherence across websites, social media, mobile applications, and email. This holistic approach significantly influences consumer purchase decisions and fosters brand trust.

REVIEW OF LITERATURE

Shams Mukhtar (2023) According to a survey, digital media has forced companies to implement digital marketing techniques in order to improve brand perception, encourage customer interaction, and guarantee client loyalty. In order to provide empirical insights into the interactions between these dimensions, this study looks at how digital marketing methods affect brand image, customer engagement, purchase intention, and loyalty. The purpose of the study is to evaluate how digital marketing tactics affect customer engagement and brand perception, as well as how these factors subsequently affect purchase intention and loyalty. Through rigorous statistical analysis, specific hypotheses are tested to determine the strength and importance of these associations. 300 respondents were given a structured questionnaire as part of a quantitative approach. Descriptive statistics, reliability analysis (Cronbach's Alpha), Pearson's correlation, and multiple regression were used to assess the correlations between digital marketing tactics, customer engagement, brand perception, purchase intention, and loyalty. Social media usage trends and demographic factors were also taken into account. The findings show that digital marketing tactics greatly improve brand image and consumer engagement, which are important factors influencing purchase intention and loyalty. In order to improve good brand views, maintain long-term loyalty, and establish brand-consumer interactions, the study emphasizes how important it is for firms to use interactive and consumer-centric digital marketing strategies.



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The changing effects of new digital technology and ethical issues in digital marketing tactics should be investigated in future studies.

Kumar et al. (2024)the impact of company-generated social media content on consumer behavior. Marketing Journal.This study emphasized the importance of company-generated content on Twitter and Facebook. It came to the conclusion that, particularly when combined with user-generated material, this kind of content boosts consumer spending and fosters enduring loyalty. This study investigated the use of social media marketing (SMM) by luxury companies to affect consumer behavior and brand equity. It was discovered that brand preference and purchase intention are strongly influenced by social media content's interaction, entertainment value, and trendiness.

METHODOLOGY

The study employed a Descriptive Design methodology, gathering information from both Primary and Secondary sources. Primary Data was gathered through surveys and face-to-face interviews using a structured questionnaire for Providing predefined options for participants to select from. We gathered secondary information from various sources such as books, the internet, digital platforms, and social media websites. Random sampling was employed, with a sample size of 200 respondents. This study adopts a combining both quantitative and qualitative approaches to gain a comprehensive understanding of how digital marketing strategies influence consumer purchase intent and brand loyalty. The quantitative method provides measurable data on consumer behavior patterns, while the qualitative approach offers deeper insights into consumer attitudes and motivations.

Significance of the study

For marketers, companies, and digital strategists looking to improve the efficacy of their online efforts, this research offers insightful information. This research supports more focused and customer-focused marketing strategies by pinpointing the precise tactics that affect purchase intent and loyalty. It fills in the gaps in current research and makes recommendations for future lines of inquiry by offering a modern viewpoint on the theoretical frameworks that explain consumer reactions to digital interaction. The study is important because it closes the gap between consumer psychology and marketing strategy in the digital sphere, providing insightful information for a range of stakeholders engaged in developing and reacting to digital marketing strategies. By providing empirical insights into the efficacy of digital methods in influencing customer behavior, this study adds to the scholarly and professional conversation on digital marketing. The study will determine certain relationships between digital marketing initiatives and important consumer indicators including engagement, brand perception, purchase intention, and loyalty by thoroughly evaluating ideas. Additionally, the study offers prescriptive insights for businesses looking to maintain competitive advantage in the changing digital world, enhance their digital branding initiatives, and create consumer-centric marketing strategies. Future research on consumer behavior analytics, digital marketing trends, and the incorporation of developing technology into marketing strategies will also benefit from the findings of this study.

Objectives

The primary objectives of this study are:

- To examine the influence of various digital marketing strategies on consumer purchase intent.
- To assess the relationship between digital marketing engagement and brand loyalty.
- To identify the most effective digital marketing tactics in fostering consumer trust and long-term relationships.

Hypotheses

- There will be significant positive relationship between the use of digital marketing strategies and consumer purchase intent.
- There will be significant difference between increased consumer engagement with digital marketing content with higher levels of brand loyalty.





- There will be significant difference between Personalized and interactive digital marketing tactics consumer trust and contribute to long-term brand relationships.

Sampling size

The study's sample size was chosen to strike a compromise between practicality and representativeness. For the quantitative survey, 300 respondents in total were chosen. This figure is enough to carry out reliable statistical analysis, such regression and correlation, with sufficient power to find important connections between digital marketing tactics and customer purchase intent and brand loyalty. Fifteen people were specifically chosen from the survey respondents to take part in in-depth interviews for the qualitative portion. This smaller sample size preserves the richness of qualitative data while enabling in-depth investigation of specific customer experiences and perspectives. The sample size was selected in accordance with conventional marketing research guidelines, which state that 10–20 interviews are usually required for qualitative research to attain topic saturation and that respondents are deemed suitable for survey-based studies combining several variables.

Data collection

In order to provide thorough insights on how digital marketing techniques affect customer purchase intent and brand loyalty, this study used both primary and secondary data gathering approaches. Using Google Forms, a structured online survey was created and sent to the 300 respondents in the target sample. To make statistical analysis easier, the questionnaire included a 5-point Likert scale for attitudinal items, ranging from "Strongly Disagree" to "Strongly Agree." Fifteen respondents were chosen for follow-up interviews in order to supplement the survey results and get qualitative insights into their perspectives and experiences with digital marketing. The interviews lasted around 20 to 30 minutes apiece and were conducted over the phone or via video conferencing. In order to give theoretical underpinnings and help data interpretation, pertinent academic publications, books, and industry reports on digital marketing, consumer behavior, and brand loyalty were examined.

Statistical tools used

The statistical tools used for SPSS Software, version 25.0 was used to carry out analysis. The analysis techniques are:

- Descriptive Analysis (Tabulation, Percentage, Mean, etc.)
- Independent-samples t-test
- Chi-Square
- Pearson Correlation
- Multiple Regression

RESULT AND DISCUSSION

The sample population's demographics assist evaluate how representative the data is of the target market and offer context for the conclusions. There are 51.7% female respondents and 48.3% male respondents in the sample. The almost equal distribution indicates a gender representation that is balanced, guaranteeing that both male and female viewpoints are included in the conclusions derived from the data. Gender may affect how customers interact with digital marketing material and react to brand messaging, so striking this balance is crucial. With fewer participation in the older age categories, the bulk of respondents (40%) are between the ages of 18 and 24, followed by those between the ages of 25 and 34 (31.7%). Of the participants, 56.7% have undergraduate degrees, 30% have finished graduate school, and 13.3% have "other" educational backgrounds.

The strength and direction of the association between digital marketing tactics and two important consumer outcomes—purchase intent and brand loyalty—were investigated using the Pearson correlation analysis. Purchase intent and brand loyalty are strongly positively correlated ($r > 0.50$) with social media marketing, content marketing, and influencer marketing. These findings suggest that consumers are more likely to make a purchase and stick with a business when they engage with these digital marketing tactics. The strong link indicates that customers are very



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receptive to online tactics that are interesting, genuine, and content-driven. Following influencers may help consumers believe their product recommendations, which improves both initial purchasing decisions and long-term emotional ties to the companies they support.

Gender and brand loyalty are statistically significantly correlated, according to the Chi-square test ($\chi^2 = 6.214$, $p = 0.045$). Compared to male respondents, female respondents expressed greater levels of brand loyalty. This implies that when creating focused campaigns, digital marketing techniques may have a somewhat greater emotional or trust-building impact on female customers. The results of the above table indicate that the five digital marketing methods account for 58% of the variation in customer purchase intent. When it comes to influencing customer purchasing decisions, social media marketing has the most influence ($\beta = 0.31$). Influencer marketing and content also play a major role. Despite being less powerful predictors, email and SEO/SEM are statistically significant, indicating that they aid in decision-making, particularly during the conversion phase. The aforementioned data indicates that the average brand loyalty score of female respondents is considerably greater than that of male respondents. This suggests that female customers are a strategically significant category for loyalty-building campaigns because they may react more emotionally or regularly to digital marketing initiatives.

FINDINGS

The following important conclusions were drawn from the descriptive, correlation, regression, ANOVA, and cross-tabulation statistical analyses:

- According to the results, social media marketing was shown to be the best predictor of consumer purchase intent ($\beta = 0.31$, $p < 0.001$), followed by influencer and content marketing.
- Purchase intent was positively impacted by all five techniques (including email marketing and SEO/SEM) in a statistically significant way ($R^2 = 0.58$). Customers are more likely to make a purchase when they engage with businesses through interesting digital channels.
- Brand loyalty was most strongly impacted by content marketing ($\beta = 0.29$, $p < 0.001$), indicating that meaningful and pertinent material is essential to establishing enduring connections.
- Influencer marketing and social media also demonstrated significant results, highlighting their significance for continuous interaction. 55% of the variance in brand loyalty was explained by the regression model ($R^2 = 0.55$), suggesting a significant overall impact of digital marketing initiatives.

CONCLUSION

The purpose of this study was to look at how customer purchase intent and brand loyalty are affected by digital marketing tactics. Understanding how internet marketing tools affect customer behavior and long-term brand connections is crucial for businesses due to the marketplace's fast digital transition. The study discovered that digital marketing tactics, namely influencer relationships, social media marketing, content marketing, and customized email campaigns, had a statistically significant impact on customer purchase intent based on the data gathered and examined. These tactics successfully boost engagement, perceived value, and product awareness, which in turn motivates customers to make purchases. Additionally, the results corroborate the idea that brand loyalty is significantly shaped by digital marketing. Digital interactions that are value-driven, customized, and consistent have been demonstrated to increase consumer trust, brand attachment, and repeat purchase behavior. In particular, loyalty indicators like customer retention and brand advocacy were most strongly correlated with social media involvement and email customization. This study adds to the body of knowledge by demonstrating that digital marketing plays a crucial role in fostering enduring client connections and loyalty in addition to being a tool for attracting new clients. It emphasizes how important it is for companies to create their digital marketing campaigns using a data-driven and customer-centric approach.





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Table: 1 Demographic Profile of Respondents

Variable	Category	N	Percent
Gender	Male	145	48.3%
	Female	155	51.7%
Age	18–24	120	40.0%
	25–34	95	31.7%
	35–44	50	16.7%
	45 and above	35	11.6%
Education	Undergraduate	170	56.7%
	Postgraduate	90	30.0%
	Other	40	13.3%



Balamurugan *et al.*,**Table: 2 The relationship between digital marketing strategies and consumer behavior**

Variable	Purchase Intent	Brand Loyalty
Social Media Marketing	0.65**	0.62**
Influencer Marketing	0.58**	0.59**
Content Marketing	0.60**	0.63**
Email Marketing	0.42**	0.47**
SEO/SEM	0.50**	0.54**

Table: 3 Gender and Brand Loyalty Response

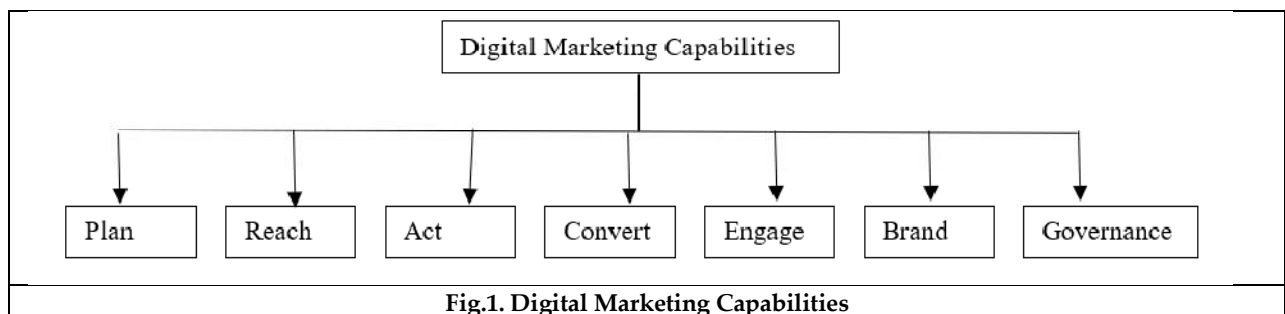
Brand Loyalty Level	Male (%)	Female (%)
High	58%	65%
Medium	32%	28%
Low	10%	7%
Chi-Square	6.214	p = 0.045

Table: 4 Multiple Regression for Predictors of Purchase Intent Regression Coefficients

Predictor	Unstandardized B	Standardized β	t	p-value
Social Media Marketing	0.415	0.31	6.25	0.000**
Influencer Marketing	0.362	0.25	4.80	0.000**
Content Marketing	0.288	0.21	4.01	0.000**
Email Marketing	0.142	0.10	1.98	0.049*
SEO/SEM	0.155	0.13	2.45	0.015*

Table: 5 Showing mean, S.D and t-value respondents level of Perceived Brand Loyalty based gender

Gender	Mean	Std. Deviation	t-value	p-value
Male	4.03	0.72	2.89	0.004**
Female	4.26	0.70		



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RESEARCH ARTICLE

Influence of Ladder and SAQ Training on Selected Motor Fitness Parameters Among Basketball Players

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ABSTRACT

The study sought to investigate the influence of ladder and saq training on selected motor fitness parameters among basketball players. To achieve the purpose of the study (N=60) sixty men basketball players were selected from National college, Tiruchirapalli, Tamilnadu, India as subjects. The age of the subjects ranged from 19 to 25 years. The selected subjects were divided into three equal groups (N=20). Group I underwent ladder training. Group II underwent saq training. Group III acted as control group who did not undergo any specialized training program other than their daily routine. The motor fitness parameters such as speed, agility, leg explosive power. Were selected as dependent variables and they were assessed by 50m dash, 3x10 shuttle run, standing broad jump respectively. The subjects were concerned with their particular training for a period of six weeks, three days per week. The collected data from three groups prior to and immediately after the training programme on selected criterion variables were statistically analyzed with analysis of covariance (ANCOVA). The level of confidence was fixed at 0.05 for all the cases to test the hypothesis. The result of the study reveals that the ladder training and saq training groups achieved significant improvement on selected respiratory variables such as speed, agility, leg explosive power of college men basketball players.

Keywords: Ladder Training, Saq Training, Motor Fitness Parameters, Speed, Agility and Leg Explosive Power.





INTRODUCTION

Basketball

Basketball is one of the most popular sports in the world. Participations of all ages have discovered basketball to be fun, competitive, educational, and recreational and fitness oriented. Individual skills such as shooting, passing, dribbling and rebounding along with offensive and defensive teamwork are prerequisites for successful participation in the sport (TeWierike SC, de Jong MC, Tromp EJ, Vuijk PJ, Lemmink KA, Malina RM, Elferink-Gemser MT, Visscher C (2014). Although the traditional 5-on-5 game is probably the most popular basketball format over the year a wide assortment of fun basketball related games and competitions have evolved to help participants develop fundamental skills and knowledge. The type of game or competition played will depend on available equipment, player skill level and number of participants. Regardless of game or competition format, basketball participation can be enriching and provide lifelong enjoyment to participants who choose to “tie up the laces” and play the game (Diana Star Helmer& Tomas s Owens, 2000).

Ladder Training

Ladder training is the multi-directional training, because the elements of strength, power, balance, agility, coordination, proprioception, core and joint stability, foot speed, hand eye coordination, reaction time and mobility. Each component should be integrated in to daily training session. Ladder skills are fun and functional ways to teach movement skills. By training, the mind and body to understand a verity of foot combinations. There are four basic skills is used when training with ladder. Runs, skips, shuffles and jump/hops. Ladder drills are fun and functional ways to teach movement skills (Arul Deva Paul, P. &Dr. D Sakthignanavel (2017). Although linear and lateral movements are biomechanical simple, their combination can be complex and many times overwhelming for the athlete. Buy teaching the mind and body to understand a variety of foot combinations, the chance for confusion and subsequent error decreases. Ladder drills should be learned in a slow controlled environment. Introducing movement skills too rapidly can ingrain poor motor patterns that may be difficult to override. Skilled movement should be optimized before the drill is advanced. The training incorporates three different types of drills. The first types of drill are steady state drills. These drills focus on quickness endurance and utilize a constant rhythm throughout the ladder. The second types of drill are burst drills. These drills focus on the ability to turn on rapid burst of foot movement. The third types of drill are elastic response drills. These drills focus on improving the reactive speed components of the lower leg. Ladder drills are also called as speed ladder drills are very important for any sport where agility, leg explosive strength, aerobic capacity and speed are important. It will greatly improve the player's footwork which will improve player's quickness, agility and coordination after constantly performing different speed ladder training. Drills for agility ladder training should be done right after warming up so that the muscles are fresh and ready to give 100% under correct form (Brown & Ferrigno, 2014).

SAQ Training

The demand to promote athletic ability is continually increasing for this SAQ training becoming a popular way to train athlete. SAQ training has proven to enhance the abilities of participants in different sports. This training improves the skills which is helpful for every sport where movements of arm fast & leg is required. Therefore all athletes should integrate to SAQ training (BujjiBabu., & Jhonson. (2012). Earlier SAQ training was not practiced by athlete due to lack of education regarding specific benefits and how it should involve in a complete training program. These training acts are a bridge between the gap of traditional resistance training & functional specific movements. Benefits of SAQ training increase the ability to exert maximal force while high speed movements it also include increased muscular power in all multi planner movements, reaction time,, motor skills, brain signal efficiency. With the acquisition of greater balance & reaction time an athlete is able to maintain proper body position at the time of skill execution and also react more pro efficiently in changing playing environment Devaraju, D. (2014).



**Boopathi****Objectives**

This study was designed to investigate the influence of ladder and saq training on selected motor fitness parameters among basketball players.

METHODOLOGY

To achieve the purpose of the study (N=60) sixty men basketball players were selected from National college, Tiruchirapalli, Tamilnadu, India as subjects. The age of the subjects ranged from 19 to 25 years. The selected subjects were divided into three equal groups (N=20). Group I underwent ladder training. Group II underwent saq training. Group III acted as control group who did not undergo any specialized training program other than their daily routine. The motor fitness parameters such as speed, agility, leg explosive power. Were selected as dependent variables and they were assessed by 50m dash, 3x10 shuttle run, standing broad jump respectively. The subjects were concerned with their particular training for a period of six weeks, three days per week. The collected data from three groups prior to and immediately after the training programme on selected criterion variables were statistically analyzed with analysis of covariance (ANCOVA). The level of confidence was fixed at 0.05 for all the cases to test the hypothesis.

RESULTS

The pre, post-test and adjusted post-test mean values of Speed on Ladder Training Group (LTG), Saq Training Group (STG) and Control Group (CG) were 7.36, 7.09, 7.05: 7.38, 7.14, 7.07 and 7.28, 7.39, 7.42 respectively. The pre, post-test and adjusted post-test mean values of Agility on Ladder Training Group (LTG), Saq Training Group (STG) and Control Group (CG) were 13.68, 12.60, 12.48: 13.79, 12.74, 12.60 and 13.75, 13.00, 12.80 respectively. The pre, post-test and adjusted post-test mean values of Leg explosive power on Ladder Training Group (LTG), Saq Training Group (STG) and Control Group (CG) were 2.32, 2.80, 2.80: 2.32, 2.53, 2.53 and 2.32, 2.53, 2.53 respectively. The obtained F values of adjusted post-test were greater than the table value of 3.16. Hence it was proved that there were significant improvements on speed, agility and leg explosive power of college basketball players.

DISCUSSION ON FINDINGS

The results of the study indicates that the experimental group namely as ladder training and saq training had significantly improved in the selected dependent variables speed, agility and leg explosive power improvement caused by ladder training and saq training. The results of the studies are in line with the studies of (Abbas, H. H. (2023).

CONCLUSION

The experimental groups namely as ladder training and saq training had achieved significant improvement on selected the motor fitness parameters such as speed, agility and leg explosive power when compared to control group. It was concluded that saq training shown better improvement when comparing to the ladder training groups on selected the motor fitness parameter. It was concluded that college level player should practice both ladder training and saq training for positive enhancement of playing.





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Table 1: Computation of Analysis of Covariance of Means of Ladder Training and Saq Trainingand Control GroupsSpeed, Agility, Leg Explosive Power.

Variable	Test Type	LTG Mean	STG Mean	CG Mean	Source	df	SS	MS	F-Ratio
Speed	Pre	7.36	7.38	7.28	Between	2	0.07	0.03	0.27
					Within	57	6.54	0.11	
	Post	7.09	7.14	7.39	Between	2	3.20	1.6	7.08*
					Within	57	12.90	0.226	
	Adjusted	7.05	7.07	7.42	Between	2	0.86	0.43	10.75*
					Within	56	2.07	0.04	
Agility	Pre	13.68	13.79	13.75	Between	2	0.28	0.14	0.43
					Within	57	18.78	0.32	
	Post	12.60	12.74	13.00	Between	2	1.28	0.64	4.26*
					Within	57	8.41	0.15	
	Adjusted	12.48	12.60	12.80	Between	2	5.38	2.69	15.82*
					Within	56	9.58	0.17	
Leg Explosive Power	Pre	2.32	2.32	2.32	Between	2	106.71	53.36	2.08
					Within	57	1085.87	19.05	
	Post	2.80	2.53	2.53	Between	2	196.84	98.42	3.91*
					Within	57	1433.47	25.14	
	Adjusted	2.80	2.53	2.53	Between	2	11.87	5.94	6.99*
					Within	56	47.37	0.85	

*Significantat 0.05level of confidence. (Table value required for significantat 0.05level of confidence were 3.16 respectively.





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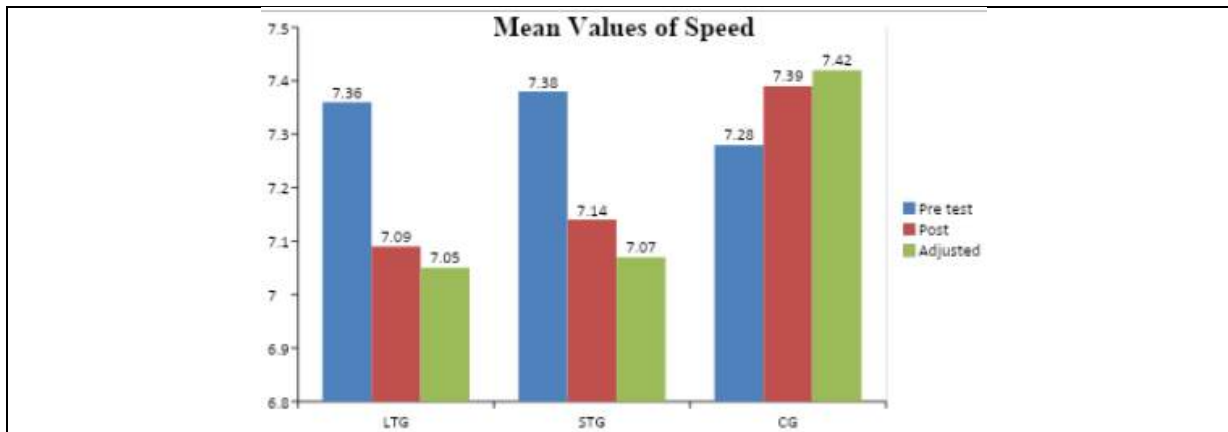


Figure-1: Pre, Post and Adjusted Post Test Means of ladder Training and Saq Training and control Group of Speed.

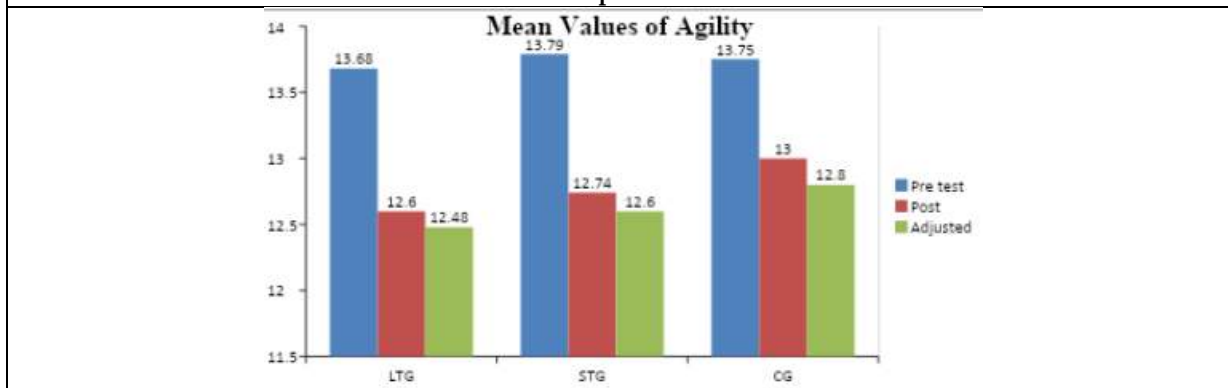


Figure-1I: Pre, Post and Adjusted Post Test Means of ladder Training and Saq Training and control Group of Agility.

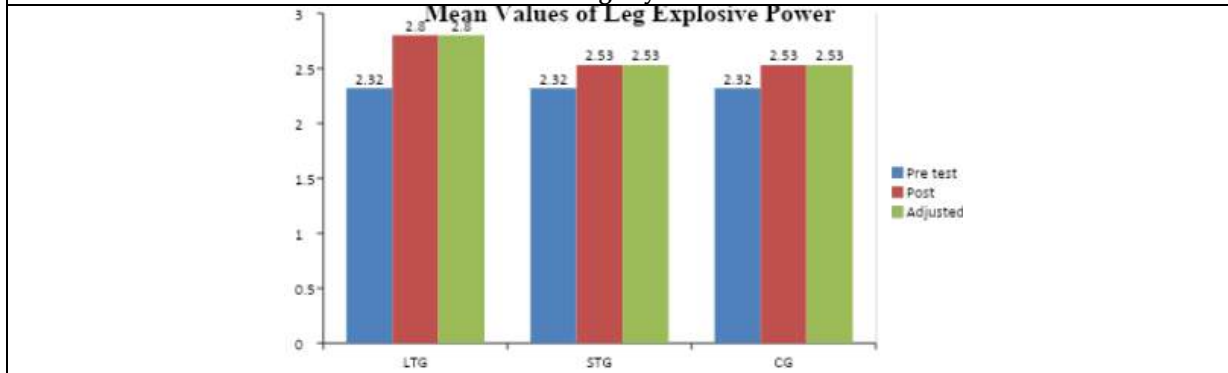


Figure-1II: Pre, Post and Adjusted Post Test Means of ladder Training and Saq Training and control Group of Leg Explosive Power.

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RESEARCH ARTICLE

Isolation of A Novel Antitubercular Dihydrofuranone from *Clausena brevistyla* Fruits

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ABSTRACT

An ethanolic extract of *Clausena brevistyla* fruits contains a novel dihydrofuranone, which was isolated and structurally elucidated by using complete spectroscopic analysis. Its molecular structure was unambiguously established through detailed analysis of 1D (¹H, ¹³C, and DEPT-135) and 2D (H-H COSY, HSQC, and HMBC) NMR spectra, supported by high-resolution LC-MS data. HR-LCMS profiling of the fruit extract revealed fifty-three major constituents, including aliphatic acids, aromatic carboxylic acids, phenolic acids, amino acids, flavonoids, and carbohydrates. The isolated dihydrofuranone exhibited antitubercular activity against *Mycobacterium tuberculosis* with a minimum inhibitory concentration of 0.91 µg/mL.

Keywords: *Clausena brevistyla*, Phytochemical profiling, Dihydrofuranone, NMR spectroscopy, HR-LCMS, Antitubercular activity





Ganapathy Sankari Subramanian and Jeyachandran Malaichamy

INTRODUCTION

Natural products have long served as a major source of novel drugs [1]. Of 217 natural product-inspired antibiotics approved between 1943 and September 2025, nearly one fourth of the molecules (52) are natural products, while three fourth (165) are semi-synthetic or synthetic derivatives [2]. Despite these advances, tuberculosis (TB) remains a serious global health concern, with rising mortality, particularly in developing countries. The World Health Organization (WHO) continues to monitor disease trends and support TB research initiatives worldwide [3]. Members of the genus *Clausena* are widely distributed and have been extensively investigated for their phytochemical and pharmacological properties. A number of *Clausena* species are used for conventional medicines [4]. Although, *Clausena* genus consists of approximately 30 species, amongst *Clausena brevistyla* remains relatively underexplored. Remarkably, *C. brevistyla* has been reported to have anti-inflammatory and analgesic properties. It also serves as a food source for the larval stages of certain Australian butterflies [5]. In this context, a comprehensive and systematic analysis is necessary for the identification of secondary metabolites and, to find out the biological applications may provide the improvement of traditional knowledge about the medicinal plants. This prompted us to examine the phytochemicals of *C. brevistyla* and their biological activities. Advanced spectroscopic techniques, including high-resolution LC-MS and one- and two-dimensional NMR, are routinely engaged to define molecular frameworks and connectivity. Such widespread structural study provides perfect support for molecular identity and forms the foundation for correlating chemical structure with biological activity. Accordingly, the present study reports the phytochemical investigation of *Clausena brevistyla* fruits (**Figure 1**), HR-LCMS profiling, isolation and structural elucidation of a novel dihydrofuranone and evaluation of antitubercular activity. Fig. 1 *Clausena brevistyla* fruits

Experimental

Measurements and reagents

1D and 2D NMR spectra were recorded on a Bruker Avance 500 MHz FT-NMR Spectrometer. Silica gel G was used for TLC and preparative TLC. Silica gel 60–120 mesh served as the stationary phase for column chromatography. HRLCMS analyses were performed using an Agilent Technologies 1290 Infinity UHPLC System joined with a 1260 Infinity HPLC with Chip Cube as well as a 6550 iFunnel Q-TOF mass spectrometer.

Plant Material

Clausena brevistyla fruits were collected in January 2023 from Alwarkurichi (8°47'29.4"N, 77°23'40.3"E), Tenkasi district, Tamil Nadu, India. The plant material was authenticated by Dr. K. Petchimuthu, Taxonomist, Sri KGS Arts College, Srivaikundam, and a voucher specimen was deposited for future reference.

Extraction and isolation

Approximately 500 g of *C. brevistyla* fruits were soaked in 1 L of ethanol for one week at room temperature. The mixture was filtered, and the solvent was removed under reduced pressure to yield 63 g of a brown, pasty crude extract (CBE), which was stored at 4 °C for further analysis.

Preliminary Phytochemical Analysis

The ethanolic extract of *Clausena brevistyla* fruits (CBE) was fractionated sequentially using *n*-hexane, chloroform, ethyl acetate, acetonitrile, and methanol. Each fraction was subjected to standard preliminary phytochemical tests to detect the presence of foremost classes of secondary metabolites.

Fractionation and isolation of Novel compound

Slurry was prepared by mixing 30 g of the ethanolic extract (CBE) with 25 mL of hot ethanol and 50 g of silica gel (60–120 mesh) for column chromatography. The dried slurry was re-extracted with increasing polarity of solvents like petroleum ether, chloroform, ethyl acetate, and ethanol by using Soxhlet extractor. The solvents of each re-extracts were removed *in vacuo* and stored at 4 °C for further analysis. A pale yellow spot on TLC was observed from the ethyl acetate re-extract. This extract was dissolved on the same solvent and applied to 41 preparative TLC plates,





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which were developed using an ethyl acetate–methanol mixture (9.5:0.5, v/v). After drying, three bands were visually observed, of which 32 plates exhibited the pale yellow band ($R_f = 0.49$). The corresponding silica gel was scraped and extracted with methanol (150 mL) in a Soxhlet apparatus. Removal of the solvent under reduced pressure yielded 23 mg of the purified compound I as a pale yellow powder.

Characterization of novel dihydrofuranone, (Compound I)

Molecular formula : $C_{20}H_{30}O_5$; Molecular weight : 350.46.

IR (KBr) : 3300 (OH str.), 1720 (C=O str). cm^{-1} .

^1H -NMR (DMSO- d_6 , 500 MHz, δ , ppm): 0.65 (s, 3H, C-8a methyl), 1.08 (s, 3H, C-5 methyl), 1.17 (m, 2H, C-4 $\underline{CH_2}$), 1.30 (m, 1H, C-4a $\underline{CH}$), 1.62 -1.96 (m, 6H) (C-4, C-8 and C-2'' $\underline{CH_2}$), 2.30 -2.45 (m, 2H, C-3 $\underline{CH_2}$), 3.82 (doublet of doublet, 2H, $J = 3.0$ Hz and $J = 11.0$ Hz, C-5 $\underline{CH_2}$ -OH), 4.02, 4.38 (doublet of doublet, 2H, $J = 6.0$ Hz and $J = 10.0$ Hz, C-5' $\underline{CH_2}$), 4.13 (doublet of doublet, 1H, $J = 3.0$ Hz and $J = 7.5$ Hz, C-6 $\underline{CH}$), 4.62; 4.81 (s, 1H, C-2 C= $\underline{CH_2}$), 4.90 (t, 1H, $J = 6.0$ Hz and $J = 6.5$ Hz, C-4' $\underline{CH}$ -OH), 5.07 (d, 1H, $J = 4.5$ Hz, C-6 OH), 5.72 (d, 1H, $J = 6.5$ Hz, C-5' $\underline{CH_2}$), 6.60 (doublet of triplet, 1H, $J = 1.0$ Hz, $J = 1.5$ Hz and $J = 6.5$ Hz, C-1'' $\underline{CH}$). ^{13}C -NMR (DMSO- d_6 , 125 MHz, δ , ppm): 15.21 (C-8a methyl carbon), 23.53 (C-5 methyl carbon), 24.41 (C-4 $\underline{CH_2}$), 24.44 (C-2' methylene carbon), 28.34 (C-7 methylene carbon), 36.96 (C-8 methylene carbon), 37.96 (C-3 methylene carbon), 40.45 (C-8a quarternary carbon), 42.73 (C-5 quarternary carbon), 54.81 (C-4a methine carbon), 55.93 (C-1), 63.10 (C-5 $\underline{CH_2}$ -OH), 64.96 (C-4' methine carbon), 74.80 (C-5' methylene carbon), 78.89 (C-6 methine carbon), 108.72 (C-2 C= $\underline{CH_2}$), 129.43 (C-3' quarternary C), 146.78 (C-1'' methine carbon), 148.05 (C-2 C= $\underline{CH_2}$) and 170.43 (C-2' C=O). DEPT-135 (δ , ppm): 15.20 (C-8a $\underline{CH_3}$), 23.54 (C-5 $\underline{CH_3}$), 24.38 (C-4 $\underline{CH_2}$), 24.44 (C-2' $\underline{CH_2}$), 28.33 (C-7 $\underline{CH_2}$), 36.97 (C-8 $\underline{CH_2}$), 37.96 (C-3 $\underline{CH_2}$), 54.81 (C-4a $\underline{CH}$), 55.93 (C-1), 63.10 (C-5 $\underline{CH_2}$ -OH), 64.96 (C-4' $\underline{CH}$), 74.80 (C-5' $\underline{CH_2}$), 78.88 (C-6 $\underline{CH}$), 108.75 (C-2 C= $\underline{CH_2}$), and 146.79 (C-1'' $\underline{CH}$).

Antitubercular activity

Compound I was evaluated for its antimycobacterial behaviour against *Mycobacterium tuberculosis* H37Rv by the MTT-based MABA [6]. The MIC was determined as the lowest concentration of **Compound I** that prohibited the change of colour from blue to pink, demonstrating complete bacterial growth inhibition.

ADMET analysis

The *in silico* absorption, distribution, metabolism, and excretion (ADMET) properties of compound I were predicted using the SwissADME online tool.

RESULTS AND DISCUSSION

Pilot Phytochemical Analysis

The pilot phytochemical screening of *Clausena brevistyla* fruit extracts established that the composition of secondary metabolites is strongly influenced by the polarity of the extraction solvent (**Table 1**). As summarized in **Table 1**, a clear trend is observed in which the number and diversity of phytoconstituents increase with solvent polarity. Specifically, *n*-hexane extract, being non-polar, exhibited the least diversity, contained two major metabolites (triterpenoids and xanthoproteins), chloroform and acetonitrile extracts contained three (triterpenoids, saponins, tannins), ethyl acetate extract contained five (reducing sugars, alkaloids, saponins, xanthoproteins, and aromatic acids), acetonitrile extract contained three (steroids, alkaloids, and flavonoids) and methanol extract contained richest profile of seven metabolites (triterpenoids, reducing sugars, phenolic compounds, saponins, xanthoproteins, flavonoids, and aromatic acids). Despite providing valuable preliminary insights, these qualitative phytochemical tests have limited sensitivity and may not detect minor or trace constituents. Consequently, HR-LCMS analysis was performed to achieve a comprehensive and precise metabolite profiling of *C. brevistyla* fruits, resulting the identification of both major and minor bioactive compounds.

HR-LCMS Analysis

The HR-LCMS analysis (**Figure 2, Table 2**) led to the identification of 53 compounds belonging to miscellaneous compounds, together with 18 aliphatic acids, 4 aromatic carboxylic acids, 23 phenolic acids, 2 amino acids, 3



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flavonoids, and 3 carbohydrate derivatives. The chromatogram displayed prominent peaks at early retention times (1–3 min), 11 aliphatic carboxylic acids, 2 aromatic carboxylic acids, 9 phenolic acids, 1 flavonoid and a carbohydrate. Mid-range retention times (10–30 min) are conquered by 4 aliphatic carboxylic acids, 1 aromatic carboxylic acid, 8 phenolic acids, 1 amino acid, 2 flavonoids and 2 carbohydrates. Peaks observed at higher retention times (>30 min) correspond to a complex carbohydrate and a phenolic acid. The HR-LCMS results thus confirm that *C. brevistyla* fruits are a rich source of bioactive metabolites, complementing the preliminary phytochemical screening and providing a complete chemical profile.

IR Spectra:

The IR spectrum exhibited characteristic absorption bands at 3300 cm^{-1} is due to the hydroxyl group and 1720 cm^{-1} is due to the carbonyl functionality (**Figure 3**).

¹H NMR Analysis

In the ¹H NMR spectrum of **compound I**, the two isolated methyl groups attached to quaternary carbons at C-8a and C-5 appeared as singlets at δ 0.65 and 1.08 ppm, respectively. Vinylic methylene protons at C-2 (C=CH₂) appeared at δ 4.62 and 4.81 ppm. The C-3 methylene, C-4 methylene and C-5 hydroxy methylene protons of decahydronaphthalene moiety resonated at δ 2.45, 1.17, and 3.82 ppm, respectively. Methylene protons of dihydrofuranone moiety at C-2'' appear δ 4.02 and 4.32 ppm. The tertiary methine protons of decahydronaphthalene moiety C-4a and C-6 resonated at δ 1.30 and 4.13 ppm, respectively, while the tertiary methine protons of dihydrofuranone moiety at C-4' appears at δ 4.90 ppm. The C-1'' methane proton resonates at δ 6.60 ppm (**Figure 4**).

¹³C NMR Analysis

In the ¹³C NMR spectrum of **compound I**, the carbonyl group present in C-2' appears at δ 170.43 ppm. Quaternary carbons C-2, C-5 and C-8a of decahydronaphthalene moiety resonated at δ 148.05, 42.73 and 40.45 ppm, respectively, whereas the quaternary carbon of dihydrofuranone moiety C-3' resonates at δ 129.43 ppm. The two methyl carbons (C-5 and C-8a) appeared at δ 23.53 and 15.21 ppm. Eight methylene carbons C-2 (C=CH₂), C-3, C-4, C-5 (CH₂-OH), C-7, C-8, C-5' and C-2'' were observed δ 108.72, 37.96, 24.41, 63.10, 28.33, 74.80 and 24.44 ppm, respectively. Five methine carbons present at C-1, C-4a, C-6, C-4' and C-1'' resonated at δ 55.93, 54.81, 78.89, 64.96 and 146.78 ppm (**Figure 5**).

DEPT-135 Analysis

In DEPT-135 spectra, positive signals corresponded to the two methyl groups C-5 and C-8a appears at δ 23.54 and 15.20 ppm respectively. The five methine carbons (C-1, C-4a, C-6, C-4', C-1''), while the eight methylene carbons ((C-2 (C=CH₂), C-3, C-4, C-5 (CH₂-OH), C-7, C-8, C-5' and C-2'')) showed negative signals. The nonexistence of quaternary carbons in DEPT confirms earlier ¹³C assignments (**Figure 6**).

HMBC technique

HMBC helps identify long-range connections between "H" and "C" atoms in **compound I**. In the HMBC spectra, the C-8a hydrogen (methyl protons) correlated with the carbons of C-8 (δ 36.96 ppm) and C-4a (δ 54.81 ppm) suggested that two and three bond correlations. The C-5 hydrogen (methyl protons) showed correlations with the carbons of C-5 (δ 42.73 ppm), C-4a (δ 54.81 ppm), C-5 CH₂-OH (δ 63.10 ppm), and C-6 (δ 78.89 ppm), that suggests two, three, two and three bond correlations respectively. The C-5' methylene hydrogens are linked with the carbons of C-2' carbonyl and C-5 hydroxy methine carbon suggests that three and two bond correlations respectively (**Figure 7**). Further correlations of methylene and methine protons are summarized in **Table 3** and illustrated in **Figure 8**. Based on these spectroscopic evidences, the structure of the novel compound was confirmed as 4-Hydroxy-3-(2-(6-hydroxy-5-(hydroxymethyl)-5,8a-dimethyl-2-methylenedeca-hydronaphthalen-1-yl)ethylidene)dihydrofuran-2(3H)-one (**Compound I**) (**Figure 9**).

Fig. 12. HMBC correlation.



**Ganapathy Sankari Subramanian and Jeyachandran Malaichamy****Antitubercular activity**

The in vitro activity of compound I against *Mycobacterium tuberculosis* H37Rv was evaluated using the MABA assay, and the MIC values are summarized in **Table 4** [7]. Compound I exhibited the maximum potency, with an MIC of 0.91 µg/mL, surpassing the activity of standard drugs ethambutol, and ciprofloxacin.

In silico ADMET Analysis

ADMET properties of compound I were predicted using the SwissADME tool. The compound (MW = 350 g/mol, TPSA = 86.99 Å², three rotatable bonds) showed favorable oral bioavailability. A consensus LogP of 2.30 indicated optimal lipophilicity and membrane permeability. Additionally, SwissADME predictions prove that the **compound I** has high gastrointestinal absorption and low risk of drug–drug interactions and also supports the drug-like pharmacokinetic profile.

CONCLUSION

An ethanolic extract of *Clausena brevistyla* fruits contains a novel dihydrofuranone, which was isolated, and completely characterized using 1D and 2D NMR spectra. HR-LCMS profiling revealed 53 major constituents, including aliphatic acids, aromatic carboxylic acids, phenolic acids, amino acids, flavonoids, and carbohydrates. The isolated dihydrofuranone exhibited potent antitubercular activity against *Mycobacterium tuberculosis* (MIC = 0.91 µg/mL). Overall, *C. brevistyla* fruits are a promising source of bioactive compounds with potential applications in biomedical research and sustainable nanotechnology.

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Table 1: Primary phytochemical analysis of *C. brevistyla* Fruits

Phyto constituents	Results for different extracts				
	<i>n</i> -Heaxane	CHCl ₃	EtOAc	CH ₃ CN	MeOH
Steriods	--	--	--	--	--
Triterpenoids	++	++	--	++	++
Reducing sugar	--	--	++	--	++
Alkaloids	--	--	++	++	--
Phenolic compound	--	--	--	--	++
Saponin	--	--	--	--	++
Xanthoproteins	++	--	++	--	++
Tannins	--	++	--	--	--
Flavonoids	--	--	--	++	++
Aromatic acids	--	++	++	--	++

Table 2: HRLCMS Analysis of ethanolic extract of *C. brevistyla* Fruits

Compound type	Name of the compounds	M.F.	RT	m/z
Aliphatic acids	Azelaic acid	C ₉ H ₁₆ O ₄	11.258	188.10
	Suberic acid	C ₈ H ₁₄ O ₄	1.246	174.09
	Oleic Acid	C ₁₈ H ₃₄ O ₂	1.585	282.26
	Palmitic Acid	C ₁₆ H ₃₂ O ₂	1.402	256.24
	<i>trans</i> -Petroselinic Acid	C ₁₈ H ₃₄ O ₂	21.302	282.26
	Linoleic acid	C ₁₈ H ₃₂ O ₂	10.562	280.24
	Methylsuccinic acid	C ₅ H ₈ O ₄	10.429	132.04
	9,10-dihydroxy-12-octadecenoic acid	C ₁₈ H ₃₄ O ₄	4.882	132.04
	6-Hydroxycaproic acid	C ₆ H ₁₂ O ₃	3.375	180.04
	DL-Mandelic acid	C ₈ H ₈ O ₃	1.767	138.03
	16- Hydroxyhexadecanoic acid	C ₁₆ H ₃₂ O ₃	1.15	138.03
	Ethylmalonic acid	C ₅ H ₈ O ₄	1.315	138.03
	16 -Hydroxyhexadecanoic acid	C ₁₆ H ₃₂ O ₃	1.761	154.03
	Ethylmalonic acid	C ₅ H ₈ O ₄	1.306	170.02
	Linolenic Acid	C ₁₈ H ₃₀ O ₂	1.678	138.03
	Citric acid	C ₆ H ₈ O ₇	1.623	152.05
	D-(-)-Quinic acid	C ₇ H ₁₂ O ₆	29.573	153.04
	Itaconic acid	C ₅ H ₆ O ₄	22.707	270.05
Aromatic Carboxylic acids	Benzoic acid	C ₇ H ₆ O ₂	1.762	286.05
	Caffeic acid	C ₉ H ₈ O ₄	1.534	153.04
	4-Anisic acid	C ₈ H ₈ O ₃	29.13	9.9
	3-Hydroxypicolinic acid	C ₆ H ₅ NO ₃	1.76	10
Phenolic acids	3-Hydroxybenzoic acid	C ₇ H ₆ O ₃	1.651	76.1
	Salicylic acid	C ₇ H ₆ O ₃	29.919	10
	2,5- Dihydroxybenzaldehyde	C ₇ H ₆ O ₃	1.765	9
	3,5- Dihydroxybenzoic acid	C ₇ H ₆ O ₄	2.129	83.4





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	4-Hydroxybenzoic acid	C ₇ H ₆ O ₃	8.299	9.9
	Gallic acid	C ₇ H ₆ O ₅	3.249	70.2
	1- Hydroxyphenylacetic acid	C ₈ H ₈ O ₃	1.576	10
	2- Hydroxyphenylacetic acid	C ₈ H ₈ O ₃	1.327	9.1
	Homogentisic acid	C ₈ H ₈ O ₄	1.369	98.7
	Gentisic acid	C ₇ H ₆ O ₄	2.128	9
	Isovanillic acid	C ₈ H ₈ O ₄	1.97	10
	4-Hydroxymandelic acid	C ₈ H ₈ O ₄	23.507	8.3
	3-Hydroxymandelic acid	C ₈ H ₈ O ₄	31.171	47.3
	Vanillic acid	C ₈ H ₈ O ₄	25.177	9.9
	Protocatechuic acid	C ₇ H ₆ O ₄	20.105	9.3
	5-Methoxysalicylic acid	C ₈ H ₈ O ₄	20.862	94.3
	3,4-Dihydroxyphenylpropionic acid	C ₉ H ₁₀ O ₄	29.358	69.6
	Isoferulic acid	C ₁₀ H ₁₀ O ₄	1.875	35
	Ferulic acid	C ₁₀ H ₁₀ O ₄	10.57	9.9
	3 Hydroxyphenylacetic acid	C ₈ H ₈ O ₃	9.053	47.1
	Homovanillic acid	C ₉ H ₁₀ O ₄	18.129	8.3
Amino acids	3- Hydroxyanthranilic acid	C ₇ H ₇ NO ₃	8.8	8.3
	Xanthurenic acid	C ₁₀ H ₇ NO ₄	32.577	8.1
Flavanoids	Genistein	C ₁₅ H ₁₀ O ₅	1.399	9.9
	Apigenin	C ₁₅ H ₁₀ O ₅	29.169	8.4
	Luteolin	C ₁₅ H ₁₀ O ₆	25.368	7.8
Carbohydrates	(3β-9ξ)-3-(β D-Glucopyranosyloxy)-14-hydroxycard20(22)-enolide	C ₂₉ H ₄₄ O ₉	1.762	9.3
	Quercetin-3β-Dglucoside	C ₂₁ H ₂₀ O ₁₂	23.596	8.4
	3-(β-D-Glucopyranosyloxy) -14-hydroxycarda-5,20(22)-dienolide	C ₂₉ H ₄₂ O ₉	31.095	9.8

Table 3: Correlation spectra

Position	HMBC
0.65 (s, 3H, C-8a $\underline{\text{CH}}_3$)	36.96 (C-8), 54.81 (C-4a)
1.08 (s, 3H, C-5 $\underline{\text{CH}}_3$)	42.73 (C-5), 54.81 (C-4a), 63.10 (C-5 hydroxy methylene), 78.89 (C-6)
3.82 (dd, 2H, J= 3.0 Hz and J=11.0 Hz, C-5 $\underline{\text{CH}}_2$ -OH)	23.53 (C-5 $\underline{\text{CH}}_3$), 54.81 (C-4a), 78.89 (C-6)
4.02, 4.38 (dd, 2H, J= 6.0 Hz and J=10.0 Hz, C-5' $\underline{\text{CH}}_2$)	170.43 (C-2' C=O), 63.10 (C-5 $\underline{\text{CH}}_2$ OH)
4.13 (dd, 1H, J= 3.0 Hz and J=7.5 Hz, C-6 $\underline{\text{CH}}$)	63.10 (C-5 $\underline{\text{CH}}_2$ OH), 42.73 (C-5 quarternary C)
4.62; 4.81 (s, 1H, C-2 C= $\underline{\text{CH}}_2$)	55.93 (C-1), 37.96 (C-3)
4.90 (t, 1H, J=6.0 Hz and J=6.5Hz, C-4' $\underline{\text{CH}}$ -OH)	170.43 (C-2' C=O)
5.07 (d, 1H, J=4.5 Hz, C-6 $\underline{\text{OH}}$)	78.89 (C-6 $\underline{\text{CH}}$), 63.10 (C-5 $\underline{\text{CH}}_2$ OH), 42.73 (C-4a quarternary C), 28.33 (C-7 $\underline{\text{CH}}_2$)



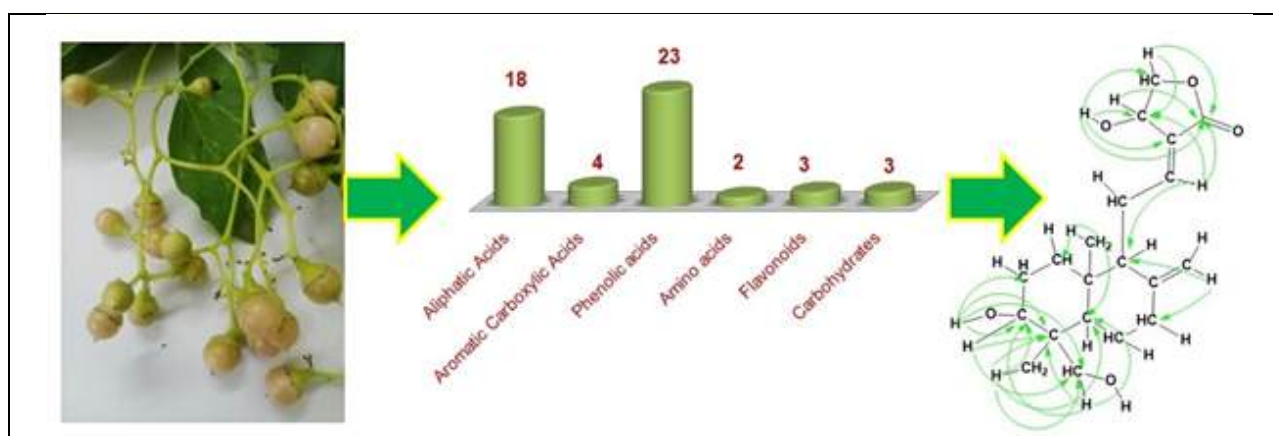


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5.72 (d, 1H, J=6.5 Hz, C-5' $\underline{\text{CH}}_2$)	170.43 (C-2' C=O), 129.43 (C-3' quarternary C), 64.96 (C-4' $\underline{\text{CH}}$)
6.60 (dt, 1H, J= 1.0 Hz, J= 1.5 Hz and J= 6.5 Hz, C-1'' $\underline{\text{CH}}$)	170.43 (C-2' C=O), 64.96 (C-4' $\underline{\text{CH}}$), 55.93 (C-1)

Table 4: Antitubercular activity of compound I

Compound	MIC($\mu\text{g/mL}$)
Compound I	0.91
Isoniazid	0.15
Rifampicin	0.25
Ethambutol	1.50
Ciprofloxacin	1.52



Graphical Abstract

Fig. 1 *Clausena brevistyla* fruits

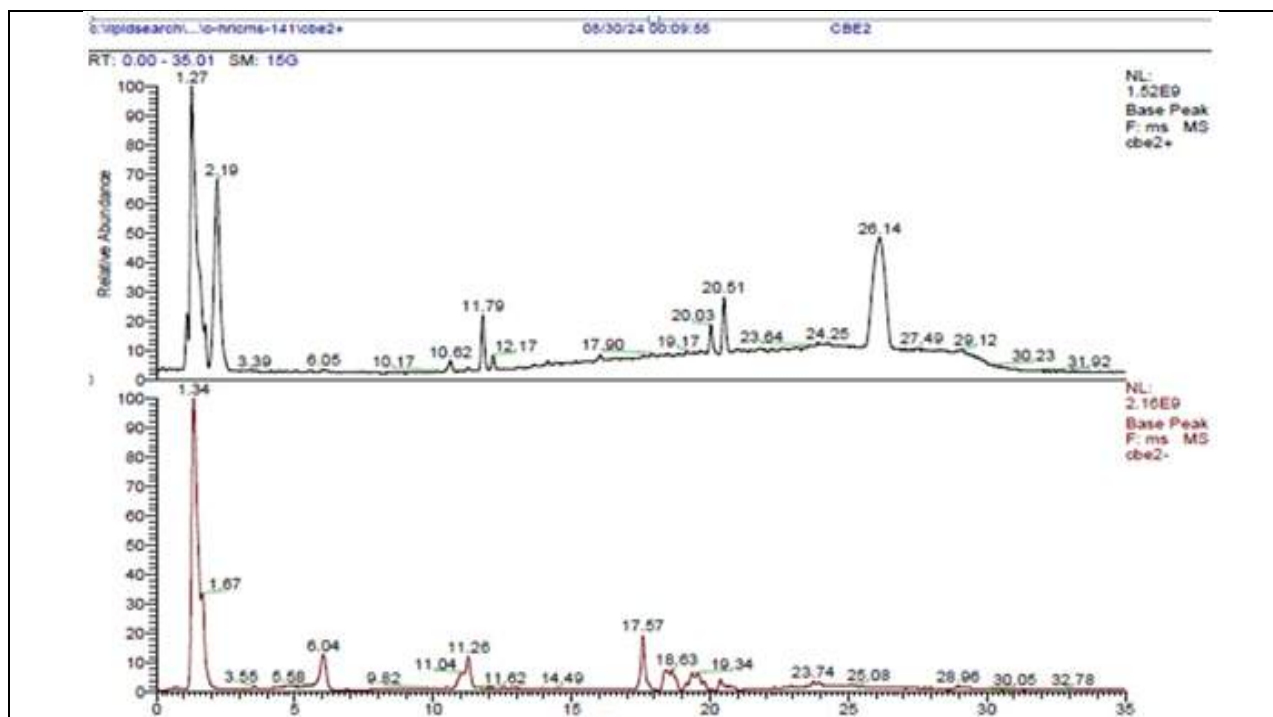


Fig. 2 HPLCMS chromatogram

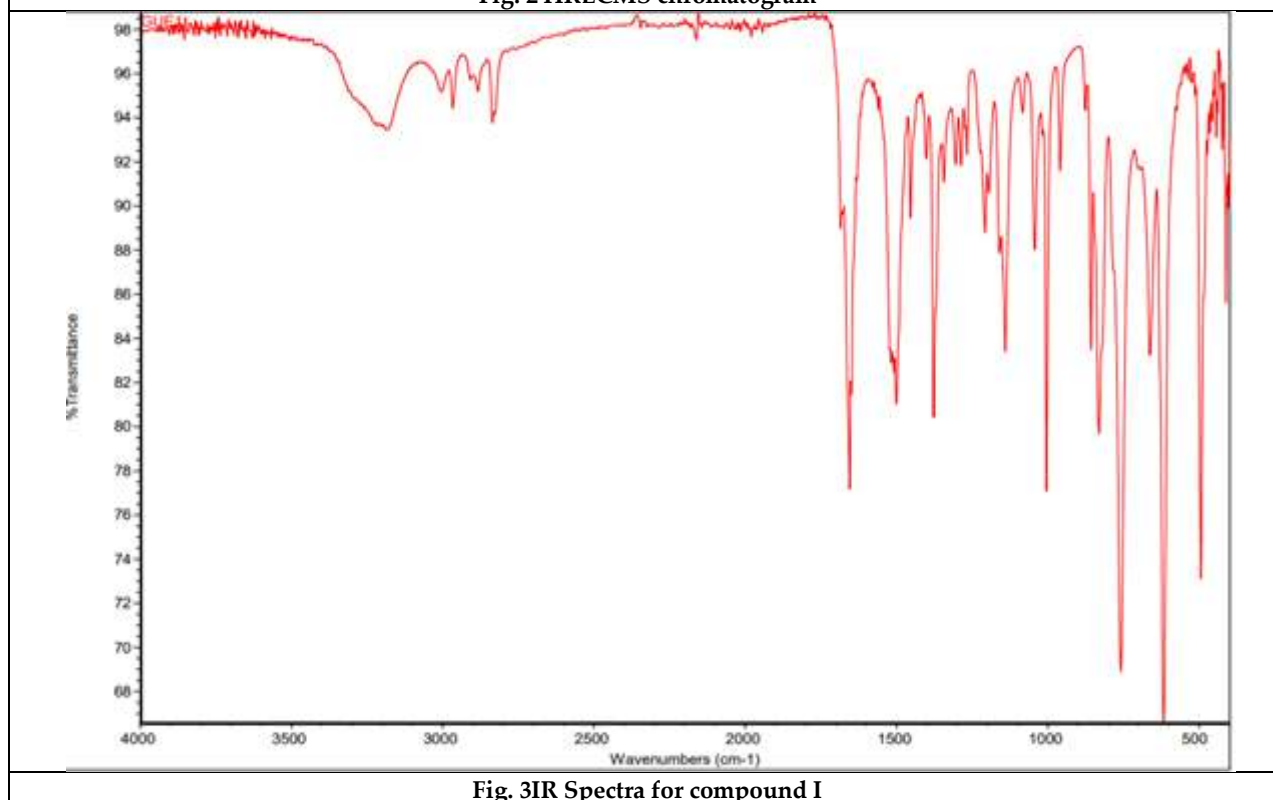


Fig. 3IR Spectra for compound I



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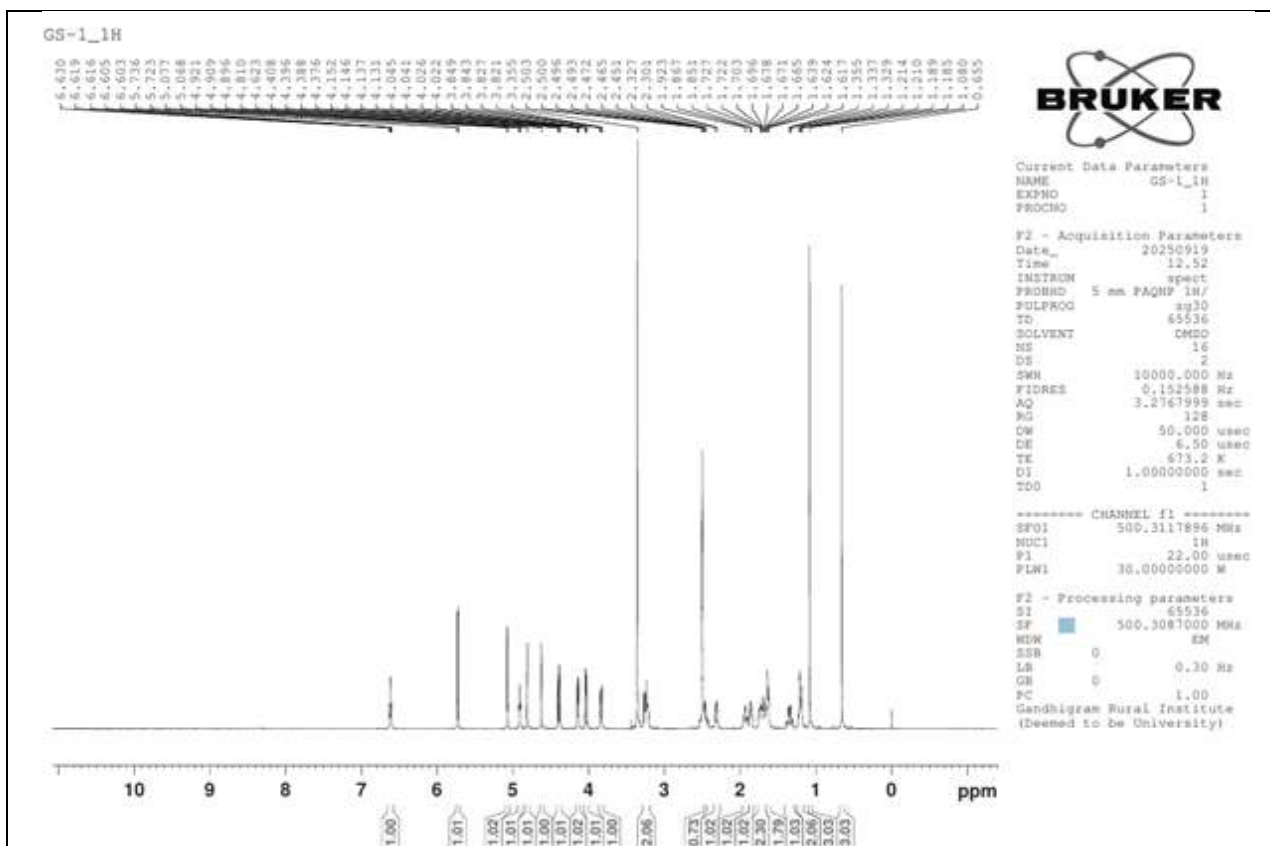


Fig. ^1H -NMR for compound I

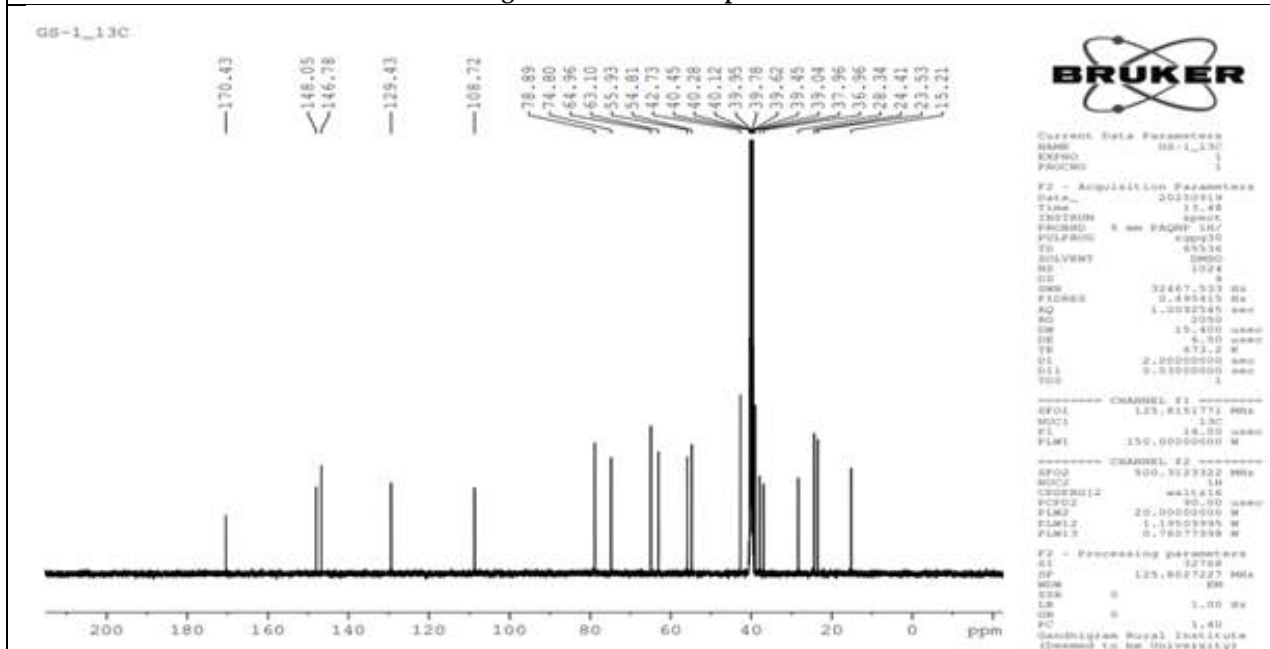


Fig. ^{513}C -NMR for compound I





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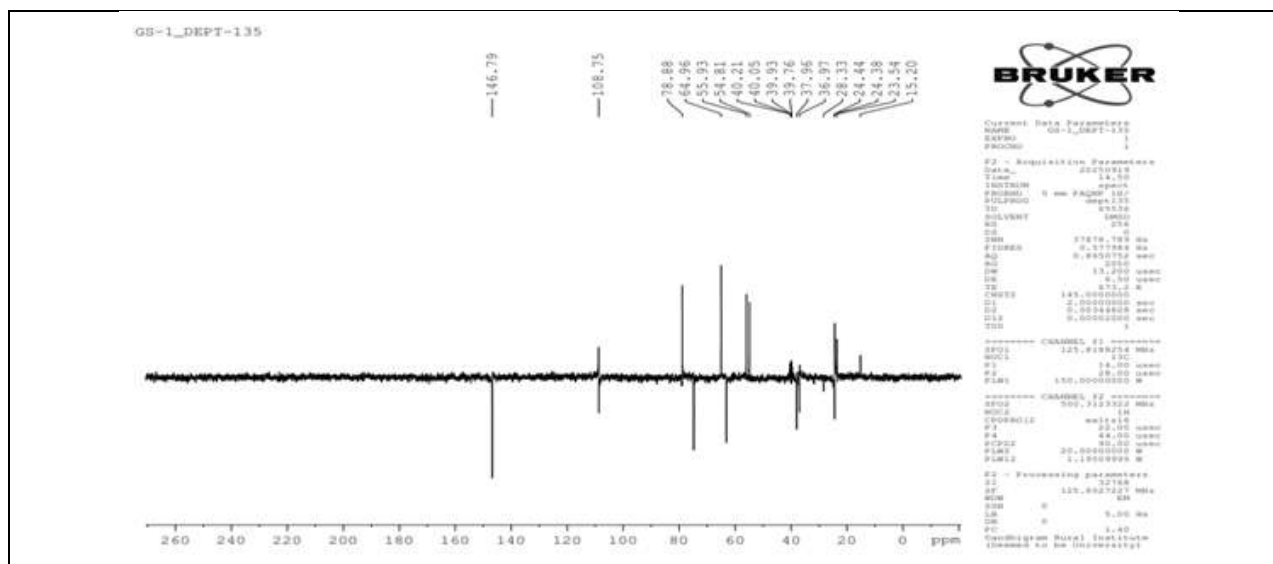


Fig. 6 DEPT-135 for compound I

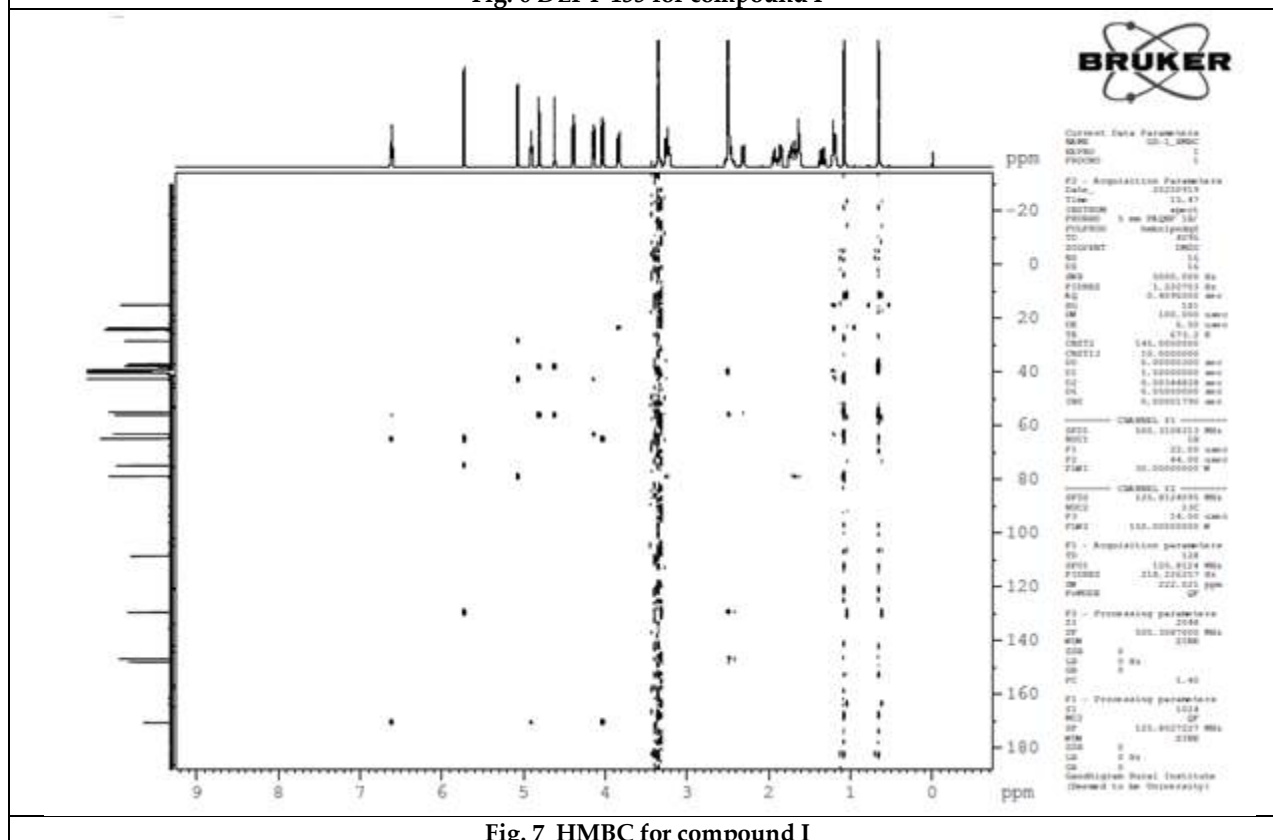


Fig. 7 HMBC for compound I





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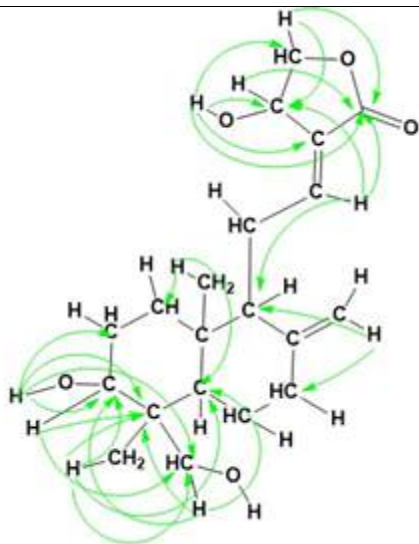


Fig. 8 HMBC correlation for compound I

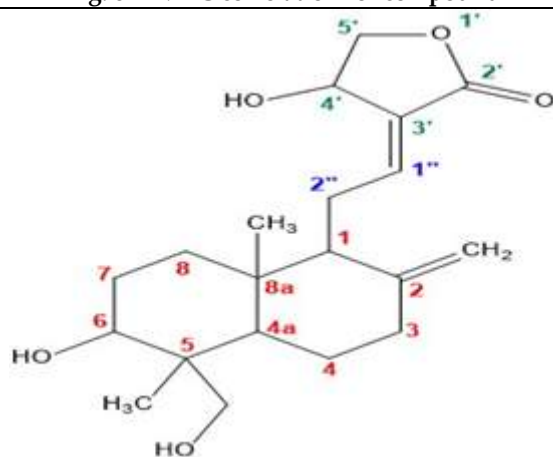


Fig.9. Compound I

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RESEARCH ARTICLE

Effectiveness of Tissue Glue and Silk Sutures After Periodontal Flap Surgery : A Split - Mouth Clinical Study

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ABSTRACT

Primary wound closure after periodontal flap surgery is critical for optimal healing and patient comfort. Traditionally, silk sutures have been used for flap approximation. However, tissue adhesives such as isoamyl 2-cyanoacrylate have emerged as promising alternatives due to their haemostatic, bacteriostatic, and patient-friendly properties. To compare the effectiveness of tissue glue (isoamyl 2-cyanoacrylate) and silk sutures in periodontal flap closure with respect to healing, pain, bleeding, and clinical outcomes.

A split-mouth randomized controlled clinical trial was conducted on 30 patients (13 males, 17 females) aged 31–60 years with Stage III periodontitis indicated for periodontal flap surgery. Each patient received tissue glue closure on one side (test group) and silk sutures on the contralateral side (control group). Clinical parameters assessed were Plaque Index (PI), Gingival Index (GI), Healing Index (HI), Probing Pocket Depth (PPD), Clinical Attachment Level (CAL), post-operative pain and bleeding (VAS scale), and time taken for flap closure. Data were statistically analysed using paired and unpaired Student's *t*-tests at 5% and 1% significance levels. Both groups demonstrated significant improvement in clinical parameters from baseline to follow-up. Test group showed significantly superior healing at 3 days and 1 week ($p=0.0001$). Post-operative pain was significantly lower in the test group on day 2 ($p=0.0001$). No significant difference between groups, though minimal bleeding was observed with tissue glue. PPD and Both groups showed significant reduction from baseline to 3 months ($p=0.0001$), with no intergroup difference. Significantly less in the test group (2.38 ± 0.78 mins) than control (7.09 ± 1.40 mins) ($p=0.0001$).



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Isoamyl 2-cyanoacrylate tissue adhesive is an effective, faster, and less painful alternative to silk sutures for flap closure following periodontal surgery. It offers excellent early wound healing and superior patient comfort without compromising clinical outcomes.

Keywords: tissue, wound, clinical, parameters, surgery

INTRODUCTION

Periodontal flap surgery is a fundamental procedure in the treatment of periodontitis aimed at gaining access for thorough debridement and root surface management. Achieving primary wound closure and favourable healing are essential determinants of surgical success.ⁱ Traditionally, sutures such as silk have been employed to approximate flap margins; however, their use is often associated with patient discomfort, plaque accumulation, and delayed healing.ⁱⁱ Tissue adhesives like cyanoacrylates, on the other hand, provide a rapid, painless, and bacteriostatic means of wound closure, forming a strong bond within seconds of application.ⁱⁱⁱ Isoamyl 2-cyanoacrylate, a biocompatible adhesive, has shown promising results in various surgical fields. This study was undertaken to clinically compare the effectiveness of tissue glue and silk sutures following periodontal flap surgery using a split-mouth design.^{iv} The aim of the present study was to compare the effectiveness of tissue glue (Iso Amyl 2-Cyanoacrylate) and silk sutures after periodontal flap closure.

MATERIALS AND METHODS

Study Design and Population

This experimental, split-mouth, randomized controlled clinical trial was conducted in the Department of Periodontology, Rural Dental College, Pravara Institute of Medical Sciences, Loni. The study protocol received ethical approval (Ref: PMT/DR/RDC/2022/514) and was registered under CTRI/2023/07/055464.

A total of 30 patients (13 males, 17 females; aged 31–60 years) diagnosed with Stage III periodontitis (AAP 2017 classification) were included.

Inclusion Criteria

- Adults aged 31–60 years
- Probing pocket depth (PPD) ≥ 5 mm
- Willingness to provide informed consent and attend follow-ups

Exclusion Criteria

- Systemic illness affecting periodontal healing
- Allergy to cyanoacrylate
- Pregnancy or lactation
- Tobacco use or smoking
- Bleeding disorders or anticoagulant therapy
- Periodontal treatment within the past year

Randomization

A lottery method was used for random allocation. The selected side for tissue glue was considered the **test site (Group B)**, while the contralateral side with silk sutures served as the **control site (Group A)**. Figure 1 depicts flow chart of the study





Surgical Procedure

After Phase I therapy (scaling and root planing), flap surgery was performed under local anesthesia. Full-thickness mucoperiosteal flaps were reflected, debridement was carried out, and the flaps were repositioned.

- **Group A:** Flap margins approximated with 3-0 silk sutures.
- **Group B:** Flap margins sealed using isoamyl 2-cyanoacrylate applied dropwise until a thin film formed.

Patients were prescribed antibiotics and 0.12% chlorhexidine rinses and followed up at 3 days, 7 days, 14 days, 1 month, and 3 months.

Clinical Parameters

- Plaque Index (Silness and Loe, 1964) – Baseline, 7 days, and 1 month
- Gingival Index (Loe and Silness, 1963) – Baseline to 1 month
- Healing Index (Landry et al., 1988) – 3 days to 1 month
- Probing Pocket Depth (PPD) – Baseline and 3 months
- Clinical Attachment Level (CAL) – Baseline and 3 months
- Post-operative pain and bleeding – VAS at days 1–5 and 1–3 respectively
- Time for flap closure – Measured in minutes

FIGURE 2 : (2a) & (2b): Pre-Operative Clinical Photograph: Assessment of Probing Pocket Depth at Baseline, (2c): Clinical Photograph of Periodontal Flap Reflection and Debridement, (2d): Cyanoacrylate Application on the Test Site, (2e): Clinical Photograph: Periodontal Flap Closure with Silk Sutures on Control Site and Cyanoacrylate on Test Site, (2f) & (2g): Post-Operative Clinical Photograph: Assessment of Probing Pocket Depth at 3 Months

Statistical Analysis

Data were analyzed using SYSTAT version 12. Student's paired *t*-test was used for intragroup comparison, and unpaired *t*-test for intergroup analysis. A *p*-value ≤ 0.05 was considered statistically significant.

RESULTS

Demographics

The study included 30 participants (13 males, 17 females) with a mean age of 38.13 ± 6.23 years.

Plaque Index

Plaque index increased at 1 week and reduced significantly by 1 month. Comparison of mean values of Plaque Index at baseline, 1 week and 1 month post-operatively are depicted in **graph 1**.

Gingival Index

There was a significant reduction in GI from baseline (1.99 ± 0.59) to 1 month (0.47 ± 0.26). Comparison of mean values of Gingival Index at baseline, 3 days, 1 week, 2 weeks and 1 month post-operatively are depicted in **graph 2**.

Healing Index

Group B (tissue glue) showed significantly higher Healing Index at 3 days (3.43 ± 0.50) and 1 week (4.23 ± 0.43) compared to Group A. No significant difference was observed at 2 weeks and 1 month. Comparison of mean values of Healing Index in Group A and Group B at 3 days, 1 week, 2 weeks and 1 month post-operatively are depicted in **graph 3**.

Probing Pocket Depth

Both groups showed significant reduction from baseline to 3 months, but intergroup difference was not significant. Comparison of mean values of Probing Pocket Depth in Group A and Group B at baseline and 3 months post-operatively are depicted in **graph 4**.

Clinical Attachment Level

Significant gain in CAL from baseline to 3 months was observed in both groups, with no intergroup difference. Comparison of mean values of Clinical Attachment Level in Group A and Group B at baseline and 3 months post-operatively are depicted in **graph 5**.



Shweta Vikhe *et al.*,**Post-operative Pain**

Pain scores were significantly lower in the test group on day 2. No significant difference was noted on other days.

Post-operative Bleeding

Minimal bleeding was observed on day 1 in the control group (0.23 ± 0.43), while no bleeding occurred in the test group. The difference was not statistically significant.

Time for Flap Closure

Closure time was significantly shorter with tissue glue (2.38 ± 0.78 min) compared to sutures (7.09 ± 1.40 min).

DISCUSSION

The results of the present study demonstrate that isoamyl 2-cyanoacrylate is a reliable alternative to silk sutures for flap closure in periodontal surgery. The faster healing and reduced post-operative discomfort observed with tissue glue can be attributed to its rapid polymerization and hemostatic properties.^v Comparable improvements in PPD and CAL between the two groups indicate that use of tissue adhesive does not compromise the clinical outcome. Similar findings were reported by Khurana *et al.*^{vi} (2016), who also noted better early healing with cyanoacrylate compared to silk sutures. Additionally, the significant reduction in operative time and improved patient comfort highlight the clinical advantages of tissue glue, particularly in multiple quadrant surgeries or patients with limited tolerance for lengthy procedures. Ashoka *et al.*^{vii} (2005) employed Octyl cyanoacrylate to close neck incisions in cancer patients and discovered it to be an effective alternative to sutures. Babu *et al.*^{viii} (2005) discovered that isoamyl cyanoacrylate outperformed butyl cyanoacrylate in the healing of surgical incisions over the neck. S. Kondoh *et al.*^{ix} (2003) applied this material impregnated in gauze as a treatment on alveolopalatal wounds following alveolar bone grafting. Rewainy, Osman and El-Prince^x (2015) found a substantial reduction in hemostasis when standard silk sutures and soft tissue glue cyanoacrylate were used to close the mucoperiosteal flap after surgical extraction of mandibular impacted third molars. Vaaka *et al.*^{xi} (2018) found that patients treated with cyanoacrylate had a lower incidence of wound infection than individuals whose wounds were closed with 3-0 black braided silk suture. When it comes to intraoral wound coaptation following open flap debridement, Kaur *et al.*^{xii} (2020) compared cyanoacrylate to braided silk sutures and discovered that the cyanoacrylate was superior to the silk sutures due to its reduced tissue reaction, immediate hemostasis, relative painlessness, and ability to prevent wound infection and dehiscence.

CONCLUSION

Isoamyl 2-cyanoacrylate tissue adhesive provides:

- Faster wound closure,
- Superior early healing,
- Reduced post-operative pain, and
- Comparable long-term periodontal outcomes to silk sutures.

Hence, from the present study it can be concluded that iso-amyl cyanoacrylate tissue adhesive is an effective and reliable alternative to conventional silk sutures as it is easy to apply, less time-consuming, causes less inflammatory response to tissues, provides immediate hemostasis, lessens the post-operative pain and discomfort, and above all has high patient satisfaction. Tissue glue can be considered a simple, efficient, and patient-friendly alternative to conventional sutures for flap closure following periodontal surgery. Perhaps, one disadvantage of using cyanoacrylate is its high cost. However, the benefits of reduced effort and improved post-operative outcomes outweigh this drawback.





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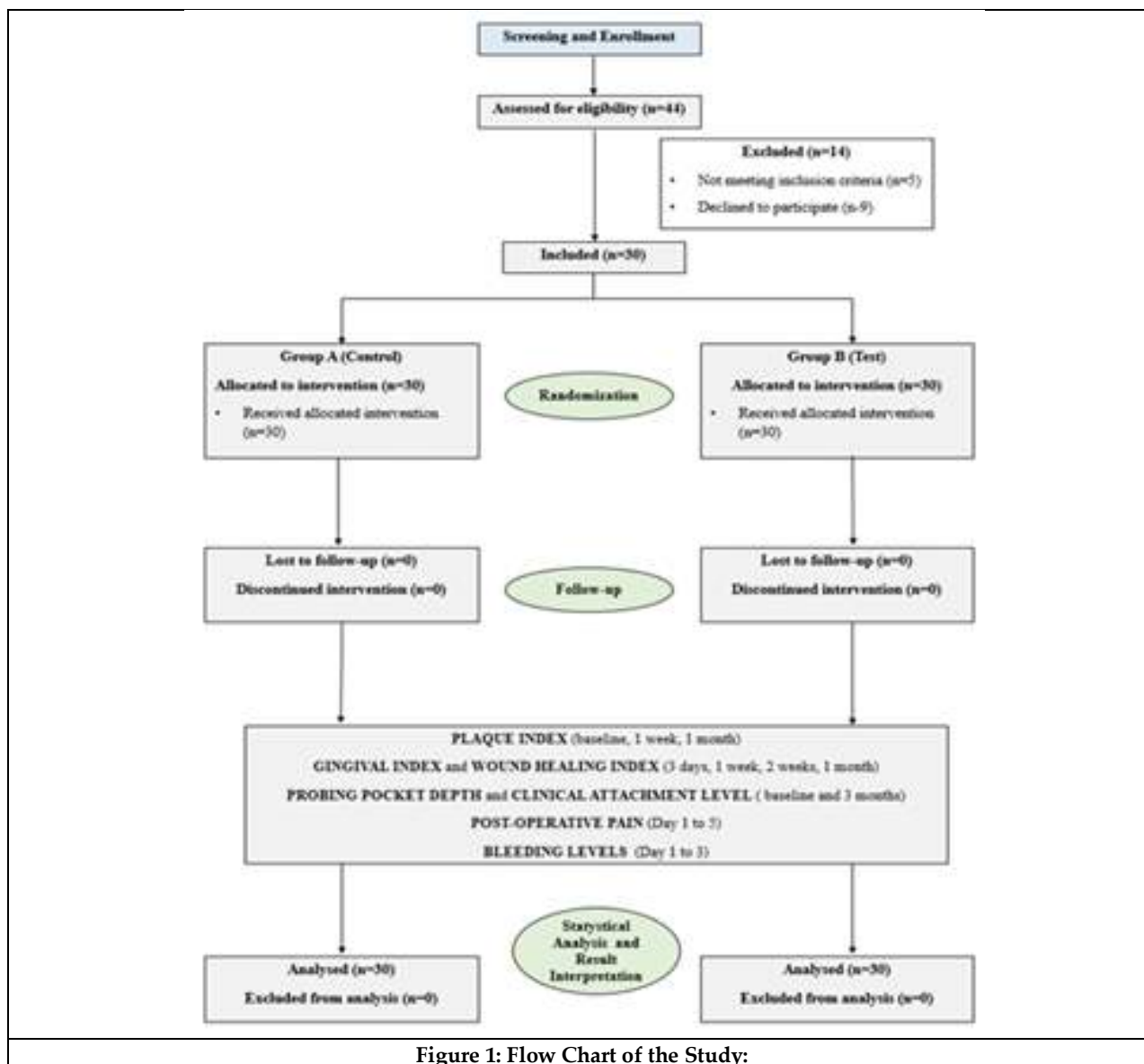


Figure 1: Flow Chart of the Study:





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Figure 2 depicts the clinical photographs showing flap closure with silk sutures and using isoamyl 2-cyanoacrylate.





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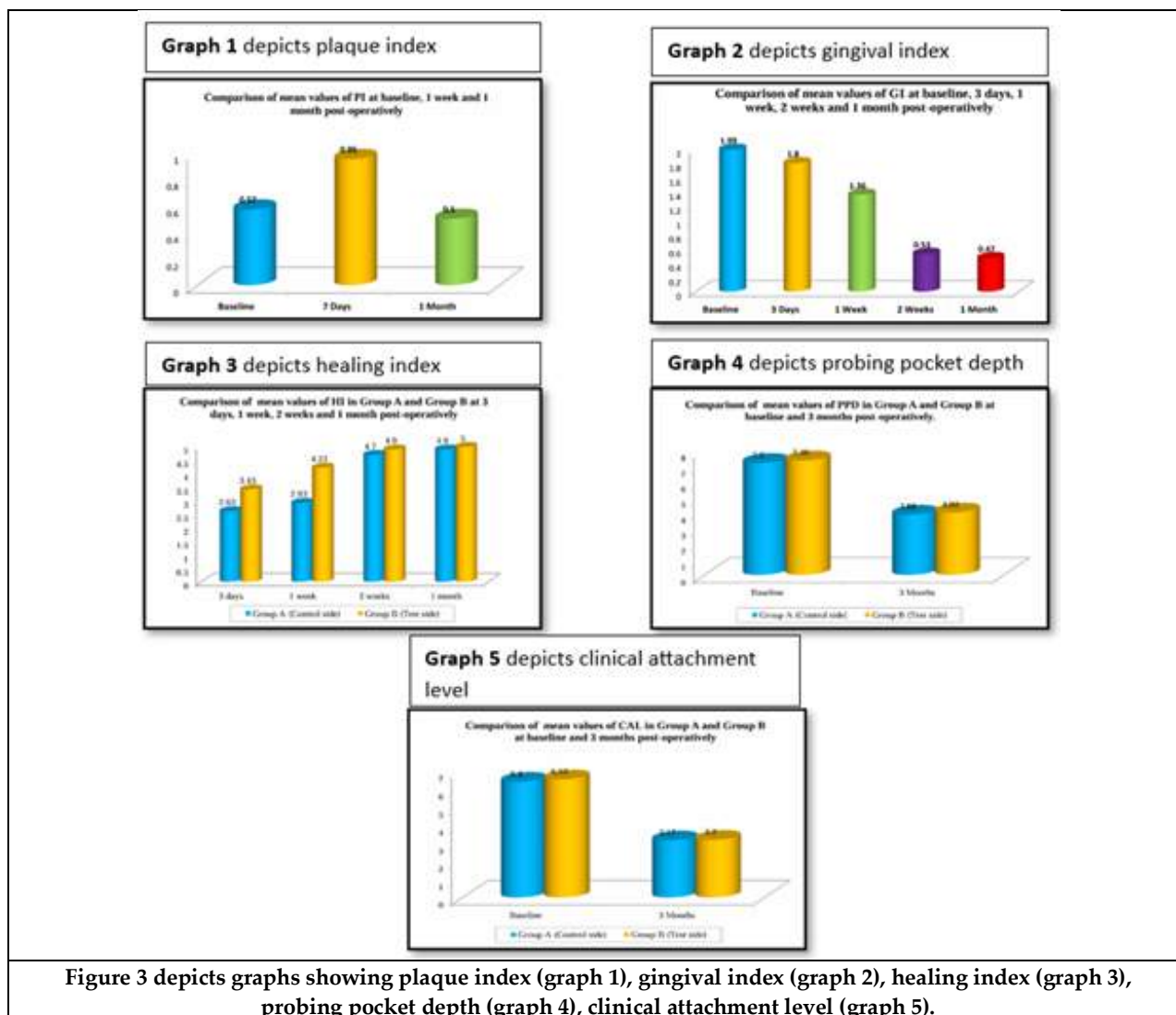


Figure 3 depicts graphs showing plaque index (graph 1), gingival index (graph 2), healing index (graph 3), probing pocket depth (graph 4), clinical attachment level (graph 5).

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RESEARCH ARTICLE

Paradigm Shift in Periodontology: Integrating Holistic Modalities and the Oral-Systemic Axis in the Management of Periodontal Disease

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ABSTRACT

Periodontitis is a chronic, globally prevalent inflammatory disorder triggered by a complex interplay of plaque biofilms, host immune responses, and environmental variables. Traditional therapies—primarily mechanical scaling, antimicrobial use, and corrective surgery—excel at managing local etiological factors but frequently overlook the patient's systemic health, psychological state, and daily habits. This paper examines the integration of holistic and biological strategies into periodontal care, supported by the latest 2024 and 2025 clinical evidence. By blending targeted dietary counseling (including probiotics and Vitamin D), herbal supplements (such as curcumin, matcha green tea, and neem), and stress-management practices (like yoga and mindfulness), practitioners can actively regulate the host's inflammatory cascade. Adopting this whole-body perspective not only helps halt periodontal tissue breakdown and combats the rise of antimicrobial resistance but also fosters systemic well-being and lasting oral health.

Keywords: Holistic Dentistry, Periodontitis, Host Modulation, Curcumin, Green Tea, Oral Microbiome, Mind-Body Medicine, Periodontal Treatment.



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INTRODUCTION

Periodontitis is a multifactorial inflammatory disease driven by a complex interplay between dysbiotic microbial biofilms, host immune responses, genetic predisposition, and environmental risk factors [1]. Affecting a significant proportion of the global adult population, the pathogenesis is initiated by gram-negative anaerobic consortia predominantly *Porphyromonas gingivalis* and *Aggregatibacter actinomycetemcomitans* [2,3]. However, the subsequent progression and severity of connective tissue degradation and alveolar bone resorption are fundamentally dictated by a dysregulated and hyper-responsive host immunoinflammatory profile. Historically, periodontal management has relied on a mechanistic paradigm emphasizing mechanical debridement, targeted antimicrobial pharmacotherapy, and surgical intervention [4]. While these modalities remain foundational, contemporary periodontology is transitioning toward a comprehensive bio-psychosocial model. It is now unequivocally recognized that oral homeostasis is inextricably linked to systemic health. A holistic framework synergizes conventional mechanical therapies with lifestyle modifications, nutritional interventions, smoking cessation, stress management, and natural adjunctive therapeutics to achieve optimal host immunomodulation.

The Oral-Systemic Axis

The pathophysiology of periodontitis involves a sustained inflammatory response triggered by plaque accumulation, leading to the local overexpression of matrix metalloproteinases (MMPs) and pro-inflammatory cytokines, notably Interleukin (IL)-1 β , IL-6, and Tumor Necrosis Factor-alpha (TNF- α). Crucially, this chronic inflammatory burden is not confined to the periodontium; it disseminates systemically [5]. A bidirectional relationship between periodontitis and chronic systemic pathologies, particularly diabetes mellitus, is well documented [6]. In diabetic cohorts, chronic hyperglycemia exacerbates the formation of advanced glycation end-products (AGEs), which amplifies oxidative stress and severely compromises periodontal collagen integrity [7]. Furthermore, transient bacteremias allow pathogens such as *P. gingivalis* to enter the systemic circulation, contributing to endothelial dysfunction and the atherogenic processes implicated in cardiovascular diseases [8]. Recent 2025 meta-analyses have elucidated further systemic ramifications, establishing strong pathogenic associations between periodontitis and autoimmune disorders, such as rheumatoid arthritis [9], as well as identifying elevated risks for prostate cancer mediated by circulating periodontal pathogens [10].

Conventional Therapy: Foundation and Limitations

Non-surgical mechanical debridement—primarily scaling and root planing (SRP) remains the gold standard and initial phase of periodontal therapy. In cases of refractory deep periodontal pockets, surgical interventions—including flap debridement, resective procedures, or guided tissue regeneration using osseous grafts and barrier membranes are indicated to re-establish a physiologic architecture. Although traditional mechanical modalities are highly efficacious in disrupting localized biofilm and removing calculus, they do not intrinsically address the systemic or behavioral determinants of host inflammation. Moreover, the escalating global threat of antimicrobial resistance precludes the long-term empirical use of systemic antibiotics in periodontitis, thereby necessitating the integration of safer, sustainable, and holistic immunomodulatory adjuncts.

Adjunctive Holistic and Integrative Modalities

To optimize tissue regeneration and actively modulate the host immune response, contemporary clinical protocols should incorporate the following adjunctive holistic strategies during both active therapy and supportive periodontal maintenance.

Nutritional Therapy, Microbiome Modulation, and Lifestyle Modifications

Nutritional deficiencies impair immune surveillance, delay wound healing, and precipitate shifts toward oral dysbiosis.



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Micronutrients (Vitamins C and D): Ascorbic acid (Vitamin C) is indispensable for collagen biosynthesis; systemic deficits directly compromise periodontal structural integrity. Vitamin D regulates bone metabolism and exhibits potent immunomodulatory and anti-inflammatory properties crucial for alveolar bone preservation.

Omega-3 Polyunsaturated Fatty Acids (PUFAs): Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) serve as essential substrates for specialized pro-resolving lipid mediators (SPMs), such as resolvins and protectins, which actively drive the resolution of inflammation [11].

Probiotic Therapy: The targeted modulation of the oral microbiome represents a critical frontier in adjunctive therapy. A 2024 systematic review demonstrated that the administration of *Lactobacillus* and *Bifidobacterium* species, delivered via lozenges, significantly attenuates the repopulation of periopathogens following SRP [12].

Behavioral Interventions: Smoking cessation remains the most critical behavioral intervention for improving periodontal prognosis [13]. Concurrently, optimizing sleep hygiene has been shown to significantly reduce circulating systemic inflammatory markers.

Phytotherapeutics and Traditional Medicine

Plant-derived pharmacotherapeutics offer biocompatible and cost-effective alternatives with established anti-inflammatory and antimicrobial profiles. Recent literature robustly supports their clinical utility:

Curcumin (Turmeric): A comprehensive 2025 review affirmed that topical curcumin applications significantly reduce plaque indices and bleeding on probing. Its clinical efficacy is comparable to standard chlorhexidine gluconate, notably devoid of adverse effects such as extrinsic tooth discoloration [14].

Epigallocatechin Gallate (Green Tea): A 2024 randomized clinical trial concluded that daily prophylactic use of matcha green tea extract mouthwash significantly suppresses the proliferation of *P. gingivalis* and other obligate anaerobes, largely attributable to its high concentration of EGCG catechins [15].

Azadirachta indica (Neem): A prominent agent in Ayurvedic medicine, a 2024 clinical analysis validated that neem-formulated mouthrinses effectively disrupt bacterial cell membranes, demonstrating high efficacy in the maintenance of gingival homeostasis [16].

Oil Pulling Therapeutics: Traditional therapies utilizing virgin coconut or sesame oil have consistently demonstrated clinical value in the saponification of bacterial toxins, resulting in significant reductions in both plaque accumulation and gingival bleeding indices.

Psychoneuroimmunology and Mind-Body Interventions

Chronic psychological stress precipitates the dysregulation of the hypothalamic-pituitary-adrenal (HPA) axis, resulting in elevated cortisol and catecholamine levels. This neuroendocrine shift suppresses immune surveillance, diminishes salivary flow, and exacerbates periodontal tissue degradation. A landmark 2025 study established that patients with severe periodontitis exhibit significantly elevated systemic cortisol, which not only impairs local mucosal immunity but actively enhances periopathogenic virulence [17]. Mind-body interventions, including Yoga and Mindfulness-Based Stress Reduction (MBSR), have been empirically proven to mitigate these effects by downregulating salivary cortisol, attenuating systemic inflammation, and promoting enhanced tissue oxygenation through controlled autonomic breathing practices (Pranayama).

CONCLUSION

The trajectory of modern periodontology is firmly oriented toward predictive, preventive, personalized, and participatory (P4) medicine. The integration of holistic modalities into standard periodontal protocols provides a customized therapeutic model that aligns seamlessly with contemporary integrative healthcare. By systematically addressing underlying risk factors such as nutritional deficiencies, chronic psychological stress, microbiome dysbiosis, sleep disturbances, and detrimental oral habits, these interventions significantly enhance intrinsic host immunomodulation. While the standardization of these biological protocols warrants continued clinical investigation, the adoption of this comprehensive, evidence-based paradigm represents a critical advancement in the longitudinal management of lifestyle-driven, oral-systemic diseases.





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Figure 1: Clinical presentation of chronic periodontitis exacerbated by systemic conditions such as diabetes.





Figure 2: Pre- and post-operative presentation of mechanical debridement

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RESEARCH ARTICLE

Site Secure Vision : An AI - Based Industrial Safety and Security Compliance Monitoring System

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ABSTRACT

Critical industries such as mechanical, manufacturing, chemical, marine and construction rely on traditional surveillance systems for monitoring and securing industrial sites. This approach present several challenges as they are not proactive and safety violations can occur without real-time enforcement of safety protocols. This leads to accidents within industrial environments and may cause operational interruptions when safety regulations are not followed. The major causes of safety violations include improper use of Personal Protective Equipment (PPE), fire or smoke outbreaks, intruders, and worker falls. This paper presents SiteSecureVision, a product developed by Invisible Fiction Company, which is an on-premises industrial safety compliance and security monitoring platform using Artificial Intelligence (AI) that transforms existing CCTV feeds into a real-time intelligent safety monitoring platform. The system performs identity-aware monitoring across 1080p RTSP and USB camera streams using machine learning models such as InsightFace for face detection and recognition and YOLOv8 for PPE detection, fire/smoke detection, license plate recognition, and fall detection. It also incorporates zone-based access control and a night-mode security mechanism. A single GPU batched inference pipeline is decouples from CPU-bound tasks such as tracking, MongoDB logging, and WhatsApp/SMS alert generation. The proposed approach demonstrates a stable operation for an AI-based industrial safety monitoring solution capable of detecting safety violations and emergency hazards in real time on across 10 -50 camera streams that achieved 15 – 25 FPS.

Keywords: Industrial safety monitoring, computer vision, YOLOv8, PPE detection, face recognition, multi-camera surveillance, AI-based monitoring



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INTRODUCTION

Industrial personnel are exposed to a variety of safety hazards like falling objects, electrical faults, temperature extremes, chemical exposure, and accidents. Occupational safety regulations strictly implemented the usage of Personal Protective Equipment (PPE) and restricted access to areas that are dangerous, thereby reducing safety risks [1]. However, it is a challenge for many industries that are operating on traditional CCTV monitoring systems, which are based on manual monitoring by security personnel. Manual monitoring is very inefficient, as the monitoring of safety violations by humans may be due to distractions and simultaneous safety violations happening at the same time. These are the drawbacks of traditional monitoring systems, resulting in unnoticed safety violations, accidents, and financial risks. Recently, with the advancement of Artificial Intelligence (AI) and computer vision technologies, it is now possible for intelligent monitoring systems to automatically detect safety violations and continuously monitor multiple areas with minimal involvement of humans [2], [3]. YOLO family of algorithms is one of the modern object detection frameworks that demonstrated a strong real-time performance in visual detection[4], [5], [6], [7], [8].

Several studies have explored AI-based PPE detection in industrial safety monitoring: Karlsson et al. proposed method of PPE detection using Histogram of Oriented Gradients (HOG) and YOLOv4 PPE detectors in finding helmets and safety vests [9]; Lema et al. in implemented a real-time PPE detection using edge devices (Jetson Nano and Raspberry Pi), and the results shows that the proposed method using Jetson Nano works efficiently because of the support of a GPU[10]. Sanjeevani et al. developed a PPE detection system using SSD MobileNet V2 and YOLOv5 models loaded onto AI-enabled cameras to find people wearing or not wearing PPE. It demonstrated high accuracy using a YOLOv5 detector, but heavy on the edge device[11]. Recently, Makandar and Naik developed a real-time PPE detection using yolov8 and computer vision for industrial safety compliances[12] that has most of the gaps that are addressed in this paper. The proposed paper, Site Secure Vision, is an intelligent industrial safety monitoring system, which uses multi-camera PPE detection with identity-aware monitoring through face recognition Technology addresses the above mentioned challenges. This is because the proposed system not only expands PPE detection to twelve categories but also incorporates other safety modules such as fire/smoke detection, Automatic License Plate Recognition (ALPR), fall detection, zone control, and alongside there is night security mode system that works after hours. These are all done through a single GPU inference pipeline that improves the existing passive CCTV system and enables the system to detect any violations in real-time.

MATERIALS AND METHODS

SiteSecureVision framework utilizes several deep learning architectures in one unified computer vision pipeline to enable real time monitoring of industrial safety. The modularity of the architecture acquires video streams from various cameras [13]. Once acquired, the video streams undergo identity aware compliance verification at GPU accelerated inference. Batch processing is utilized during the inference process and the CPU is utilized for event driven processing [14], [15]. This is accomplished by using multithreading

Acquisition of multi-camera video

The platform can operate on multiple cameras such as IP cameras (RTSP) or USB cameras using processed using Open CV to process video streams acquired on the industrial environment that is being monitored in real-time[13]. Video streams from each camera are captured on a single thread and continuously update a common frame buffer that is managed by the camera manager. A desktop application is used for visualization and this system is a local solution for industrial monitoring that preserves privacy. Synchronization of the most recent frames that are processed from all active cameras occurs.

Real-time batched inference





SiteSecureVision works in real-time using GPU batched inference that maximizes utilization the resources and maintains stable real-time performance in multiple cameras streams. It takes the latest frames from live streams of all active cameras, and combine them into a batched tensor processed on GPU for face detection, face recognition, PPE detection, fire/smoke detection, license plate recognition, person and person fall detection. To maintain real-time responsiveness, GPU inference is separated from CPU-based application logic. The inference outputs are queued on the CPU thread that will carry out other tasks such as attendance logging, violation logging, alert triggering and visualization updates. This queue-based architecture decouples GPU inference from CPU processing so that both pipelines operate asynchronously without blocking each other. As a result, the system can process multiple camera streams simultaneously while maintaining stable frame rates and efficient use of computing resources.

Face detection and recognition

The identification of an individual through identity aware recognition use Buffalo-L model of the InsightFace framework for the identification task[16]. A person's face is localized by the SCRFD detector that performs well with varying degrees of illumination, pose and partial occlusion. It use iResNet-100 backbone for the ResNet architecture, an ArcFace 512 dimensional embedding is then generated for each localized face[17]. The generated embeddings are then compared with the registered worker embeddings in the database using cosine similarity to determine if a match existed. If the cosine similarity exceeded a predetermined threshold, the corresponding worker identity will be assigned to the individual; if the similarity did not exceed the threshold, the individual will be identified as a visitor (unknown) with a temporary identifier. Temporal smoothing over 5 frames reduced the rate of identity flicker.

PPE detection

PPE detection is done using a custom-trained YOLOv8m model object detection model [8] that is capable of detecting twelve classes of PPEs, namely apron, boots, face mask, gloves, hearing muff, reflective vest, safety goggles, safety harness, safety helmet, safety jacket, suit, and welding mask. Batched frame processing is employed to allow concurrent execution of PPE detection on multiple camera feeds without FPS dropping and attain maximum GPU throughput. In addition to PPE and hazard detection, the system includes Automatic License Plate Recognition (ALPR) by applying object detection and OCR techniques, as well as pose estimation models for fall detection by skeletal key point analysis [18], [19], [20] that are all using YOLOv8n detection models.

Spatial PPE verification

Spatial verification is applied to reduce false positive by filtering detected PPEs from background or held items. Therefore only worn PPE will be considered by putting the detected persons' bounding boxes with respect to the bounding box of the detected face using geometric rules to determine area of interest.

Identity-aware tracking

Identity anchors are used to perform tracking instead of a deep learning-based tracking algorithm like Deep SORT or ByteTracker. Overlap and temporal smoothing are used to ensure the tracking of a person's bounding box from frame to frame. Identity of a person is then used to perform tracking (worker ID or visitor ID). Tracks are automatically removed when a person go out of frame using a time-to-live mechanism.

Compliance evaluation

An Individual is evaluated against their respective role's PPE compliance criteria retrieved from the database. If all required PPEs are present, then the individual is considered to be in compliance. Otherwise, a list of missing PPEs is recorded as a violation with a snapshot. The following formula calculate PPE detected based on the role of an individual. Missing PPE = required PPE - verified PPE.

Alert generation

In MongoDB, violation incidents are recorded along with violation types, identity details, camera ID, zone, and timestamps along with evidence snapshots or a short video. A cooldown mechanism is set per individual per camera to prevent repetitive alerts. Alerts notification is sent to the supervisor via WhatsApp using the WS Panel API, along



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with automatic SMS support in the absence of internet connection. In the presence of emergency hazards such as fire and smoke, high-priority alerts are sent, halting all other alerts.

Fire and smoke detection

In the proposed system, there is a separate module for fire and smoke detection using the YOLOv8n model for detecting fire, sparks, and smoke from videos captured in real-time[8], through surveillance cameras. In the presence of fire and smoke, the violation is categorized as a high-priority emergency, overriding all other violation alerts. The system records the emergency, takes a snapshot and short video, and sends alerts to the supervisor. In addition to mobile alerts, there is also a buzzer alarm that immediately goes off to notify persons present in the zone with fire do evacuate the place.

Night mode security monitoring

A night mode security monitoring mechanism is provided alongside PPE compliance system to monitor the industrial area after work hours, which can be done in automatic or manual mode to activate it. When night mode is active, a lightweight YOLOv8n model is activated to detect persons in the area, while the PPE compliance system is disabled, and any person detected in the area is considered a violation (intruder).

Zone management and access control

A zone-based security monitoring mechanism is also provided in this system to restrict access of unauthorized personnel to hazardous areas in the industrial area. Each camera is assigned to a specific industrial area (zone), which is stored in the database. Each worker's permission to work in a specific area is also provided in this system's configuration. When a person is detected in a monitored area, it is checked whether that person is allowed to work in that area or not.

RESULTS AND DISCUSSION**Experimental setup**

The implementation and evaluation of SiteSecureVision was done on a workstation equipped with an AMD Ryzen 7 7445HS processor, 16 GB RAM, and an NVIDIA RTX 4050 GPU with 6 GB VRAM for accelerated deep learning inference. RTSP-based IP cameras and USB webcam devices operating at 1080p resolution were used to test the multiple camera system. Experiments were carried out in simulated industrial environments (videos from different industrial areas) under both indoor and outdoor conditions, different scenarios with varying illumination levels to assess system robustness on all functions. The system real-time capabilities and scalability was evaluated during the experiment by continuously using multiple camera feeds with different environment scenes. A total of 7 deep learning models used in the experiments were YOLOv8 for PPE detection, InsightFace for biometric identification, person detection for night security mode, and pose for falling person, YOLOv8 for fire/smoke detection and EasyOCR for license plate character detection. The performance of the system was evaluated by executing benchmarking tests that measured parameters, size, latency, frame rate, and system response time.

For the experimental deployment phase, SiteSecureVision system was distributed as a standalone .exe installer for ease of workstation deployment. In order to ensure robust security and software integrity, the system utilizes a hardware-bound licensing mechanism, which is secured using RSA-2048 digital signatures. The system is no longer depending on a locally generated file but instead verifies the vendor-supplied license, i.e., .lic, that cryptographically binds the software to a unique workstation MAC address via a salted SHA-256 hash algorithm. The application verifies the license's authenticity via a public RSA key, which is embedded in the software package, to ensure that the configuration is not modified or moved to another workstation without permission. The installer now also automates the initialization of a MongoDB compass database and the creation of all required data structures, including personnel, cameras, and audit logs."

3.2 Model performance evaluation Deep learning models integrated into SiteSecureVision system's performance was assessed and considered inference latency as well as frame rate



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processing. Table 1 presents a summary of the runtime performance of the used models within the system. The results for latency and FPS indicate that it is possible to perform different deep learning models concurrently by using a GPU acceleration approach. Pytorch (.pt) trained models such as PPE detection, person detection, fire & smoke detection, fall detection and license plate detection were converted to Open Neural Network Exchange (ONNX) format to improve inference performance and independent deployment out of Pytorch[21],[22].

Real-time system performance

The system architecture employs batched GPU inference, along with asynchronous CPU processing, to support simultaneous video streams coming from multiple cameras. The experimental evaluation results indicate that it offers an overall stable performance. The system attain 25-30 FPS when processing a single camera feed and 10-25 FPS when processing 10- 50 cameras continuously, which indicated a stable rate as Invisible Fiction Company target 15 camera per deployment. The system design decouples CPU from GPU inference such that CPU-based processing, including database logging, compliance checking, and graphical visualization, does not affect the performance of GPU-based inference processing.

Compliance monitoring and alert reliability

The occurrence of duplicate violation of the same incident can cause a lot of alerts to be triggered. Therefore a cooldown mechanism of 30 seconds is employed to minimize the repetition of alerts by 85% for continuous monitoring. This is achieved by identity-aware as face recognition is linked to PPE detection for evaluation of PPE. The system successfully monitored different industrial safety and security violations such as the absence of PPE such as helmets, vests, and unauthorized entry into certain zones. The emergency hazards module for fire, smoke detection, fall detection and intruders after working hours security also worked successfully and sent instant alerts. The instant alerts were sent via WhatsApp and SMS for emergency hazards. The system activate a buzzer in case of fire/smoke outbreak to evacuate people in the zone or nearby zone with fire incident. This shows that the modular architecture can be used for safety monitoring while ensuring real-time response with smooth video streaming.

Comparison with existing systems

Comparing SiteSecureVision provides several additional capabilities compared to existing PPE monitoring system reviewed. This includes covering a wide range of PPE categories, multi-camera monitoring, person identification, role based PPE rules, zone based access control, fire and smoke detection, falling detection and night security monitoring resulting in an integrated operational workflow. Some studies primarily focused on dataset-level detection accuracy, while this system emphasizes operational deployment and real-time monitoring in industrial environments. It integrate multiple safety monitoring modules in a single GPU inference pipeline enabling the system to function as a comprehensive real-time industrial safety management platform.

Limitations

The performance of the system is dependent on the position of the camera, lighting conditions, distance and the availability of hardware resources. In addition, cases of occlusions or camera angles may affect the face recognition or PPE detection for a certain period of time or certain people. Moreover, SiteSecureVision implementation does not allow re-identification for a person moving between non-overlapping camera views.

Practical implications

The experimental deployment shows that existing CCTV infrastructure can be transformed to create an intelligent safety enforcement system with the help of AI-based computer vision. It helps to achieve identity-based compliance monitoring, automated notifications, and surveillance to achieve active safety management in an industrial setup.

CONCLUSION



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The safety monitoring system, SiteSecureVision presented, is a smart industrial safety compliance solution that is developed to upgrade existing CCTV infrastructure using AI technologies. It uses deep learning algorithms such as YOLOv8 for PPE detection and hazard monitoring, InsightFace for face recognition, and EasyOCR for license plate monitoring. Batched GPU inference pipeline with asynchronous CPU processing is used to enable efficient multi-camera monitoring while maintaining real-time responsiveness even after the number of cameras increases. The experimental results indicated a consistent frame rate between 18-25 FPS, achieved in real-time processing on different industrial scenes. This system is capable of identifying persons, monitoring spatial PPE, and real time alerting for industrial safety violations. This system presents effective techniques for safety management that allow for flexibility in industrial environments, minimizing conventional monitoring techniques while facilitating instant violation alerts. The architecture follows a modular design that employs spatial PPE verification and links violations directly to responsible individuals while allowing additional modules to be integrated easily. The future work will aim on improving the person re-identification across cameras, enhancing the system for edge environments, and extending the system to monitor other industrial safety hazards such as unsafe lifting and behavioural safety.

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Table 1. Runtime performance of deep learning models used in SiteSecureVision system

SINo	Model	Task	Latency	Throughput (FPS)	Accuracy metrics
Trained					
1	YOLOv8m (best.onnx)	PPE detection	266 ms CPU 25.7 ms GPU	3.4 FPS CPU, 38.9 FPS GPU	Precision 0.88, Recall 0.88, mAP@0.5 = 0.92
2	YOLOv8n (best.onnx)	Person detection	131 ms	7.6 FPS	Precision: 0.92, Recall = 0.84, mAP@0.5 = 0.89
3	YOLOv8n (best.onnx)	Fire & smoke detection	50 ms	19.7 FPS	Precision 0.91, Recall 0.78, mAP@0.5 ≈ 0.88
Pre- trained					
4	SCRFD det_10g	Face detection	80 ms	12.4 FPS	High-accuracy face localization
5	ArcFace w600k_r50	Face recognition	48 ms	20.6 FPS	Recognition accuracy ≈ 92.9%
6	YOLOv8n-Pose	Fall detection	56 ms	17.8 FPS	Pose-based fall detection
7	ALPR YOLOv8n	License plate detection	51 ms	19.3 FPS	Runtime detection validated



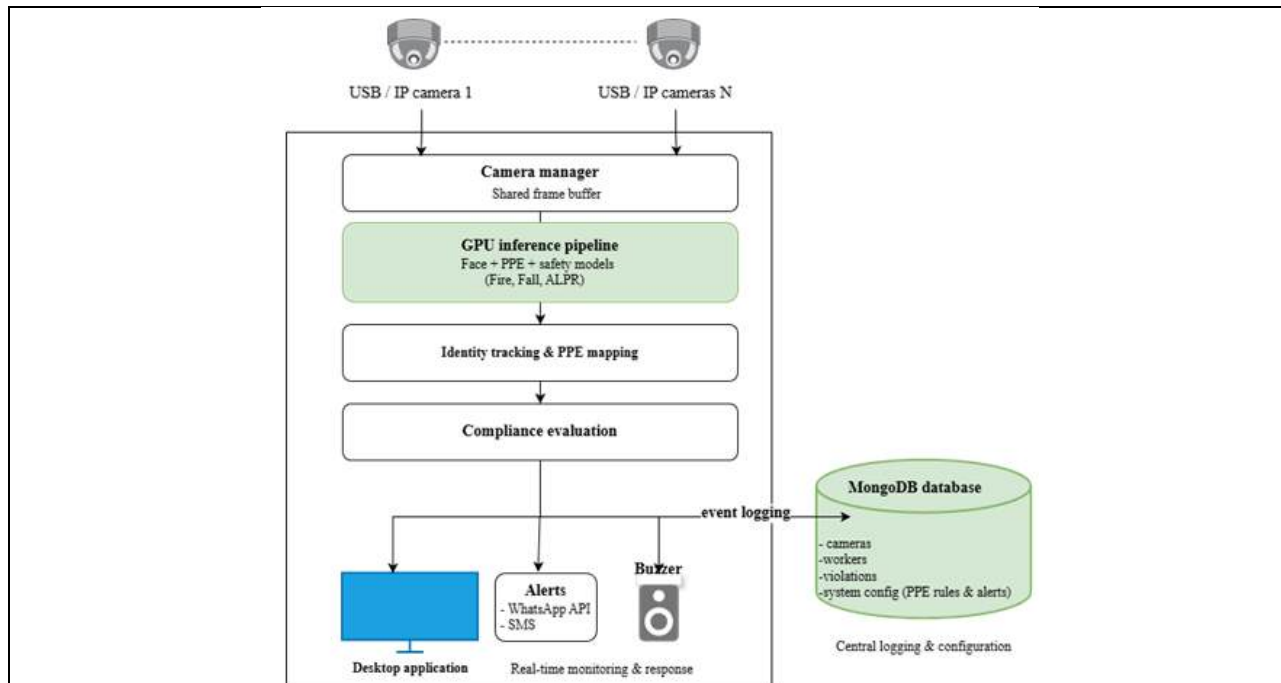


Fig. 1. Architecture of SiteSecureVision System illustrating acquisition of multi-camera video, the inference pipeline of the GPU, evaluation of identity compliant video and event log with alerting mechanisms.

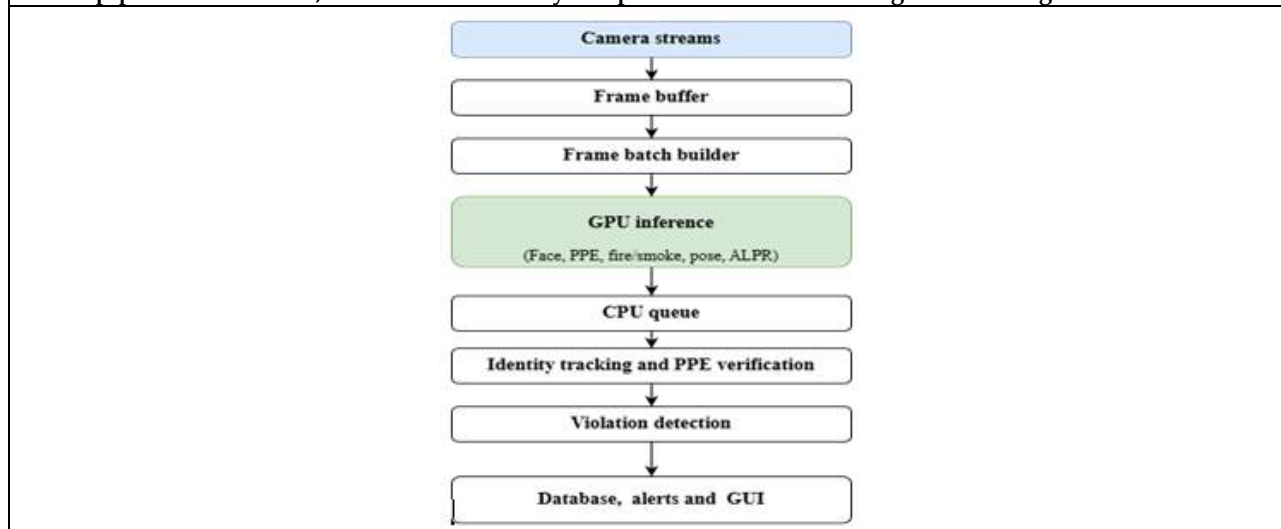


Fig. 2. Real-time inference pipeline showing batched GPU processing and asynchronous CPU post-processing for violation detection and event logging.

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RESEARCH ARTICLE

High Resolution-Liquid Chromatography Mass Spectrometry (HR-LCMS) - Based Phytochemical Profiling of *Pogonatum neesii* (Mull.Hal.) Dozy

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ABSTRACT

Plant-based therapeutics have gained increasing attention due to their perceived safety, reduced toxicity and demonstrated pharmacological efficacy compared with many synthetic compounds. A significant number of contemporary drugs currently used in clinical practice are derived from natural sources, particularly medicinal plants. Therefore, integrating traditional ethnomedicinal knowledge with modern drug discovery approaches is essential for the identification of novel bioactive compounds. In this context, the present study aimed to screen and identify, potential bioactive constituents from the ethyl acetate extract of *Pogonatum neesii*. The investigation focused on the phytochemical profiling of the ethyl acetate extract using advanced analytical techniques. Liquid Chromatography-Mass Spectrometry (LC-MS) was employed to detect and characterize the phytoconstituents present in the plant extract. This analytical method enables sensitive and accurate identification of secondary metabolites based on their mass spectral patterns and chromatographic behavior. The LC-MS analysis results provide valuable insights into the chemical composition of the *Pogonatum neesii* extract and may inform the discovery of pharmacologically active compounds for future drug development. Among them, Chamaemeloside, Madasiatic acid, Genistein 8-C-glucoside, Ohioensin-A, Ferulic acid 4-O-glucuronide, Kaempferol 3-(2",6"-di-(E)-p-coumarylglucoside), Cichoriin, Tectorigenin, Esculetin, 2,6-dihydroxybenzoic acid, Grossamide, Isolimononic acid, Pretazettine, Dihydrocapsaicin, Cajanin, Sarmentosin, Ruspolinone, Sphagnum acid, Scoparone, Vanillic acid etc. are major compounds having reported diverse pharmacological activities. This is the first report of these active compounds from this plant. Extracted





information is useful for future perspectives in drug development and understanding of its pharmacological actions.

Keywords: HR-LCMS, Chamaemeloside, Ruspolinone, Sphagnum acid, Scoparone, Vanillic acid

INTRODUCTION

Plants are significant sources of natural medicine. However, the availability of these plant resources is limited and often insufficient to meet the growing global demand driven by the increasing human population [1]. Plant-derived natural products have long served as valuable therapeutic resources and have been used for centuries in the treatment of numerous diseases. In recent years, the use of bioactive compounds obtained from plants has increased significantly, largely due to concerns about the adverse effects associated with many synthetic drugs, which may sometimes pose greater risks than the conditions they are intended to treat. In contrast, plant-based medicines contain naturally occurring compounds that can support health and aid in the management of various illnesses. These herbal remedies are often considered safer, better tolerated by patients, relatively cost-effective and widely accepted across the globe. Consequently, recognizing the therapeutic potential of medicinal plants and promoting a renewed reliance on natural remedies has become increasingly important in both present and future healthcare system [2,3,4].

Mosses are a group of plants widely distributed worldwide. Currently, it is estimated that there are approximately 22,000-25,000 of these organisms all over the World [5,6]. However, only a small percentage of these minute, photosynthetic, terrestrial, green spore-producing plants have been chemically investigated to date [7,8]. In this study, we used *Pogonatum neesii*, which belongs to the family Polytrichaceae in the order Polytrichales. The genus *Pogonatum* P. Beauv. is the most species-rich genus in the Polytrichaceae family, comprising more than 50 species [9]. Phytochemicals are broadly classified into primary and secondary metabolites. Primary metabolites include essential compounds such as chlorophyll, proteins and simple sugars that are directly involved in plant growth and metabolism. In contrast, secondary metabolites comprise diverse groups such as terpenoids, alkaloids and phenolic compounds, which often play protective and ecological roles in plants. Among these, terpenoids are known to exhibit a wide range of pharmacological activities, including anti-inflammatory, antimalarial, antiviral, antibacterial effects and the ability to inhibit cholesterol synthesis. Alkaloids, another important class of secondary metabolites, are widely distributed in medicinal plants and possess significant therapeutic properties. Many alkaloids are utilized in medicine as anesthetic agents and contribute substantially to the pharmacological value of medicinal plants [10,11,12,13]. High Resolution-Liquid Chromatography Mass Spectrometry (HR-LCMS) is one such powerful analytical technique used for separation, identification and quantification of both unknown and known compounds, small molecules, as well as to elucidate the structure and chemical properties of different molecules, multicomponent containing substances [14]. This study focused on the identification of active compounds in *Pogonatum neesii* through HR-LCMS.

MATERIALS AND METHODS

Plant materials and sample preparation

Pogonatum neesii were collected from Kodaikanal, Tamil Nadu and authenticated by the Bryology Division, Department of Botany, University of Calicut. Voucher specimen (Collection number 195032) was deposited in the Calicut University herbarium (CALI). The collected material was thoroughly washed, shade-dried at room temperature and then ground into fine powder using a mechanical blender. The powdered samples were stored in a zip-lock bag for further analysis.



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Preparation of Plant Extracts

The plant material was subjected to sequential solvent extraction using hexane, petroleum ether, chloroform, ethyl acetate, methanol and distilled water. The resulting extracts were concentrated using a rotary evaporator and stored in sealed containers at 4 °C for future use.

HR-LCMS

The HR-LCMS analysis is conducted using a TOF/Q-TOF mass spectrometer (model G6550A) equipped with a Dual AJS ESI source operating at Sophisticated Analytical Instrument Facility (SAIF) Bombay. The acquisition mode is Auto MS/MS, covering an m/z range of 120 to 1200, with a scan rate of 1 spectrum per second for both MS and MS/MS scans. Collision energy is ramped based on precursor ion charge, with specific slope and offset values of -2.643, -2.662 and -2.681. Chromatographic separation is performed with a binary solvent system, where solvent A is 0.1% formic acid in water and solvent B is acetonitrile. The gradient starts with 5% solvent B, increasing linearly to 100% by 25 minutes, holding at 100% until 30 minutes, then ramping back to 5% by 31 minutes with a re-equilibration phase lasting until 35 minutes. The flow rate is maintained at 0.300 ml/min, with the column compartment temperature set at 40°C. The injection volume is 3 µl and needle washing is enabled at the flush port with a wash time of 3 seconds. Source conditions include a sheath gas flow of 11 l/min at 300°C, a drying gas flow of 13 l/min at 250°C and a nebulizer pressure of 35 psig. The capillary voltage is set at 3500 V, while the nozzle voltage is maintained at 1000 V. MS/MS isolation width is approximately 4 amu and dynamic precursor selection is based on abundance, with a purity cutoff of 30% and strict stringency at 100%. Active exclusion is enabled, with excluded precursors released after 0.2 minutes or excluded after one spectrum. A maximum of 10 precursors is selected per cycle, targeting 25,000 counts per spectrum.

RESULTS AND DISCUSSION

HR-LCMS analysis of the ethyl acetate extract of *Pogonatum neesii* in negative ionisation mode enabled the tentative identification of 39 secondary metabolites belonging to diverse phytochemical classes, including flavonoids, phenolic compounds, terpenoids, saponins, coumarins, fatty acids, oxylipins, glycosides and esters. The presence of these metabolites indicates the chemical diversity of the extract and suggests its potential pharmacological relevance.

Phenolic compounds are one of the major and diverse groups found in plants. They contain at least one aromatic ring and one or more hydroxyl groups in their structure, with the simplest form of phenol being C₆H₅OH [31,32]. Phenolic compounds may also be used in several fields like antioxidant, anti-inflammatory, antimicrobial, antiviral, antipyretic and analgesic [33]. The abundance of phenolics in the extract supports its potential role as a natural antioxidant source. Several phenolic compounds and phenolic glycosides were identified, including ferulic acid 4-O-glucuronide, 1-O-sinapoylglucose, 1-caffeoyl-β-D-glucose, 2,6-dihydroxybenzoic acid and shoyuflavones A and B. Rotenonone used as an insecticide and pesticide [24]. Ferulic acid 4-O-glucuronide has significant antioxidant activity [26]. And 2,6-dihydroxybenzoic acid also shows Antioxidant properties [30]. HR-LCMS analysis revealed the presence of flavonoid compounds such as Kaempferol 3-(2'',6''-di-(E)-p-coumarylglucoside), 2,3-dihydroamentoflavone, Genistein 8-C-glucoside, Ohioensin-A and Tectorigenin were identified. Flavonoids are the most abundant and broadly distributed class of phenolic compounds found in plants [34].

Flavonoids are well known for their various biological activities, including anti-allergic, anti-inflammatory, antiviral, anti-proliferative and anti-carcinogenic effects and they also influence certain aspects of mammalian metabolism [35]. Kaempferol 3-(2'',6''-di-(E)-p-coumarylglucoside) is reported to possess strong antioxidant and antibacterial properties [15]. Similarly, 2,3-dihydroamentoflavone has been associated with antidiabetic activity [22], while Genistein 8-C-glucoside exhibits hepatoprotective and antioxidant properties [36]. The presence of these flavonoids may contribute significantly to the biological activity of the extract. Coumarin is a naturally occurring compound found in many plants and essential oils. From a pharmacological perspective, it is classified as a flavonoid, along with several other related compounds [37]. Coumarins have also been shown to inhibit lipid peroxidation and to neutralize reactive species such as hydroxyl radicals, superoxide radicals and hypochlorous acid [38], soybean



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lipoxygenase/or 5-lipoxygenase [39] and to possess anti-inflammatory and anticoagulant abilities [40]. Coumarins and coumarin glycosides such as esculetin, cichoriin, 5-hydroxy-6-methoxycoumarin-7-glucoside and furocoumarinic acid glucoside were also present in the ethyl acetate extract. Esculetin has been reported to exhibit antioxidant, antidiabetic and anti-inflammatory activities [29], while cichoriin has demonstrated antioxidant, antidiabetic and cardioprotective properties [27]. These compounds are known to contribute to free-radical scavenging and metabolic regulation.

Terpenes are a large and diverse group of organic compounds produced by various plants [41,42]. Terpenes are hydrocarbons that often have a strong odor. They may help protect the plants that produce them by attracting predators and parasites of herbivores, as well as by deterring herbivores [43,44]. Terpenes perform several roles in plants, including signaling functions, acting as pigments, solvents and flavoring agents and they also have various medicinal applications [45]. Terpenes possess various therapeutic properties, including antimicrobial, antiviral, antifungal, analgesic, antihyperglycemic, antiparasitic and anti-inflammatory activities. They are also used to enhance skin penetration and help prevent inflammatory diseases. In medicine, terpenes are utilized in the development of several pharmaceutical drugs [46]. Terpenoid compounds, including Madasiatic acid and Kessyl glycol were also detected. Madasiatic acid is widely recognized for its anti-inflammatory, antioxidant, antimicrobial and wound-healing properties [21]. These compounds may play a crucial role in mediating therapeutic effects related to inflammation and tissue repair. In addition, sesquiterpene lactone glycosides such as “Chamaemeloside” were identified and are known for their anti-inflammatory effects [19]. The presence of 12-hydroxyamoorastatin, a terpene with reported antileukemic activity [20] Triterpenoid saponins were also detected, including Cyclopasifloside II. Cyclopasifloside II has been reported to exhibit anti-inflammatory activity through inhibition of inducible nitric oxide synthase [16].

The analysis also revealed the presence of iridoid glycosides. Iridoids are oxygenated monoterpenes that commonly occur as glycosides attached to glucose. They have been reported in several plant families and have shown a broad spectrum of biological activities [47,48]. Iridoid glycosides represented by Kanokoside C, which has been reported to show neuroprotective and nerve growth factor (NGF) potentiating activity [17]. Such compounds are often associated with neuroprotective and anti-inflammatory effects, indicating potential neurological benefits of the plant extract. The HR-LCMS analysis also identified a saponin, Notoginsenoside T2. Saponins are defined as triterpenoid or steroid glycosides produced by some bacteria, lower marine animals and plants [49]. Saponins have antioxidant activity [49] and antimicrobial activity [50]. Notoginsenoside T2 has no reported activities. Chlorophyll a complex green pigment found in plants, algae and certain bacteria, plays a crucial role in the process of photosynthesis by absorbing light energy and converting it into chemical energy [51]. Chlorophyll derivatives exhibit a range of beneficial effects, including antioxidant, antigenotoxic and anti-obesogenic properties [52]. Chlorophyll derivatives such as phaeophorbide b were detected, which have been reported to possess antioxidant activity [18]. Fatty acids, including omega-hydroxy behenic acid, (2S)-2-hydroxyphytanic acid, 16-hydroxyhexadecanoic acid, 8S-HODE and 9-HOTE, along with several oxylipins such as 9,10-dihydroxy-12,13-epoxyoctadecanoate and corchorifatty acid F. Other detected compounds included esters (dioctyl hexanedioate, diethyl succinate), fatty alcohol derivatives (avocadene 4-acetate) and sugars (hamamelose). Although their biological activities are not reported, more studies are needed.

The HR-LCMS analysis of the ethyl acetate extract in positive ionisation mode revealed the presence of 30 secondary metabolites belonging to diverse phytochemical classes such as alkaloids, flavonoids, terpenoids, phenolic compounds, coumarins, cyanogenic glycosides, carotenoids and amino acid derivatives. The detection of these compounds highlights the chemical complexity of the extract and provides insight into its potential pharmacological properties. Several phenolic compounds are detected, including feruloyl C1-glucuronide, Lucidin omega-methyl ether, sphagnum acid, vanillic acid and (E)-3-(2-hydroxyphenyl)-2-propenal. For instance, vanillic acid has demonstrated antibacterial and anti-inflammatory activities [69,70]. Similarly, sphagnum acid has been reported to possess antibacterial properties [66]. Phenyl propanoids such as methoxyeugenol are also reported, but their activity has not been reported yet. Flavonoids and isoflavonoids were also detected. These compounds are widely recognized for their antioxidant, antibacterial, antifungal and anti-inflammatory activities. For example, cajanin has been



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reported to exhibit antibacterial and antioxidant properties [59], along with antifungal activity [60] and anti-inflammatory effects [61]. Coumarin derivatives such as scoparone and 8-hydroxy-7-methoxy-2H-1-benzopyran-2-one were also identified. Scoparone, in particular, has been reported to exhibit anti-inflammatory activity [67] as well as antibacterial effects [68]. The presence of lignanamides, represented by grossamide, is noteworthy due to their well-documented anti-inflammatory activity [53]. The extract also contained cyanogenic glycosides, lotaustralin, which are naturally occurring plant defense compounds. Although these compounds are primarily known for their role in plant defense [71]. Similarly, sarmentosin has been associated with anti-inflammatory and antioxidant activities [63]. Several terpenoid compounds were also identified in the extract, including physalin O, isolimonic acid, D-linalool 3-(6"-malonylglucoside) and antheraxanthin

A. Carotenoid derivatives such as antheraxanthin A play an important role in plants by protecting photosynthetic systems against photooxidative damage through the xanthophyll cycle [54]. Terpenoids such as isolimonic acid have demonstrated antibacterial properties [55], suggesting their potential contribution to the antimicrobial activity of the extract. Among the identified metabolites, chlorophyll derivatives, including red chlorophyll catabolite, phaeophorbide a and phaeophorbide b. phaeophorbide a and phaeophorbide b are degradation products of chlorophyll and have been reported to exhibit significant antioxidant activity [18]. The LC–MS profile also revealed the presence of several alkaloids, including pretazettine, (S)-neolitsine, dihydrocapsaicin, (±)-clausenamide and ruspolinone. Alkaloids are the main secondary metabolites that have medical properties. Alkaloids can help avoid several degenerative diseases by scavenging free radicals or binding with a catalyst to the oxidative reaction. Several studies indicated that the alkaloids from several plants have a wide range of pharmaceutical applications [72]. Pretazettine has demonstrated antiviral activity [56], while (S)-neolitsine has shown strong cytotoxic activity against cancer cell lines such as MCF-7 and B16-F10 [57]. Dihydrocapsaicin has been reported to possess antioxidant and anti-inflammatory properties [58]. Additionally, clausenamide has been studied for its anti-lipid peroxidation and neuroprotective effects [62]. In addition to the major constituents, several other compounds were also identified, including organic acids such as 2,6-diamino-7-hydroxy-azelaic acid, amino acid derivatives like N-acetyl-L-phenylalanine, fatty acid esters such as isobutyl 2-furanpropionate, carboxylic acid derivatives including methyl 2,3-dihydro-3,5-dihydroxy-2-oxo-3-indoleacetic acid and polyketides such as ornaline. However, the biological or pharmacological activities of these compounds have not yet been reported in the literature, indicating the need for further investigation to determine their potential significance.

SUMMARY AND CONCLUSION

HR-LCMS analysis of the ethyl acetate extract in both negative and positive ionisation modes revealed a diverse array of phytochemicals, highlighting the complex chemical composition of the extract. A total of 69 secondary metabolites were tentatively identified, comprising 39 compounds in negative ionisation mode and 30 compounds in positive ionisation mode. These metabolites belong to several important phytochemical classes, including flavonoids, phenolic compounds, terpenoids, saponins, coumarins, alkaloids, lignanamides, carotenoids, cyanogenic glycosides, fatty acids, oxylipins and amino acid derivatives. Flavonoids and phenolic compounds represented a major portion of the detected constituents. Compounds such as kaempferol derivatives, genistein glycosides, tectorigenin, liquiritin apioside, cajanin and vanillic acid are well known for their antioxidant, anti-inflammatory, antimicrobial and antidiabetic activities. Coumarin derivatives, including esculetin, cichoriin and scoparone, further contribute to the antioxidant and anti-inflammatory potential of the extract. Several terpenoids and carotenoids, such as Madasiatic acid, physalin O, isolimonic acid and antheraxanthin, were also detected and are associated with antimicrobial, cytoprotective and anti-inflammatory effects.

Additionally, the presence of alkaloids including pretazettine, (S)-neolitsine, dihydrocapsaicin and clausenamide suggests possible antiviral, anticancer and neuroprotective activities. Other metabolites such as saponins, lignanamides, cyanogenic glycosides, fatty acids and oxylipins may further contribute to the biological properties of the extract. Overall, the LC–MS profiling demonstrates that the ethyl acetate extract is a rich source of bioactive





compounds, supporting its potential pharmacological significance and providing a chemical basis for its therapeutic applications.

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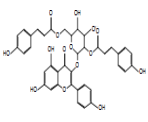




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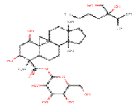
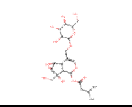
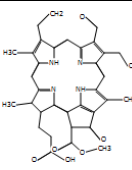
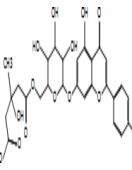
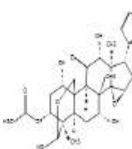
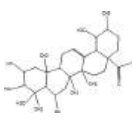
Table 1 HR-LCMS analysis of the ethyl acetate extract of *Pogonatum neesii* and identification of compounds with their biological uses using negative ionization mode

Sl. No.	Name of the compound	Molecular formula	RT	Mass	M/Z	Class	Structure	Activities
1	Kaempferol 3-(2",6"-di-(E)-p-coumarylglucoside)	C ₃₉ H ₃₂ O ₁₅	3.973	740.1834	739.1764	Flavonoids		Antioxidant and Antibacterial properties [15].





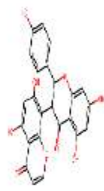
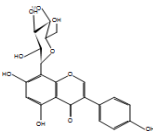
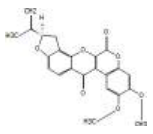
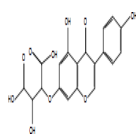
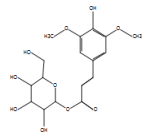
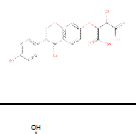
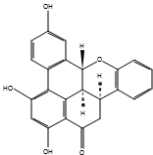
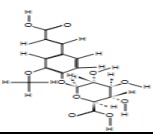
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2	Cyclopasifloside II	$C_{37}H_{62}O_1$ 1	23.46 4	682.42 25	681.41 55	Triterpenoid Saponins		Anti-inflammatory Activity (iNOS Inhibition) [16].
3	Notoginsenoside T2	$C_{37}H_{62}O_1$ 0	23.92 3	666.42 82	665.42 12	Saponins		Not reported
4	Kanokoside C	$C_{27}H_{42}O_1$ 7	15.47 5	638.24 86	683.24 71	Iridoid glycosides		Neuroprotective and NGF-Potentiating Activity [17].
5	Phaeophorbide b	$C_{35}H_{34}N_4O_6$	18.87 8	606.25 04	605.24 3	Chlorophyll		Antioxidant activity [18].
6	Chamaemeloside	$C_{27}H_{28}O_1$ 4	7.649	576.15 13	575.14 41	Flavonoid		Anti-inflammatory effects [19].
7	12-alpha hydroxyamoorastatin	$C_{28}H_{36}O_1$ 0	10.94 6	532.23 43	531.22 73	Terpenes		Antileukemic Activity [20].
8	Madasiatic acid	$C_{30}H_{48}O_5$	17.27 6	488.35 27	487.34 59	Terpenes		Anti-inflammatory, Antioxidant, Antimicrobial properties and wound healing properties [21].
9	2,3-Dihydro-5,5',7,7'-tetrahydroxy-2-(4-hydroxyphenyl)[3,8'-bi-4H-1-benzopyran]-4,4'-dione or 2,3-dihydroamentoflav	$C_{24}H_{16}O_9$	5.913	448.07 79	447.07 27	Flavonoid		Anti-diabetic activity [22].





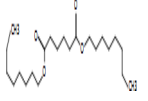
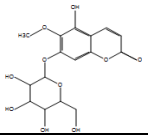
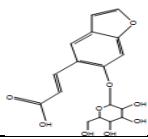
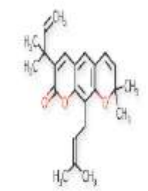
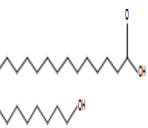
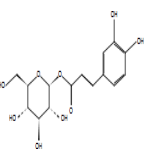
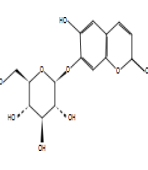
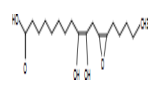
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	one							
10	Genistein 8-C-glucoside	$C_{21}H_{20}O_{10}$	6.554	432.1077	431.1005	Flavonoids		Antioxidant properties [23].
11	Rotenonone	$C_{23}H_{18}O_7$	7.969	406.1076	405.1006	Phenolic compound		Used as an insecticide and pesticide [24].
12	Shoyuflavone B	$C_{19}H_{14}O_{10}$	8.046	402.061	401.0539	Phenolic compound		Not reported
13	1-O-Sinapoylglucose	$C_{17}H_{22}O_{10}$	4.961	386.1228	385.1158	Phenolic compound		Not reported
14	Shoyuflavone A	$C_{19}H_{14}O_9$	10.388	386.0658	385.0586	Phenolic compound		Not reported
15	Ohioensin-A	$C_{23}H_{16}O_5$	13.479	372.102	371.0943	Flavonoids		Antioxidant, Anti-inflammatory and Anticancer properties [25].
16	Ferulic acid 4-O-glucuronide	$C_{16}H_{18}O_{10}$	3.974	370.0919	415.0903	Phenolic compound		Antioxidant properties [26].
17	Diocetyl hexanedioate	$C_{22}H_{42}O_4$	20.598	370.31	369.3028	Esters		Not reported





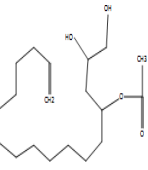
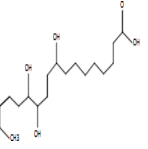
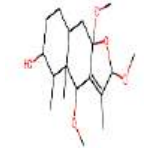
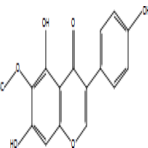
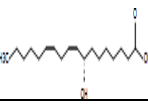
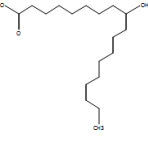
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18	5-Hydroxy-6-methoxycoumarin 7-glucoside	$C_{16}H_{18}O_{10}$	3.971	370.09 21	369.08 5	Coumarin glycosides		Not reported
19	Furocoumarinic acid glucoside	$C_{17}H_{18}O_9$	5.508	366.09 69	411.09 52	Coumarin glycosides		Not reported
20	3-(1,1-Dimethyl-2-propenyl)-8-(3-methyl-2-butenyl) xanthyletin	$C_{24}H_{28}O_3$	10.08 9	364.20 13	363.19 56	Pyrano coumarins		Not reported
21	omega-hydroxy behenic acid	$C_{22}H_{44}O_3$	24.96 3	356.33 07	355.32 34	Fatty acid		Not reported
22	1-Caffeoyl-beta-D-glucose	$C_{15}H_{18}O_9$	11.81	342.09 18	387.09 03	Phenolic glycoside		Not reported
23	Cichoriin	$C_{15}H_{16}O_9$	4.388	340.08 12	339.07 38	Polyphenolic coumarin glycoside		Antioxidant, Antidiabetic and Cardioprotective Activity [27].
24	9,10-Dihydroxy-12,13-epoxyoctadecanoate	$C_{18}H_{34}O_5$	10.70 5	330.24 28	329.23 55	Oxylipins		Not reported
25	(2S)-2-	$C_{20}H_{40}O_3$	23.22	328.29	327.29	Fatty acid		Not reported





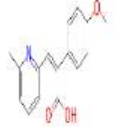
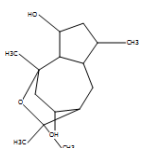
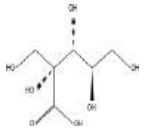
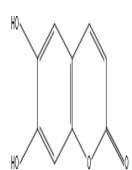
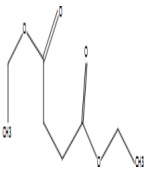
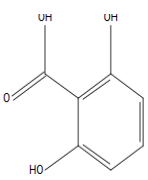
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	hydroxyphytanic acid		6	93	21			
26	Avocadene 4-acetate	$C_{19}H_{36}O_4$	19.16 2	328.26 31	327.25 58	Fatty alcohols		Not reported
27	Corchorifatty acid F	$C_{18}H_{32}O_5$	10.00 7	328.22 67	327.21 94	Oxylipins		Not reported
28	(3b,6b,8a,12a)-8,12-Epoxy-7(11)-eremophilene-6,8,12-trimethoxy-3-ol	$C_{18}H_{30}O_5$	10.10 1	326.20 99	325.20 28	Naphthofurans		Not reported
29	9Z-Octadecenedioic acid	$C_{18}H_{32}O_4$	13.14 4	312.23 2	311.22 48	Dicarboxylic acid		Not reported
30	Tectorigenin	$C_{16}H_{12}O_6$	8.259	300.06 52	299.05 8	Flavonoid		Anti-inflammatory activity [28].
31	8S-HODE	$C_{18}H_{32}O_3$	15.86 5	296.23 71	295.23	Fatty acid		Not reported
32	9-HOTE	$C_{18}H_{30}O_3$	15.13 5	294.22 12	293.21 4	Fatty acids		Not reported
33	16-Hydroxy hexadecanoic acid	$C_{16}H_{32}O_3$	19.41 8	272.23 66	271.22 94	Fatty acids		Not reported





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34	alpha-(p-Methoxyphenyl)-6-methyl-2-pyridineacrylic acid	$C_{16}H_{15}NO_3$	10.01 2	269.10 67	268.09 95	Carboxylic acid		Not reported
35	Kessyl glycol	$C_{15}H_{26}O_3$	11.21 3	254.18 96	299.18 8	Terpenes		Not reported
36	Hamamelose	$C_6H_{12}O_7$	1.201	196.05 9	195.05 17	Sugars		Not reported
37	Esculetin	$C_9H_6O_4$	5.192	178.02 75	177.02 02	Coumarin		Antioxidant property, Antidiabetic and Antiinflammatory activities [29].
38	Diethyl succinate	$C_8H_{14}O_4$	6.166	174.09	173.08 27	Dicarboxylic acid esters		Not reported
39	2,6-dihydroxybenzoic acid	$C_7H_6O_4$	3.059	154.02 71	153.01 98	Phenolic compounds		Antioxidant properties [30].





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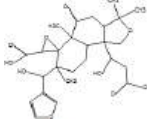
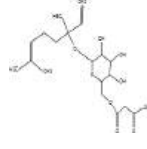
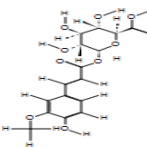
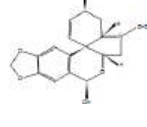
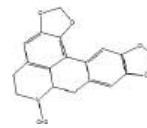
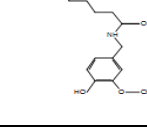
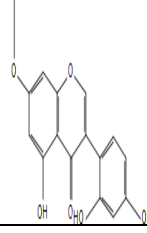
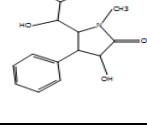
Table 2. HR-LCMS analysis of the ethyl acetate extract of *Pogonatum neesii* and identification of compounds with their biological uses using positive ionization mode

Sl. No.	Name of the compound	Molecular formula	RT	Mass	M/Z	Class	Structure	Activities
1	Red chlorophyll catabolite	C ₃₅ H ₃₈ N ₄ O ₇	14.25	626.2691	627.2764	Linear tetrapyrrole		Not reported
2	Grossamide	C ₃₆ H ₃₆ N ₂ O ₈	19.916	624.2542	625.2617	Lignanamides		Anti-inflammatory properties [53].
3	Phaeophorbide b	C ₃₅ H ₃₄ N ₄ O ₆	18.778	606.2437	607.251	Chlorophyll		Antioxidant activity [18].
4	Phaeophorbide a	C ₃₅ H ₃₆ N ₄ O ₅	21.1	592.2652	593.2725	Chlorophyll		Antioxidant activity [18].
5	Antheraxanthin A	C ₄₀ H ₅₆ O ₃	23.189	584.4161	585.4234	Carotenoids / Terpenoids		Protect plants from photooxidative damage [54].
6	Liquiritin apioside	C ₂₆ H ₃₀ O ₁₃	1.818	550.1752	276.0949	Flavonoid glycosides		Not reported
7	Physalin O	C ₂₈ H ₃₂ O ₁₀	15.19	528.1989	529.2063	Terpenoids		Not reported





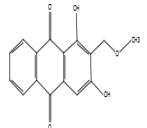
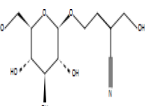
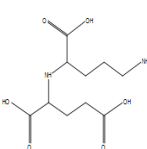
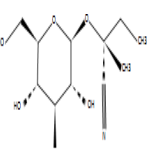
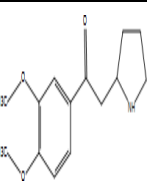
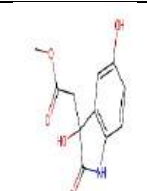
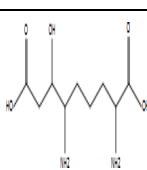
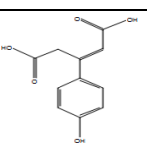
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8	Isolimononic acid	$C_{26}H_{34}O_{10}$	15.18 7	506.21 73	507.22 45	Terpenoids		Antibacterial properties [55].
9	D-Linalool 3-(6''-malonylglucoside)	$C_{19}H_{30}O_9$	11.77 6	402.19 12	403.19 86	Terpenoids		Not reported
10	Feruloyl C1-glucuronide	$C_{16}H_{18}O_{10}$	3.79	370.08 72	371.09 45	Phenolic compounds		Not reported
11	Pretazettine	$C_{18}H_{21}NO_5$	14.08 2	331.13 88	332.14 61	Alkaloid		Antiviral activity [56].
12	(S)-Neolitsine	$C_{19}H_{17}NO_4$	5.236	323.11 86	324.12 61	Alkaloid		The most cytotoxic alkaloid to MCF-7 and B16-F10 cells [57].
13	Dihydrocapsaicin	$C_{18}H_{29}NO_3$	8.631	307.21 13	308.21 96	Alkaloids		Antioxidant and Anti-inflammatory activities [58].
14	Cajanin	$C_{16}H_{12}O_6$	8.154	300.06 03	301.06 76	Isoflavonoids		Antibacterial and Antioxidant properties [59] Antifungal activity [60] Anti-inflammatory activity [61].
15	(±)-Clausenamide	$C_{18}H_{19}NO_3$	11.48 7	297.13 38	298.14 07	Alkaloids		Anti-lipidperoxidation and cerebral protective effects [62].





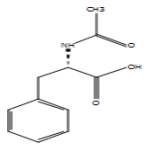
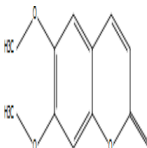
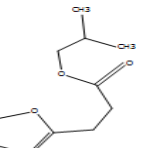
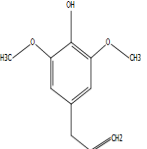
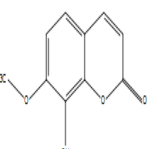
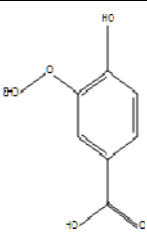
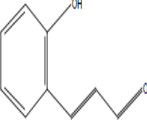
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16	Lucidin omega-methyl ether	$C_{16}H_{12}O_5$	8.084	284.06 56	285.07 27	Phenolic compounds		Not reported
17	Sarmentosin	$C_{11}H_{17}NO_7$	2.223	275.09 81	276.10 55	Cyanogenic glycosides		Anti-inflammatory and antioxidant activities [63].
18	Ornaline	$C_{10}H_{18}N_2O_6$	5.753	262.11 77	263.12 49	Polyketides		Not reported
19	Lotaustralin	$C_{11}H_{19}NO_6$	5.061	261.11 79	262.12 61	Cyanogenic glycosides		Not reported
20	Ruspolinone	$C_{14}H_{19}NO_3$	6.4	249.13 41	250.14 13	Alkaloid		Organocatalysts and building blocks in organic synthesis [64,65].
21	Methyl 2,3-dihydro-3,5-dihydroxy-2-oxo-3-indoleacetic acid	$C_{11}H_{11}NO_5$	1.434	237.06 15	238.06 88	Indolyl carboxylic acid		Not reported
22	2,6-Diamino-7-hydroxy-azelaic acid	$C_9H_{18}N_2O_5$	6.705	234.12 25	235.13 03	Organic acid		Not reported
23	Sphagnum acid	$C_{11}H_{10}O_5$	7.077	222.05 05	223.05 77	Phenolic compounds		Antibacterial activity [66].





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24	N-Acetyl-L-phenylalanine	$C_{11}H_{13}NO_3$	1.471	207.0873	208.0946	N acyl alpha aminoacids		Not reported
25	Scoparone	$C_{11}H_{10}O_4$	7.916	206.0554	207.0626	Coumarins		Anti-inflammatory activity [67]. Antibacterial activity [68].
26	Isobutyl 2-furanpropionate	$C_{11}H_{16}O_3$	6.55	196.1079	197.1152	Fatty acid ester		Not reported
27	Methoxyeugenol	$C_{11}H_{14}O_3$	6.64	194.0922	195.0995	Phenyl propanoids		Not reported
28	8-Hydroxy-7-methoxy-2H-1-benzopyran-2-one	$C_{10}H_8O_4$	6.342	192.0404	193.0477	Hydroxy coumarins		Not reported
29	Vanillic acid	$C_8H_8O_4$	3.792	168.0406	169.0476	Phenolic acid		Antibacterial activity [69]. Anti-Inflammatory activity [70].
30	(E)-3-(2-Hydroxyphenyl)-2-propenal	$C_9H_8O_2$	14.046	148.0508	149.0581	Phenyl propanoids		Not reported



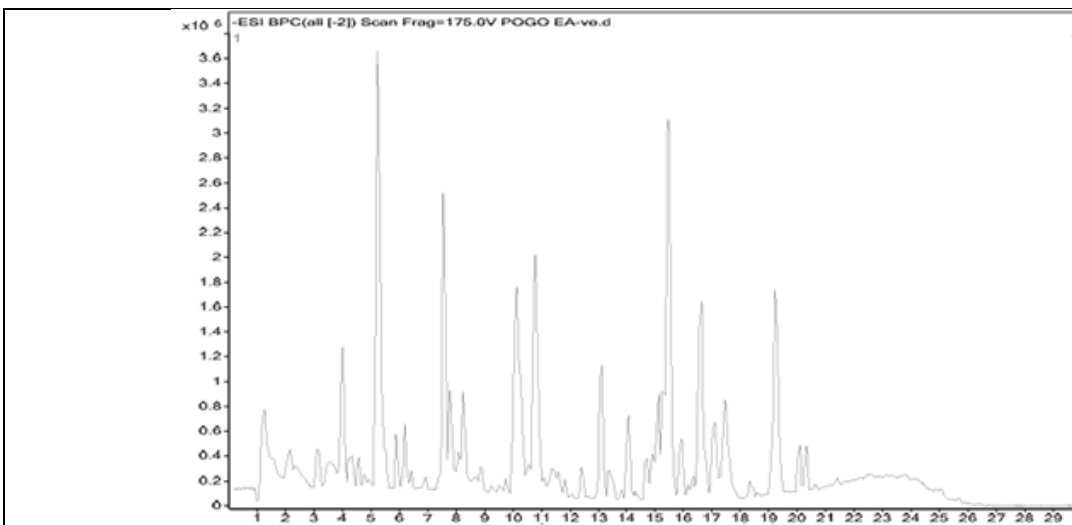
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Fig. 1. Chromatogram showing different peaks corresponding to various compounds in the negative ionization mode.

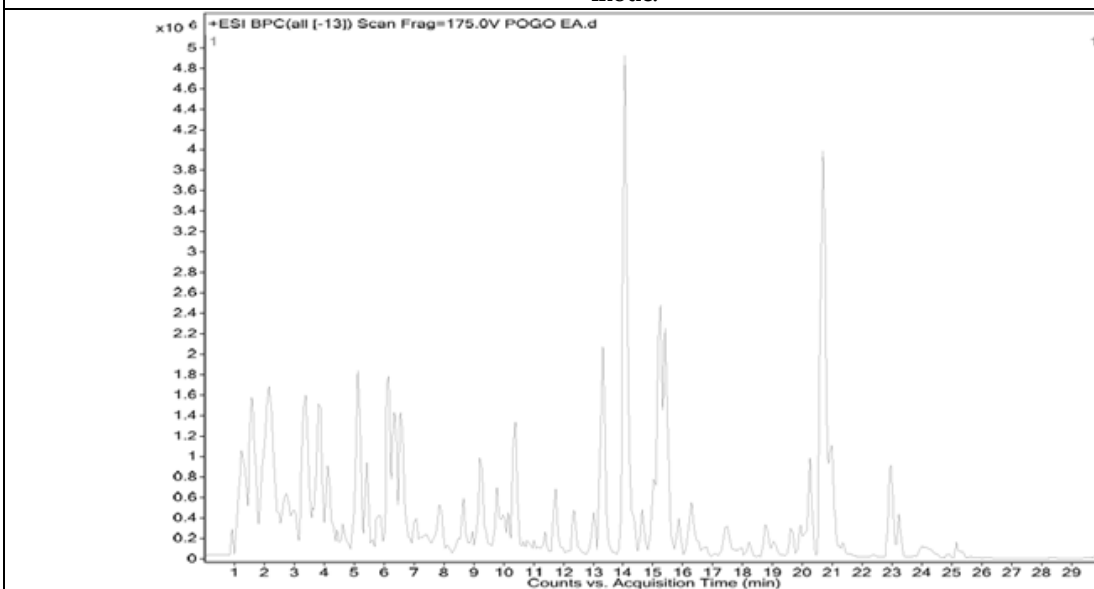


Fig. 2. Chromatogram showing different peaks corresponding to various compounds in the positive ionization mode.

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RESEARCH ARTICLE

Thymidine Oxidation by the Sodium Chromate – Hydrogen Peroxide System: Kinetic and Mechanistic Insights, and the Modulating Roles of Ascorbic Acid and Riboflavin

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ABSTRACT

The oxidation of Thymidine with sodium chromate and hydrogen peroxide (Cr(VI) - H₂O₂) system in presence of ascorbic acid at pH 8 has been carried in tris HCl buffer. The reactions are followed by measuring the absorbance of Thymidine at λ_{max} of 267nm. The rates of oxidation of Thymidine increased with increase in [chromate], [hydrogen peroxide] and [ascorbic acid]. The plot log (initial rate) versus log [chromate], and log (initial rate) versus log [ascorbic acid] was found to be linear with slope less than one indicating fractional order dependence on [chromate] and [ascorbic acid]. The fractional order dependence of reaction rate on [ascorbic acid] and [chromate] indicates that reaction might be proceeding through the initial formation of a complex between ascorbic acid and Cr (VI). The first order dependence of rate of oxidation on [H₂O₂] suggests that Chromium-Ascorbate complex might react with H₂O₂ in the rate determining step via Fenton like mechanism to generate OH radicals. An increase in [Thymidine] at constant [chromate], [hydrogen peroxide] and [ascorbic acid] has no significant increase of rate of oxidation suggests that OH radicals react with Thymidines in a fast step to form product. It has been found that riboflavin protects Thymidine to the extent of 78.9% at 64 μ M concentration of riboflavin from OH radicals.

Keywords: Oxidation of Thymidine, Chromium (VI), Hydrogen peroxide, ascorbic acid, Chromium-Ascorbate complex, Protection by riboflavin





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INTRODUCTION

Chromate, Cr(VI), as a human carcinogen has been established, although its mechanism of action has not been clearly defined [1,2]. The reaction of DNA with chromate causes a number of putative lesions in cellular systems including oxidized nucleic acid bases, abasic sites, DNA strand breaks, inter- and intrastrand cross-linked adducts and DNA–protein cross-links [3–7]. The tetrahedral structure of anionic conformation of +6 oxidation state of chromium facilitates active transport into cell systems through the phosphate and sulfate cellular transport systems [8]. Cr(VI) does not directly react with isolated DNA; rather, its genotoxic effects are mediated through reduction by cellular reductants, producing Cr(V) species that are considered key intermediates in DNA damage [8,9]. Various biological systems contribute to this reduction, including microsomes [10,11], mitochondria [12], superoxide radicals [13], flavin-containing enzymes [14–16], mitochondrial electron transport chain complexes [17], ascorbate [18,19], and thiol- or diol-containing molecules [8,20–22]. Jennette [10] proposed that Cr(V) represents the ultimate carcinogenic form of chromium. Earlier studies by Kawanishi et al. [23] suggested that Cr(V)(O₂)₄³⁻ mediates hydroxyl radical (•OH) formation from a mixture of 40 mM Na₂CrO₄ and 400 mM H₂O₂ at pH 8.

However, these concentrations exceed physiological levels, as noted by Aiyar et al. [24]. Subsequent ESR and spin-trapping studies revealed that Cr(V)(O₂)₄³⁻ is not formed in significant amounts with biologically relevant reductants. Instead, Cr(V) forms complexes with reductant-derived ligands, which generate hydroxyl radicals from H₂O₂ through Fenton-like reactions [25–27]. Chromium(VI)-induced DNA damage also exhibits tissue specificity. In animal models, DNA-protein and DNA interstrand crosslinks are observed in the livers of chick embryos treated with Cr(VI), whereas in red blood cells, damage manifests mainly as strand breaks [28]. This indicates that Cr(VI) reduction follows different metabolic pathways depending on the tissue type. The present study investigates the mechanism of DNA constituent damage induced by hydroxyl radicals generated from the Cr(VI)-H₂O₂ system, both in the presence and absence of naturally occurring antioxidants. By analyzing the reaction products of chromate with nucleosides and nucleic acid bases, we aim to gain deeper insights into the oxidative pathways involved in DNA damage.

Experimental

Thymidine, sodium chromate and ascorbic acid were from sigma and used as such. The solutions were prepared afresh with double distilled water, standardized and de-aerated by bubbling nitrogen. The Hydrogen peroxide solution was standardized using the method described in the literature [29]. The concentration of thymidine was determined by measuring the absorbance at $\lambda_{\max}$ of 267nm from the known absorption coefficient values. In a typical reaction required amounts of thymidine and H₂O₂ solution were then injected as aqueous solution into the mixture of ascorbic acid and sodium chromate solutions present in a 1-cm path length quartz cuvette suitable for absorbance measurements. The progress of the reactions were followed by measuring the absorbance at $\lambda_{\max}$ of thymidine on double beam UV-visible Spectrophotometer model T60U of Lab India at different time intervals from which rate of oxidation of thymidine were calculated.

The HPLC system used for analysis of products includes shimadzu LC-10AT equipment with dual piston pump system, a solvent programmer and Reodhyne injector model 7725 fitted with 20 μ l loop. A prepacked octadecylsilyl silica gel ODS hypersil column 25cm $\times$ 0.46cm, mean particle size 5 μ m was used. The column effluents were monitored at 280nm, using variable wavelength SPD-10A UV-Visible detector equipped with 8 μ l flow cell and attached to C-R7Ae plus chromatographic integrator. Samples were eluted with aqueous solutions containing 5% (v/v) methanol and buffered with 10mM KH₂PO₄ solution adjusted to pH 8. Before use the phosphate buffer was filtered through Millipore type HA 0.45 μ m membrane filter. All mobile phases were degassed using a vacuum pump. The solvent flow rate was kept at 0.5ml/min and all the HPLC runs were carried out at ambient temperatures.





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RESULTS AND DISCUSSION

The oxidation of Thymidine with sodium chromate and hydrogen peroxide (Cr(VI) - H₂O₂) system in presence and absence of ascorbic acid at pH 8 has been carried in tris HCl buffer. Thymidine is not oxidized even with highest concentration of sodium chromate (1×10⁻⁴ M) and hydrogen peroxide (5×10⁻³ M) system in the absence of ascorbic acid but in presence of ascorbic acid (1×10⁻⁵ M), thymidine is oxidized even with concentration as low as of sodium chromate (1 × 10⁻⁸ M) and hydrogen peroxide (5 × 10⁻³ M). The oxidation of thymidine with Cr(VI) - H₂O₂ system in presence of ascorbic acid were carried out (Spectra 1). The oxidation of Thymidine with Cr(VI) - H₂O₂ system in presence of ascorbic acid were carried out at different [chromate] varying from 2 × 10⁻⁴ to 1× 10⁻⁸ M keeping [ascorbic acid], [Thymidine] and [H₂O₂] constant. The plot of log (initial rate) versus log [chromate] was found to be linear with slope less than one indicating fractional order dependence on chromate (Figure 1). The effect of [ascorbic acid] varying between 1 × 10⁻⁵ – 4 × 10⁻⁵ M was studied keeping [H₂O₂], [Thymidine] and [chromate] constant. The plot of log (initial rate) versus log [ascorbic acid] was found to be linear with slope less than one indicating fractional order dependence on ascorbic acid (Figure 2).

An increase in [H₂O₂] was found to increase the rate of oxidation and order with respect to [H₂O₂] has been found to be unity from the slopes of log (initial rate) versus log [H₂O₂]. The concentration of H₂O₂ was varied between 1× 10⁻³- 1×10⁻² M. An increase in [Thymidine] at constant [chromate], [hydrogen peroxide] and [ascorbic acid] has no significant effect on rate of oxidation of Thymidine. In the present work, the fractional order dependence of reaction rate on [ascorbic acid] and [chromate] indicates that reaction might be proceeding through the initial formation of complex between ascorbic acid and Cr (VI) to give Cr(V)-ascorbate complex. Reduction of Cr(VI) by biological reductants such as ascorbic acid is well established to proceed via Cr(V) intermediates, which are highly reactive and play a key role in oxidative damage. Jennette demonstrated that Cr(V) species are crucial intermediates in chromium-induced carcinogenic processes[10]. Shi al confirmed the formation of Cr(V) during reduction of Cr(VI) by biological reductants using ESR spectroscopy[11]. These studies support Cr(VI) + ascorbate → Cr(V)-ascorbate complex.

The first order dependence of rate of oxidation Thymidine on [H₂O₂] suggests that Cr(V)-Ascorbate complex reacts with H₂O₂ in the rate determining step via Fenton like mechanism to generate OH radicals. Cr(V) complexes are known to react with hydrogen peroxide to generate hydroxyl radicals through Fenton-like chemistry. Kawanishi et al. reported hydroxyl radical formation in Cr(VI)-H₂O₂ systems[23]. Aiyar et al. clarified that under biologically relevant conditions, Cr(V) forms ligand-bound complexes that mediate •OH generation rather than free peroxo species [24]. Shi et al. further demonstrated that Cr(V)-ligand complexes catalyze H₂O₂ decomposition to produce •OH radicals [25].

This supports the step: Cr(V)-ascorbate + H₂O₂ → Cr(VI) + •OH

With the addition of ethanol, oxidation of Thymidine decreased indicating that OH radicals are generated in our system. The rate constant of OH radical with ethanol is reported to be $1.8 \pm 0.2 \times 10^9 \text{ dm}^3\text{mol}^{-1}\text{s}^{-1}$ [29]. The rate constant of OH radical with thymidine are calculated using equation (1) and found to be $4.2 \times 10^9 \text{ dm}^3\text{mol}^{-1}\text{s}^{-1}$. Hence in this system there might be a competition between Thymidine and ethanol for OH radicals. The relative amounts of OH radicals reacting with Thymidine decreases with increasing [ethanol]. An increase in [Thymidine] at constant [chromate], [hydrogen peroxide] and [ascorbic acid] has no effect on rate of oxidation suggests that OH radicals react with Thymidine in the fast step to form product. In order to understand the site of attack of OH radical on thymidine i.e, at the base/sugar moiety, a quantitative estimation of the base and sugar moieties present in the Thymidine has been made simultaneously and independently under same kinetic conditions at different times. The results indicated that the sugar moiety is not significantly affected during the oxidation either in the absence or presence of riboflavin [Table.1]. The rate of oxidation of D-ribose by OH radicals is lower than the rate of oxidation of Thymidine under the same experimental conditions. Further, the rates of oxidation of Thymidine by OH radicals are comparable to those of the rates of oxidation of Thymine (Table.1). These results indicate that it is the base moiety





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that is preferentially attacked by OH radicals. Therefore protection offered by riboflavin is thought to be mainly against base moiety oxidation.

Effect of pH : With increase in pH, rate of oxidation of Thymidine have been found to increase with Cr(VI)-H₂O₂ system in presence of ascorbic acid. Increase in rate of oxidation of Thymidine with pH clearly shows that oxidation occurs by OH radicals generated by reaction of H₂O₂ with Cr(V)-ascorbate complex via Fenton reaction (Table 2).

Anti oxidant activity of Riboflavin : The initial rates of oxidation of Thymidine by Cr (VI) - H₂O₂ system in presence of ascorbic acid have been found to decrease with increase in [Riboflavin] indicating that riboflavin is protecting the Thymidine from OH radicals generated with Cr (V)-ascorbate complex reaction with H₂O₂ via Fenton like mechanism [Table 3] & [Figure 3].

In this system there is a competition between Thymidine and riboflavin for OH radicals. The relative amounts of OH radicals reacting with Thymidine decreases with increasing [riboflavin]. The rate constant of riboflavin with hydroxyl radical has been reported to be $1.2 \pm 0.05 \times 10^{10} \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$ over the pH range 1–11 [30]. The rate constant of hydroxyl radical with ascorbic acid at physiological pH has been reported to be $2.7 \times 10^5 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$ [31]. This indicates that ascorbic acid is not specific hydroxyl radical scavenger at physiological pH. Since the rate constant of OH radical with riboflavin is much higher than rate constant of OH radical with ascorbic acid, it is understood that ascorbic acid does not compete for OH radicals under the experimental conditions. The rate constant of the reaction of the OH radical with thymidine has been calculated by the Thymidine competition method at pH 8 in tris HCl buffer, which is very similar to the one chosen by Akhalaq et al [32] to determine the rate constant for the reaction of OH radicals with polyhydric alcohols in competition with KSCN[33,34]. Solutions containing thymidine with Cr(VI)-H₂O₂ system in presence of ascorbic acid and in the absence and also presence of varying amounts of riboflavin were made to react for 4 minutes and decrease of absorbance of Thymidine was measured. The decrease of absorbance of thymidine reflects the number of OH radicals that have reacted with thymidine. From the reported rate constant of riboflavin with OH radicals at pH 8 ($k_{\text{riboflavin} + \text{OH}} = 1.23 \times 10^{10} \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$) by Sudha et al [35], the rate constant of OH radical with Thymidine can be calculated using equation (1).

$$\frac{[\text{Absorbance of Thymidine}]_0}{[\text{Absorbance of Thymidine}]_{\text{riboflavin}}} = 1 + \frac{k_{(\text{OH} + \text{Riboflavin})} [\text{Riboflavin}]}{k_{(\text{OH} + \text{Thymidine})} [\text{Thymidine}]} \quad (1)$$

Where [Absorbance of Thymidine]₀ and [Absorbance of Thymidine]_{riboflavin} indicate the decrease in the absorbance of Thymidine in the absence and presence of riboflavin respectively, in the same interval of time. Experiments of this kind can be carried out with great accuracy. The rate constant for the reaction of OH radical with thymidine has been calculated with five different concentrations of Thymidine and average value obtained is $4.2 \times 10^9 \text{ dm}^3 \text{ mol}^{-1} \text{ s}^{-1}$. The probability of OH radicals reacting with Thymidine {p (OH + Thymidine)} is calculated using the following equation.

$$p(\text{OH} + \text{Thymidine}) = \frac{[\text{Thymidine}] k_{\text{Thymidine}}}{[\text{Thymidine}] k_{\text{Thymidine}} + [\text{Riboflavin}] k_{\text{Riboflavin}}} \quad (2)$$

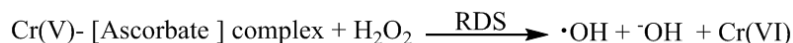
$k_{\text{Thymidine}}$ and $k_{\text{riboflavin}}$ are the rate constants of OH radical with Thymidine and riboflavin respectively. From the rate constant of OH radical with riboflavin and Thymidine (Equation (2)), the fraction of OH radicals scavenged by riboflavin (Percentage scavenged = $(1 - p) \times 100$) at different [riboflavin] were calculated (Table.3). These values were a measure of protection of Thymidine due to scavenging of OH radicals by riboflavin. It has been found that riboflavin is protecting thymidine to the extent of 78.9% at 64 μM concentration of riboflavin from OH radicals. Based on the above results and discussion the following mechanism has been proposed in scheme 1





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Scheme 1



CONCLUSIONS

The present study exhibit that under biologically relevant conditions, mixture of Cr(VI) and H₂O₂ does not oxidize Thymidine by OH radicals generated in this system but Cr(VI) Concentration as low as 1×10⁻⁸ M and H₂O₂ 5×10⁻³ M could oxidize Thymidine in presence of ascorbic acid. It has been found that riboflavin protects Thymidine to the extent of 78.9% at 64μM concentration of riboflavin from OH radicals.

ACKNOWLEDGEMENT

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Table 1 : Rates of oxidation of thymine, thymidine , and D-ribose with Cr(VI)-H₂O₂ system in presence of ascorbic acid

Substrate	10 ⁸ × initial rate (mol dm ⁻³ s ⁻¹)
Thymine	19.50
Thymidine	9.032
D-ribose	0.249

[H₂O₂] = 5.0 × 10⁻³ mol dm⁻³, [substrate] = 5.00 × 10⁻⁵ mol dm⁻³,

[Na₂CrO₄] = 1.0 × 10⁻⁴ mol dm⁻³, [Ascorbic acid] = 2.5 × 10⁻⁵ mol dm⁻³ Temp = 298 K

Table 2 : Effect of pH on rate of oxidation of thymidine with Cr(VI)-H₂O₂ system in presence of ascorbic acid in aqueous solutions.

S.No	pH	10 ⁸ × (Initial rate) (mol dm ⁻³ s ⁻¹)
1	8.0	9.032
2	6.0	5.786
3	4.5	3.488

[H₂O₂] = 5.0 × 10⁻³ mol dm⁻³, [thymidine] = 5.00 × 10⁻⁵ mol dm⁻³,

[Na₂CrO₄] = 1.0 × 10⁻⁴ mol dm⁻³, [Ascorbic acid] = 2.50 × 10⁻⁵ mol dm⁻³ Temp =

Table 3 : Effect of [Riboflavin] on the rate of oxidation of thymidine with Cr(VI)-H₂O₂ system in presence of ascorbic acid

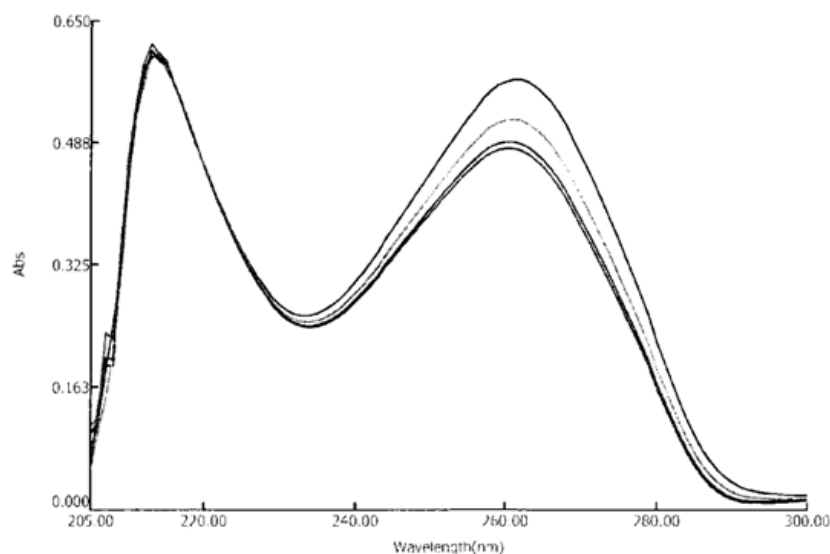
S.No	10 ⁶ × [Riboflavin] (mol dm ⁻³)	10 ⁸ × rate (mol dm ⁻³ s ⁻¹)	p	% Scavenging (1-p)×100
1	0.00	9.032	-	-
2	4.00	7.577	0.810	18.98
3	8.00	6.330	0.681	31.9
4	16.0	4.835	0.516	48.37
5	32.0	3.120	0.348	65.20
6	64.0	2.040	0.210	78.90





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 $[\text{H}_2\text{O}_2] = 5.0 \times 10^{-3} \text{ mol dm}^{-3}$, $[\text{thymidine}] = 5.00 \times 10^{-5} \text{ mol dm}^{-3}$,

 $[\text{Na}_2\text{CrO}_4] = 1.0 \times 10^{-4} \text{ mol dm}^{-3}$, $[\text{Ascorbic acid}] = 2.50 \times 10^{-5} \text{ mol dm}^{-3}$ pH= 8, Temp = 298 K


Spectra 1 Absorption spectra of Thymidine oxidation

 $[\text{H}_2\text{O}_2] = 5.0 \times 10^{-3} \text{ mol dm}^{-3}$, $[\text{Thymidine}] = 5.0 \times 10^{-5} \text{ mol dm}^{-3}$,

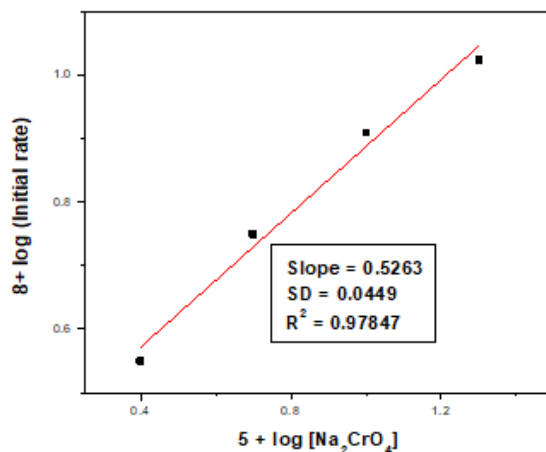
 $[\text{Na}_2\text{CrO}_4] = 1.0 \times 10^{-4} \text{ mol dm}^{-3}$, $[\text{Ascorbic acid}] = 2.5 \times 10^{-5} \text{ mol dm}^{-3}$. Temperature = 298K, pH = 8


Figure 1 Order in [Chromate] in the oxidation of thymidine with Cr(VI)- H_2O_2 system in presence of ascorbic acid





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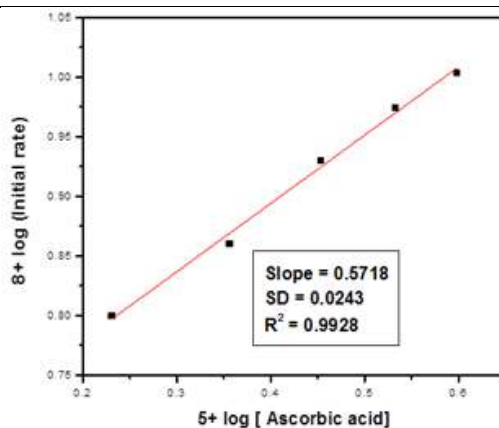


Figure 2 Order in [ascorbic acid] in the oxidation of thymidine with Cr(VI)-H₂O₂ system in presence of ascorbic acid

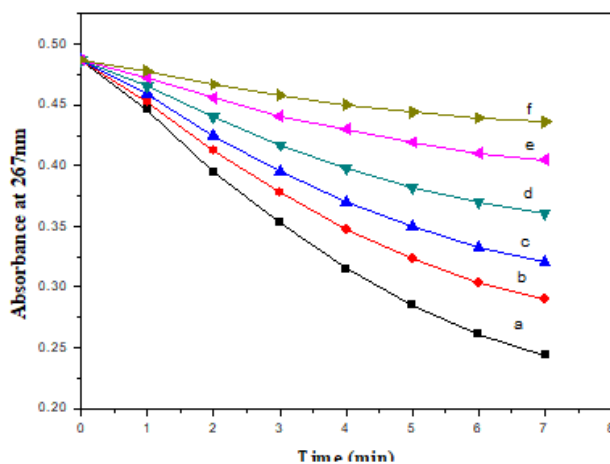


Figure 3 Effect of Riboflavin on the oxidation of thymidine with Cr(VI)-H₂O₂ system in presence of ascorbic acid

[H₂O₂] = $5.0 \times 10^{-3} \text{ mol dm}^{-3}$, [Thymidine] = $5.0 \times 10^{-5} \text{ mol dm}^{-3}$,
 [Na₂CrO₄] = $1.0 \times 10^{-4} \text{ mol dm}^{-3}$, [Ascorbic acid] = $2.5 \times 10^{-5} \text{ mol dm}^{-3}$
 [Riboflavin] = a) 0.00 b) $2.0 \times 10^{-6} \text{ mol dm}^{-3}$ c) $4.0 \times 10^{-6} \text{ mol dm}^{-3}$
 d) $8.0 \times 10^{-6} \text{ mol dm}^{-3}$ e) $16.0 \times 10^{-6} \text{ mol dm}^{-3}$ f) $32.0 \times 10^{-6} \text{ mol dm}^{-3}$
 g) $64.0 \times 10^{-6} \text{ mol dm}^{-3}$

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RESEARCH ARTICLE

Lane - Wise Modelling of Time Headway Distribution Under Mixed Traffic Conditions on Urban Divided Highways

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ABSTRACT

The knowledge of traffic flow characteristics in heterogeneous traffic situation is vital in order to enhance the efficiency in capacity estimation and analysis of such multilane highways. This research focuses on studying the traffic characteristics and time headway distribution by vehicle type on selected urban divided highways that are operating in heterogeneous traffic situation. The traffic data was gathered using video recording techniques. The analysis focused on traffic composition, speed characteristic, DPCU, LOS and lane wise time headway behavior. The traffic stream comprised 33.6% two-wheelers, 39.2% small and big cars, and 12.1% trucks, indicating highly heterogeneous traffic conditions, while the dynamic PCU values estimated using Chandra's method showed noticeable variations from IRC:106–1990 standards, particularly for larger vehicles due to their greater space occupancy and influence on traffic operations; additionally, LOS assessment based on flow, density, and volume-to-capacity ratio indicated that most study sections operated under LOS-C conditions. Distributions of time headway were done using Easy Fit 5.6 and were tested using K–S goodness of fit test at 5% significance level. The Log-Pearson Type III distribution manifested effective fitting performance among the considered statistical distributions for most leader–follower vehicle combinations in all study lanes.. It was also established that two-wheeler following combinations had comparatively smaller headways owing to increased maneuverability while truck following combinations had higher headways owing to cautious behavior



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and longer braking times. These findings clearly indicate that there is a significant impact of traffic composition and leader follower combinations on driver behavior and headway.

INTRODUCTION

Time Headway is the most crucial parameter that describes the interaction of successive vehicles along the road. Time headway is defined as the transient spacing between two successive vehicles passing a fixed reference point on a roadway section. Time headway plays a critical part when analyzing traffic flows, estimating capacities, assessing safety performance, and evaluating levels of service. Proper modeling of the distribution of time headways will aid in analyzing vehicle and driver behavior. In the context of designing traffic situations like those found in India, traffic along the roadways is noted for its heterogeneity, given the simultaneous existence of various types of vehicles with different static and dynamic parameters. With the occurrence of irregular lane changes and wide-ranging speed differences, the resultant patterns of traffic behavior deviate considerably from those seen in homogenous traffic systems. It therefore follows that conventional headway models may not be very relevant in such heterogeneous traffic systems.

Thus, there is an urgent need for developing a suitable time headway model which takes care of the traffic dynamics prevailing in urban and peri-urban highways. Sardar Patel Ring Road is one of the busiest high-speed corridors in the state of Gujarat that faces huge and mixed traffic during daytime. The road has both local and through traffic, hence making their composition and interactions dynamic. With the consideration of heterogeneity traffic as well as drivers' behaviors, it makes it necessary to study time headways on this particular route. The current study attempts to develop models for time headway distributions for the Sardar Patel Ring Road based on the field traffic data obtained under various traffic conditions. Different probability distributions are considered and assessed for their appropriateness in capturing the characteristics of observed time headways. Also, the presence of platoon and determination of acceptable gap and margin gaps followed by drivers while following vehicles is considered. Margin gap can be defined as the smallest temporal distance maintained between the vehicles, which gives a valuable insight into driver behavior and perception under mixed traffic condition.

MATERIALS AND METHODS

Time headway is a key microscopic traffic flow measure describing the interval between consecutive vehicles passing a predefined location on the roadway. The distribution analysis of time headways is an important part of the microscopic traffic flow modeling process, capacity analysis on roadways, and the assessment of traffic safety. Differences in the distribution of time headways reveal differences in driver behavior and vehicle following behavior, and intricate interactions between different vehicle classes on the highway. A research study carried out in Denpasar, Bali Province, on time headway distributions in heterogeneous traffic flow classified the traffic flow into three categories, namely; low, medium and high. From this study, it was noted that Negative Exponential, Pearson Type III and Normal were some of the appropriate distributions that could be used for different traffic flows, with Normal being the most appropriate locally (Wiryawan). The analysis was performed on a suburban arterial road in the city of Chennai through an rigorous investigation of microscopic time headway characteristics in a mixed traffic environment based on data collected by the TIRTL traffic sensor. Several leader-follower combinations including two-wheelers, auto-rickshaws, passenger cars, and heavy vehicles were considered by applying statistical distribution fitting methodologies.

Out of all the distributions considered in the study, it was found that the Weibull distribution provides better goodness-of-fit characteristics for most of the vehicle pairs. It was also found that the average headway values vary between 2.2 seconds and 3.0 seconds, with greater headways for those combinations including heavy vehicles.



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(Badhrudeen, December 2014). The impact of lane location on time headway distributions in heavy traffic situations was examined through an experiment conducted on an urban multilane highway by using videographic techniques of data acquisition on a six-lane highway. It was found that each lane had a unique statistical distribution, where Lognormal distribution best described the passing lane headway distribution, and Gamma distribution fitted best for middle lane headway distribution (Abtahi, 2011). This study involved analysis of distribution of time headways on an individual vehicle basis for different mid-block sites in Ahmedabad, Gujarat based on videographic surveys during peak hours. Various probability distributions like Dagum (4P), Burr, Pearson 5, Pearson 6, and Generalized Extreme Value distributions were tried out on the basis of Kolmogorov-Smirnov test and it was observed that different leader-follower vehicle combinations exhibited different best fit probability distributions including Burr and Dagum (4P) distributions (Malvi, 2022). A study on vehicle type-specific car following behavior has been conducted to identify the distribution of distance headway (DHW) and time headway (THW) for different leader follower pairs such as car-car, car-truck, truck-car, and truck-truck situations. The various distributions considered include Gamma, Weibull, Lognormal, Inverse Gaussian, and Log-logistic distributions. It has been found that Log-logistic distribution is better suited for car following situations, whereas Gamma distribution suits truck following situations better (Dong S. W., 2015).

Research that was done in a suburban arterial road in Korea formulated theoretical headway distribution models based on the use of large traffic data obtained using the sensors based on laser detectors. This analysis was carried out based on various traffic flow states from 5 to 29 vehicles per minute and the results showed that the best fit was achieved by the Johnson SB and Johnson SU distributions (Jang, 2011). Empirical research was carried out on a traffic link in Amman-Jordan to investigate speed and time headway behavior by analyzing video-recorded traffic data on a 25m long road link under mixed traffic conditions. Various probability distribution functions such as Normal, Lognormal, Weibull, Gamma, Logistic, and Log-logistic distributions were considered for different levels of traffic flows (0-1200 PCU/h) by means of Chi-square goodness-of-fit test. The results were found useful in estimating the capacity of the link, assessing LOS, safety, and microscopic traffic simulations (Alghazawi, 2021). The statistical investigation carried out for two lane and four lane highways in Assam examined time headways for various levels of traffic flow (0 to 2400 PCU/hr) using videographic traffic data obtained at eight sites. Several statistical distribution functions such as Log-Pearson Type III, Burr, Weibull, Lognormal, and Log-logistic distribution functions were considered for various vehicle-to-vehicle interactions and it was found that there are different best fit distribution functions for different traffic and road characteristics which have application in capacity and safety analysis and traffic simulation modeling (Das S. &, (2017)). An empirical analysis of headway distribution for specific types of vehicles performed in a freeway work zone at Greenfield, Massachusetts was done through the study of traffic data obtained from pneumatic tubes in a five-hour morning period. Various leader-follower vehicles were analyzed through the use of Gaussian Kernel and Lognormal distributions such as Car-Car, Car-Van, and Truck-Truck, using Kolmogorov-Smirnov and Chi-square statistical tests (Dong S. W., (2015)).

A case study on a two-lane National Highway stretch in eastern India analyzed the effect of traffic heterogeneity on microscopic time headways in terms of statistical distribution using observed time headway data for traffic flow varying from 310 to 1310 veh/h. Results from fitting observed headways with Log-logistic, Lognormal, Pearson Type V, and Pearson Type VI distributions showed that the Log-logistic distribution model fitted better at moderate traffic densities compared to the Pearson Type V distribution for highly skew headway data according to the Kolmogorov-Smirnov test. (Roy, 2018). In this paper, a statistical analysis was done to analyze the headway distribution characteristics of vehicles using Erlang and Pearson Type III distribution models using continuous traffic data gathered over an eight-week period for each traffic direction. It was found that Erlang distribution is suitable for describing headway distribution as it is a simple form of Pearson Type III distribution (Ben-Edigbe, 2014). The study done on six-lane divided roads in Baghdad, Iraq was based on modeling the time headway for each lane using videographic analysis that was processed using image analysis and Python software.

The statistical analysis involving the use of distributions such as Pearson Type VI, Inverse Gaussian, Dagum, Generalized Pareto, and Generalized Gamma revealed that different lanes had their own best-fit distributions with



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time headways of 0.2 seconds to 41.48 seconds (Alhamdany, 2022). Research was carried out in Chennai City on urban four-lane roads on traffic headway characteristics. It examined the Log Normal 2, Inverse Gaussian and Exponential distribution models and gave recommendations of the most appropriate distribution models for various vehicles' categories by fitting them to traffic headways (uresh, (2014)). An investigation carried out at two-lane two-way roads in Kanpur studied the vehicle headway distributions in mixed urban traffic flow situations by means of video observations during peak hours. Different distributions such as Inverse Weibull, Gamma, Erlang, Burr, Log-logistic and Lognormal were tested and compared on the basis of the K-S goodness-of-fit test. Log-logistic proved to be the best fit (Maurya A. K., December 2011). In a study carried out on a two-lane two-way highway in Guwahati, the analysis of speed and headway distributions were done under heterogeneous traffic conditions for various densities. Statistical distributions were applied in analysing the data from the research and it was found that the beta distribution model gave the best results in most instances while higher headways were kept by heavy vehicles like trucks and LCVs (Maurya A. K., 2016). A study carried out in cities of Kolkata, Mumbai, Pune, and Guwahati examined the determinants behind drivers' selection of time headways during staggered car following based on trajectories. It was noted that the mean value of time headways decreased as a result of an increase in the road widths. Also, most of the drivers had headways less than 2 seconds (Das S. M., 2019).

Study Site and Data Collection

The Sardar Patel Ring Road is an important urban arterial road corridor constructed by Ahmedabad Urban Development Authority for enhancing connectivity and alleviating congestion in the region of Ahmedabad. The total length of the corridor is about 76 km long and has a divided six-lane expressway facility. The ring road facilitates connectivity to various highways including NE-1 highway connecting Ahmedabad-Vadodara, National Highway No. 8, National Highway No. 64, and National Highway No. 147. Thus, it acts as an important bypass route for diversion of through traffic from urban road network. The field data used in this research were obtained from three selected sections along the road known as Sardar Patel Ring Road, which include Vastral Road sections (1 & 2), Hanspura Road sections (3 & 4) and Odhav Road sections (5 & 6) within the city of Ahmedabad. Selected sites were chosen without any disturbance such as an intersection, entry point, roadside encroachment, and horizontal curvature in order to maintain uninterrupted heterogeneous traffic flow. A longitudinal trap of 60 meters length was used for each study section.

It is noteworthy that each section of roads was characterized by the same width of road surface, equaling 7.5 m with paved shoulders of 1.1 m on both sides. Also, all sections were placed no closer than 500 meters from traffic signals and intersections in order to eliminate effects of interrupted traffic flows. Traffic data were obtained during the daytime when weather conditions were appropriate to conduct research in the winter season. Traffic was videotaped during four hours per day, including peak morning hours (09:00-11:00 h) and peak evening hours (04:00-06:00 h). Digital cameras were installed on the elevated platform to record traffic stream in two directions with sufficient space coverage for carriageway width. The video data obtained were used to extract microscopic traffic characteristics, including vehicle speeds, time headway, and margin gaps in heterogeneous traffic streams [Figure1].

Data Extraction and Manipulation

The captured video data was manually analyzed in laboratory conditions by viewing them on the projector screen for extracting traffic-related attributes. Traffic volumes were counted based on classification at one-minute intervals to get more detailed information on traffic volumes and traffic composition. The vehicles detected were classified into nine groups: two wheelers (2W), three wheelers (3W), standard cars (SC), big cars (BC), light commercial vehicles (LCV), trucks, buses, tractors, and non-motorized vehicles (NMV). The speed of each vehicle was calculated based on the time of entry and exit of the vehicle through the defined 60m trap length. From the gathered data, parameters related to traffic flow like traffic volume, traffic composition, speed distribution (85th percentile speed), and time headway distribution could be derived for each type of vehicle. This collected data set was further analyzed and used in modeling traffic flow using probability theory. Traffic volume and composition observed from the chosen test sections.





RESULTS AND DISCUSSION

Classified Volume survey

As The two-wheelers (2W) make up the largest proportion of the traffic stream on the entire study sections with an average composition of 33.6%, followed by standard cars (SC) with an average proportion of 27.9% of the total traffic stream. The trucks make up an average of 12.1% of the total traffic stream. This implies the significant amount of freight traffic on the study corridor. On the other hand, the big cars (BC) and the light commercial vehicle (LCV) make up an average of 11.3% and 6.6% of the traffic stream, respectively. Three wheelers (3W) make up 7.71% of the total traffic stream. The buses and tractors have been found to make up an average of less than 1% of the traffic stream, respectively. On the other hand, the non-motorized vehicles (NMV) have been found to be negligible in the traffic stream [Table1].

Category-Wise Speed Characteristics of Various Vehicles

Speed characteristics of various types of vehicles identified on the Sardar Patel Ring Road in both directions of travel. SC and BC types of vehicles were recorded to have relatively higher speed rates among all the types of vehicles identified on the road. For instance, while standard cars had a mean speed of 59.0 km/h in the up direction, big cars had a speed rate of 60.5 km/h. On the other hand, the average speeds of big cars in the down direction were 55.5 km/h and 57.5 km/h for SC and BC classes of vehicles, respectively. The two-wheeled (2W) vehicles had a comparatively moderate speed rate with mean speeds of 53.5 km/h in the up direction and 50.5 km/h in the down direction. Heavy vehicles including trucks and buses were observed to be operated at relatively low speeds compared to passengers' vehicles. For instance, the mean speeds of trucks and buses on the road were 44.5 km/h and 47.5 km/h, respectively. Such differences in speeds by type of vehicles could be attributed to traffic flow and interaction characteristics prevalent along the studied route [Table2].

Speed Distribution Characteristics

In heterogeneous traffic, there will be considerable speed disparities between various vehicle types. To understand the speed-flow relationship, the traffic data were analyzed in five minutes' intervals to obtain the changes in traffic flow rate and speed. Spread Ratio (SR), representing the nature of speed distribution, is calculated by Equation (1):

$$SR = (V_{85} - V_{50}) / (V_{50} - V_{15}) \quad (1)$$

where V_{85} , V_{50} , and V_{15} represent the 85th percentile, median, and 15th percentile speeds, respectively [Table 3].

Estimation of Dynamic Passenger Car Unit (PCU)

Dynamic estimation of PCU is one of the key factors in estimating roadway capacity and LOS. Heterogeneity in traffic can create significant differences among vehicles concerning their physical dimensions, maneuverability, acceleration-deceleration properties, and speeds. Thus, a considerable difference in traffic flow characteristics occurs because of these variations. In India, for instance, where such heterogeneity in traffic is quite common, the use of a constant PCU value can be insufficient in representing the actual traffic scenario. The Indian Road Congress suggested static PCU values for various vehicles in IRC:106-1990 based on limited empirical observations carried out under certain roadway circumstances. But due to the dynamism of the heterogeneous traffic flow, the PCU values were found to vary contingent upon the composition of traffic, geometry of road, traffic volume, and traffic speed. In order to rectify this problem, Chandra S. and Kumar U. (2003) suggested a dynamic PCU value estimation method that is represented by Eq. (2).

$$DPCU_i = V_c / V_i A_c / A_i \quad (2)$$

Where, $DPCU_i$ represents the dynamic Passenger Car Unit value for vehicle class i ; V_c/V_i corresponds to the speed ratio between the standard passenger car and the subject vehicle type; and A_c/A_i indicates the ratio of the effective projected rectangular area of the passenger car to that of vehicle type i . The projected rectangular area characterizes





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the roadway space occupancy requirement of a vehicle within the traffic stream and is estimated as the product of the effective vehicle length and width under prevailing traffic operating conditions. [Table 4].

Fundamental Relationship among Speed, Flow, and Density

The relationship between speed, flow, and density forms the core idea of the traffic stream behaviour in traffic flow theories on macro scale and is the key element in analyzing traffic flow under various traffic conditions. The linear relationship between speed and density first described by Bruce Greenshields contributed to the development of or the development of several theoretical and empirical models for traffic flow analysis. These relations have been widely used to analyze the capacity of the roadways and traffic performance analysis under varied traffic conditions. In the current study, the relationships between speed, flow, and density have been examined using the real traffic data available from the selected sections of Sardar Patel Ring Road. A total of 79 traffic data sets comprising stream speed, flow, and density parameters have been obtained at the selected sections of Sardar Patel Ring Road during peak hour as well as non-peak hour traffic to analyze the effect of congestion on traffic operational characteristics. The findings reveal that the vehicle speed reduces as density increases, whereas traffic flow rises with increasing density until it reaches a critical value followed by decline in flow [Figure2].

Capacity and Level of Service

The capacity of a highway can be described as the number of vehicles that can be reasonably expected to pass through a point on the road in unit time, considering the prevailing road traffic and control conditions. Capacity plays an integral role in a traffic engineer when designing the road sections. The criteria for estimating the capacity of the roads as outlined by different organizations, such as TRB(HCM), Induce (2017), Indian road congress, is indirect empirical approaches. The Level of Service (LOS) is the qualitative criterion used to analyze the quality of service perceived at the different levels of flow. Table 5 illustrates the LOS of lanes and locations using the indoHCM2017 standard that falls within the LOSC category [Table 5].

Statistical Characteristics of Time Headway Distribution

Statistical analysis was conducted for the combined sections of roads consisting of Sections 1 & 2, Sections 3 & 4, and Sections 5 & 6. Microscopic headways distributional changes with regard to their mean, median, minimum, maximum, and standard deviation were analyzed to study the time-dependent characteristics of heterogeneous traffic streams. Several theoretical probability distributions were used to statistically analyze the vehicle headway patterns, which include the following: Lognormal, Weibull, Burr, Log-Pearson Type III, Pearson Type VI, and Generalized Gamma distributions. To check for the suitability of a particular probability model, Kolmogorov-Smirnov (K-S) test of goodness of fit was used to obtain a particular probability distribution that best characterizes the empirical headway pattern. The mathematical expressions related to probability distributions selected are shown below, which form the basis of probabilistic models to be used for modeling the vehicular headway phenomenon. Finally, comparative assessment of lane-wise vehicular headway distributions was undertaken for all combined road sections. [Table 6].

$$f(x) = \frac{\exp\left(-0.5\left(\frac{\ln(x-\tau)-\mu}{\sigma}\right)^2\right)}{(x-\tau)\sigma\sqrt{2\pi}} \quad (3)$$

$$f(x) = \frac{\lambda}{\alpha} \left(\frac{x-\mu}{\alpha}\right)^{\lambda-1} \exp\left(-\left(\frac{x-\mu}{\alpha}\right)^{\lambda}\right) \quad (4)$$

$$f(x) = \frac{\alpha k \left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}}{\beta \left(1 + \left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{k+1}} \quad (5)$$

$$f(x) = \frac{1}{x|\beta|\Gamma(\alpha)} \left(\frac{\ln(x)-\gamma}{\beta}\right)^{\alpha-1} \exp\left(-\left(\frac{\ln(x)-\gamma}{\beta}\right)\right) \quad (6)$$

$$f(x) = \frac{\left(\frac{\alpha}{\beta}\right)^{\alpha_1-1}}{\beta B(\alpha_1, \alpha_2) \left(1 + \frac{\gamma}{\beta}\right)^{\alpha_1+\alpha_2}} \quad (7)$$





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$$f(x) = \frac{k(x-y)^{k\alpha-1}}{\beta K \alpha \Gamma(\alpha)} \exp\left(-\left(\frac{x-y}{\beta}\right)^k\right) \quad (8)$$

Where $f(x)$ is the probability density function that defines the behavior of the vehicles' time headway statistically; k and α represent the shape parameters of the distribution, which determine the skewness of the distribution; β is the scale parameter that affects the spread of the distribution; while τ represents the shift parameter in seconds. Γ symbolizes the Gamma function used for the probability formula, while λ represents the location parameter, which determines the position of the distribution. Finally, μ represents the mean of the observed headway values of vehicles.

Microscopic Time Headway Distribution for Different Traffic Lanes

A robust statistical framework has been adopted in selecting the most suitable probability distribution model for the vehicular time headway analysis. In this regard, the upper 5% of the extreme headway values were eliminated from consideration in order to minimize any anomalous observations while preserving the underlying traffic characteristic that were captured in the 95% of the total data. Following this step, the Kolmogorov-Smirnov (K-S) test for goodness-of-fit test was carried out using a 5% significance level in testing the suitability of several probability distribution models. In addition to this, all data sets with more than 30 observations have been considered in order to ensure consistency in the statistical analysis process. This is illustrated below by the fitted headway distribution of Lane 1 in Section 1. [Figure3]. The goodness-of-fit test was conducted using six probability models, which included Weibull, Pearson Type VI, Burr, Lognormal, Generalized Gamma, and Log-Pearson Type III distributions for the headway time data of all the four lanes. Each theoretical model's fitness was calculated using the Kolmogorov-Smirnov (K-S) goodness-of-fit test statistics and the p-values. Out of all the theoretical probability distribution models tested, it was found that the Log-Pearson Type III distribution showed the best results with relatively higher p-values and lower K-S test statistics. Regarding Lane 1, the best-fitting theoretical distribution was observed for the Log-Pearson Type III distribution, with the highest p-value of 0.68 and lowest K-S test statistics of 0.02. Likewise, in Lane 2, the best fitting for the distribution was achieved from the Log-Pearson Type III distribution,

where the highest p-value was calculated as 0.89 with the lowest K-S statistics of 0.01. For Lane 3, overall fitting was slightly poor in comparison with other lanes; however, the best results were obtained from the Log-Pearson Type III distribution, with the p-value of 0.35 and K-S statistics of 0.02. As opposed to this, the fitting properties were found to be comparatively weak in the case of the Weibull and Lognormal probability distributions owing to low p-values and high K-S statistics. In contrast, the Pearson Type VI and Burr distributions have shown fairly good agreements with the observed data, while the Generalized Gamma distribution model offered good fitting performance in some cases but was not able to match the fitting efficiency of the Log-Pearson Type III distribution model. Based on the findings of statistical analysis, it can be stated that there are positive skewness characteristics in the observed data and that the Log-Pearson Type III distribution fits best with the observed data in all the lanes. [Table 7]. From the statistical test results illustrated in Table 7, it is apparent that the Log-Pearson

Type III distribution showed superiority in terms of goodness-of-fit due to comparatively high p-values and low K-S statistics. Estimation of the shape (α) and scale (β) parameters showed variations for different sections of the road, which were attributed to varying traffic conditions and vehicle interactions. High shape parameters denoted sharpness of the distribution peak, while high scale parameters suggested wider distributions. Moreover, through further analysis of individual lanes in each section, variations in appropriate probability distributions were noted. While the Burr, Pearson Type VI, Generalized Gamma, and Weibull probability distributions proved to be superior in fitting particular lanes, the Log-Pearson Type III probability distribution was found to be more suitable for most sections under heterogeneous traffic conditions.



**Amit A Amin and L.B.Zala****Statistical Modelling of Headway Distributions for Different Vehicle Pair Categories**

The study of time headway distributions of vehicles according to their types is a crucial aspect that helps understand the nature of interactions between different combinations of leaders and followers in heterogeneous traffic situations. In particular, the study illustrates how the driving behaviors of vehicles vary by type and shows the influence of leader vehicle characteristics on follower vehicle response behaviour. Moreover, the research shows the impact of lane positioning on the distribution of time headways. The headways were categorized according to the different combinations between the leaders and the followers, such as 2W-2W, 2W-SC, 2W-BC, 2W-Truck, SC-2W, SC-SC, SC-BC, SC-Truck, BC-2W, BC-SC, BC-BC, BC-Truck, Truck-2W, Truck-SC, Truck-BC, and Truck-Truck, where 2W, SC, BC, and Truck are two-wheelers, small cars, big cars, and trucks. From the findings obtained, it is evident that small combinations especially those composed of two-wheelers tend to have relatively smaller and more dispersed headways as compared to large combinations due to their manoeuvrability and flexibility in lateral movements. On the other hand, large combinations like Truck-Truck and Truck-BC tend to have relatively larger headways due to cautious driving and long reaction times. Moreover, it was noted that there was variation in the distribution of headways by lane [Table 8].

CONCLUSION

- The traffic flow characteristics and time headways were analyzed in this study in relation to heterogeneous traffic on selected four-lane divided urban highways. The traffic composition analysis revealed that there is great variability in traffic flow, where two wheelers constituted 33.6%, small and big cars made up 39.2%, and trucks made up 12.1%. This reveals the presence of different vehicles in the traffic composition and hence the complexity in traffic flow.
- The speed distribution study conducted for the chosen sections found that the spread ratio ranged between 0.89 and 1.57, suggesting considerable differences in speed behavior across various vehicle types and sections of the roadways. The calculated dynamic PCU values using Chandra's formula showed clear differences compared to the recommended values in IndoHCM (2017) and IRC:106–1990 standards, especially for big cars (1.52), buses (5.15), and trucks (4.10). These increased PCU values for heavy-duty vehicles can be explained by the greater size, reduced maneuverability, and influence on roadway capacity of such vehicles.
- The LOS assessment was conducted based on field observation data at an interval of 5 minutes with regards to flow, volume-to-capacity ratio, and density. The LOS values that were computed were found to be in line with the values recommended by IndoHCM (2017), and the majority of the selected links operated within the LOS-C range.
- The fitting analysis of time headway distributions was carried out by using the EasyFit 5.6 software employing Kolmogorov-Smirnov (K-S) test for a goodness-of-fit at a 5% level of significance. It is observed that among the various distributions that have been studied, the Log-Pearson Type III distribution proved to be the best for most combinations of vehicles for all lanes and sections. Some other distributions, like Pearson Type VI, Weibull, Burr, Log-Normal, and Generalized Gamma distributions, also showed their adequacy for some lane-wise cases. The minimum and maximum values of headways were observed as 0.12 sec and 16.84 sec, respectively.
- It was found through the analysis of traffic composition in the lanes that the middle lanes (Lane 2 and Lane 3) had a higher number of cars and trucks, while the outer lanes (Lane 1 and Lane 4) had more two wheelers and cars but fewer trucks. This difference in vehicle composition has played a crucial role in influencing the headways.
- Analysis of headway by vehicle type revealed that interacting pairs consisting of truck exhibited comparatively larger headways as a result of careful driving behavior and higher safety considerations. On the other hand, 2W-2W interactions had the lowest headways, mainly due to the increased maneuverability and lack of lane discipline associated with two-wheelers. Drivers were also found to keep larger headways behind trucks because of their large sizes and relatively poor braking capacity.





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- The results also show that the traffic flow in the middle lanes depends significantly on the interaction between vehicles coming from adjacent lanes, which shows the significance of lane-changing behavior and interactions between lanes in heterogeneous traffic streams. Thus, future research must concentrate on the study of lane-changing behaviors, drivers' behavior, and variation in speed in different lanes.

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Table 1 Percentage distribution of vehicle classes at study locationn

Sections	Location	2W	3W	SC	BC	LCV	Truck	Others
Section-1 (vastral)	Morning up	45.00	7.00	25.00	9.00	5.00	9.00	0.7
	Morning down	39.00	8.00	27.00	8.00	5.00	12.00	0.9
Section-2 (vastral)	Evening up	30.00	8.00	27.00	11.00	10.00	14.00	0.9
	Evening down	28.00	8.00	27.00	9.00	11.00	16.00	0.7
Secion-3 (Odhav)	Morning up	47.00	10.00	25.00	6.00	3.00	8.00	0.4
	Morning down	35.00	8.00	26.00	17.00	6.00	9.00	0.5
Section-4 (Odhav)	Evening up	27.00	8.00	35.00	11.00	7.00	11.00	0.8
	Evening down	27.00	8.00	35.00	11.00	9.00	11.00	0.6
Section-5 (Hanspura)	Morning up	34.00	8.00	26.00	12.00	5.00	15.00	0.9
	Morning down	40.00	6.00	25.00	11.00	4.00	12.00	1.2
Section-6 (Hanspura)	Evening up	29.00	7.00	26.00	16.00	7.00	14.00	0.7
	Evening down	23.00	8.00	30.00	16.00	8.00	15.00	0.5
Average Composition (%)		33.67	7.83	27.83	11.42	6.67	12.17	0.73

Table 2 Characteristics of Speeds for Different Classes of Vehicles

Vehicle Type	Speed of Up direction of All Sections (kmph)				Speed of Downward direction of All Sections(kmph)			
	Min Speed	Max Speed	Mean Speed	Std.Dev	Min Speed	Max Speed	Mean Speed	Std.Dev
2W	30.00	88.00	54.00	10.40	27.00	83.00	51.00	9.90
3W	27.00	66.00	46.00	7.40	27.00	64.00	52.00	7.10
SC	34.00	93.00	59.00	12.00	28.00	92.00	56.00	11.20
BC	31.00	95.00	61.00	14.00	27.00	96.00	58.00	11.70
LCV	25.00	81.00	50.00	11.00	23.00	73.00	47.00	9.70
Truck	36.00	85.00	50.00	8.00	28.00	73.00	45.00	8.00
Bus	24.00	67.00	51.00	11.00	28.00	66.00	48.00	8.90





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Table 3 Distribution of percentile speeds under heterogeneous traffic conditions

Vehicle Type	Average Up direction all sections (kmph)					Average Down direction all sections (kmph)				
	98th	85th	50th	15th	SR	98th	85th	50th	15th	SR
2W	82.00	66.00	53.00	43.00	1.19	77.00	62.00	50.00	41.00	1.26
3W	63.00	55.00	46.00	37.50	1.00	61.00	52.00	41.00	37.00	0.95
SC	88.00	74.00	59.00	45.00	1.13	85.00	67.00	55.00	47.00	1.70
BC	90.00	76.00	60.00	44.50	1.12	88.00	69.50	58.00	44.00	0.89
LCV	77.00	63.00	50.00	40.00	1.24	69.00	58.00	46.00	37.00	1.27
Truck	77.00	59.00	50.00	42.00	1.28	66.50	53.00	43.50	36.00	1.19
Bus	69.00	64.00	51.00	37.00	0.90	64.50	58.50	46.00	38.00	1.57

Table 4 Assessment of observed PCU characteristics with standard codal values

Vehicle type	Projected Area(m ²)	Acceleration(m/s ²)		Deceleration(m/s ²)		Suggested PCU from IRC 106-1990	Suggested PCU from Indo HCM 2017	Estimated PCU from Chandra's Method
		Maximum	Desired	Maximum	Desired			
2W	1.20	2.20	1.60	1.50	0.50	0.75	0.22	0.23
3W	1.20	1.10	0.90	1.10	0.80	1.20	0.90	0.97
SC	2.40	2.70	1.30	1.80	1.20	1.00	1.00	1.00
BC	2.80	2.70	1.30	1.80	1.20	1.00	1.00	1.52
Buses	7.80	2.50	1.50	1.70	1.20	2.20	4.60	5.15
Trucks	5.00	2.50	1.50	1.70	1.20	3.70	3.90	4.10
LCV	2.70	2.70	1.30	1.80	1.20	1.40	2.38	2.78

Table 5 Evaluation of operational performance using V/C ratio and LOS criteria

Locations	Road Location	Lane (PCUs/hr)	Lanae capacity (s/hr) Indo HCM2017	V/C Ratio	LOS
1	Vastral Morning	984	1350	0.73	Los C
	Vastral Evening	823	1350	0.61	Los C
2	Hanspura Morning	880	1350	0.65	Los C
	Hanspura Evening	848	1350	0.62	Los C
3	Odhav Morning	810	1350	0.6	Los C
	Odhav Evening	842	1350	0.62	Los C

Table 6 Descriptive statistical distribution of time headway at selected study locations

Vastral Location (sections 1 and 2)						
Lane	Sample	Min (sec)	Max (sec)	Mean	Median	Sta Dev
Lane-1	3376	0.20	16.25	3.11	2.36	2.52
Lane-2	3402	0.31	15.85	2.99	2.09	2.55
Lane 3	2398	0.33	16.44	3.24	2.25	2.84
Lane 4	3729	0.20	16.24	2.63	1.89	2.40
Hanspura Location (sections 3 and 4)						
Lane-1	3946	0.12	14.77	3.2	2.36	2.7
Lane-2	3012	0.19	15.79	4.05	2.95	3.3





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Lane 3	3258	0.30	15.75	3.84	2.81	3.17
Lane 4	4905	0.22	15.65	2.89	2.15	2.4
Odhav Location (sections 5 and 6)						
Lane-1	2430	0.2	16.14	2.9	2.13	2.46
Lane-2	2099	0.24	15.55	3.24	2.34	2.68
Lane 3	1625	0.28	16.26	3.06	2.07	2.80
Lane 4	2417	0.17	15.88	2.74	1.90	2.56

Table 7 Goodness-of-fit evaluation and best-fit model identification for headway data

Location	Type of Distribution	Parameters	P - Value	K-S value	Best Fit
Lane 1	Weibull	$\alpha=1.4906 \beta=3.8688$	0.14	0.03	Log-Pearson 3
	Pearson 6	$\alpha_1=1.8528 \alpha_2=2.8179E+8 \beta=5.3699E+8$	0.17	0.03	
	Burr	$k=1007.9 \alpha=1.4579 \beta=448.77$	0.47	0.02	
	Log Normal	$\sigma=0.8508 \mu=0.968$	8.52E-06	0.06	
	Gen. Gamma	$k=0.96597 \alpha=1.9783 \beta=1.7244$	0.13	0.03	
	Log-Pearson 3	$\alpha=7.0802 \beta=-0.31985 \gamma=3.2326$	0.68	0.02	
Lane 2	Weibull	$\alpha=1.3401 \beta=4.0495$	0.15	0.03	Log-Pearson 3
	Pearson 6	$\alpha_1=1.5226 \alpha_2=2.6595E+6 \beta=6.6297E+6$	0.77	0.02	
	Burr	$k=415.26 \alpha=1.286 \beta=445.6$	0.35	0.02	
	Log Normal	$\sigma=0.94439 \mu=0.97045$	5.41E-04	0.05	
	Gen. Gamma	$k=0.98217 \alpha=1.5698 \beta=2.3841$	0.76	0.02	
	Log-Pearson 3	$\alpha=9.1806 \beta=-0.31179 \gamma=3.8329$	0.89	0.01	
Lane 3	Weibull	$\alpha=1.4303 \beta=4.0656$	2.34E-06	0.06	Log-Pearson 3
	Pearson 6	$\alpha_1=2.0244 \alpha_2=6.8441 \beta=11.149$	0.06	0.03	
	Burr	$k=2.9366 \alpha=1.5351 \beta=7.0297$	0.02	0.03	
	Log Normal	$\sigma=0.87461 \mu=1.0012$	0.04	0.03	
	Gen. Gamma	$k=1.0257 \alpha=1.4857 \beta=2.6612$	1.21E-03	0.05	
	Log-Pearson 3	$\alpha=53.745 \beta=-0.11934 \gamma=7.4149$	0.35	0.02	
Lane 4	Weibull	$\alpha=1.3775 \beta=3.2559$	0.01	0.03	Log-Pearson 3
	Pearson 6	$\alpha_1=1.7319 \alpha_2=11.364 \beta=18.457$	0.6	0.02	
	Burr	$k=3.8885 \alpha=1.4573 \beta=7.3384$	0.52	0.02	
	Log Normal	$\sigma=0.9175 \mu=0.76319$	7.11E-05	0.05	
	Gen. Gamma	$k=1.0291 \alpha=1.423 \beta=2.2259$	0.03	0.03	
	Log-Pearson 3	$\alpha=16.667 \beta=-0.22478 \gamma=4.5097$	0.77	0.01	

Table 8 Vehicle-specific time headway distribution by study section

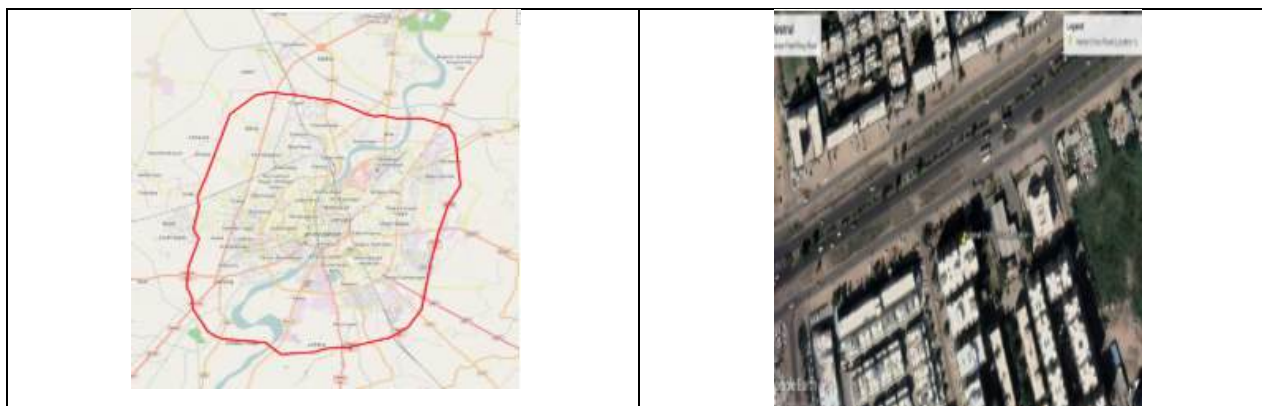
Section 1								
Leading Vehicle	Following Vehicle	Best - fit	P - Value	K-S Value	Mean (Sec)	Median (sec)	Standard deviation (sec)	Sample Size
Lane 1								
2w	2w	Log-Pearson 3	0.433	0.02	2.301	1.6	2.171	1808





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2w	Sc	Log-Pearson 3	0.943	0.051	2.353	1.71	2.164	100
2w	Bc	Log-Pearson 3	0.927	0.054	2.234	1.7	1.951	97
2w	Truck	Burr	0.641	0.091	3.601	2.3	3.032	63
Sc	2w	Log-Pearson 3	0.4	0.014	2.316	1.64	2.157	100
Sc	Sc	Burr	0.988	0.043	1.834	1.20	1.62	100
Sc	Bc	Log-Pearson 3	0.4	0.014	2.358	1.64	2.047	33
Sc	Truc	Log-Pearson 3	0.971	0.178	2.513	1.57	2.264	14
Bc	2w	Pearson 6	0.757	0.068	2.493	1.66	2.493	94
Bc	Sc	Pearson 6	0.77	0.099	1.889	1.54	1.198	42
Bc	Bc	Burr	0.997	0.105	2.298	1.38	2.068	12
Bc	Truck	Log-Pearson 3	0.971	0.178	3.047	2.96	1.055	6
Truck	2w	Log-normal	0.938	0.061	2.887	2.27	2.11	72
Truck	Sc	Log-Pearson 3	0.851	0.153	3.036	2.20	2.175	14
Truck	Bc	Log-Pearson 3	0.914	0.224	1.996	1.64	0.877	15
Truck	Truck	Log-Pearson 3	0.716	0.244	2.574	1.82	1.517	17



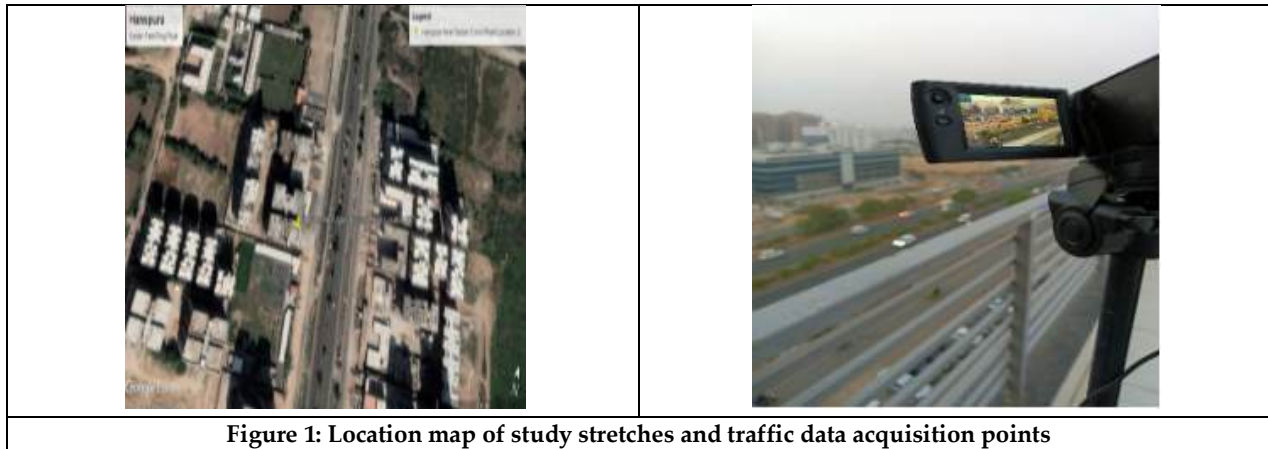


Figure 1: Location map of study stretches and traffic data acquisition points

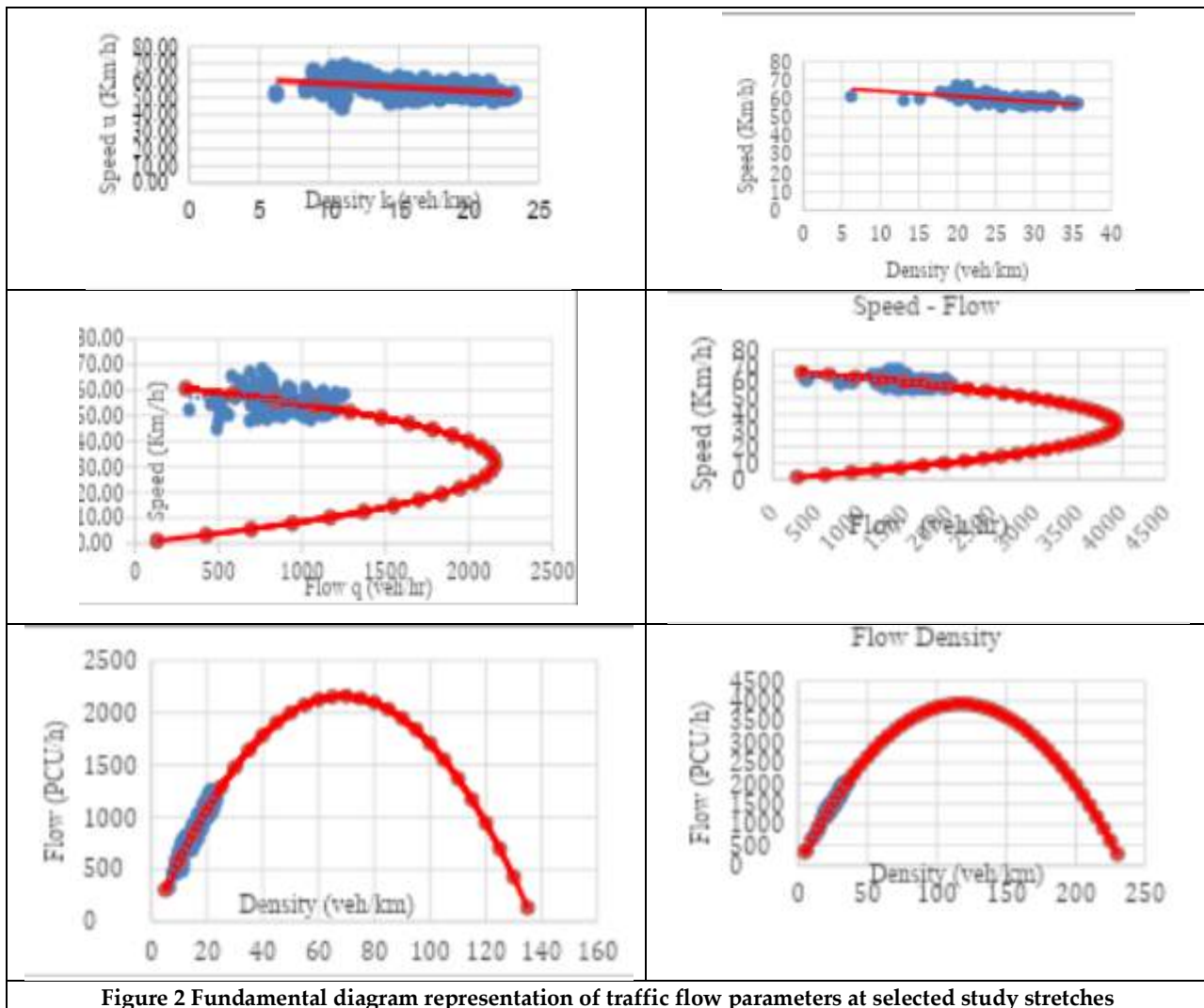


Figure 2 Fundamental diagram representation of traffic flow parameters at selected study stretches





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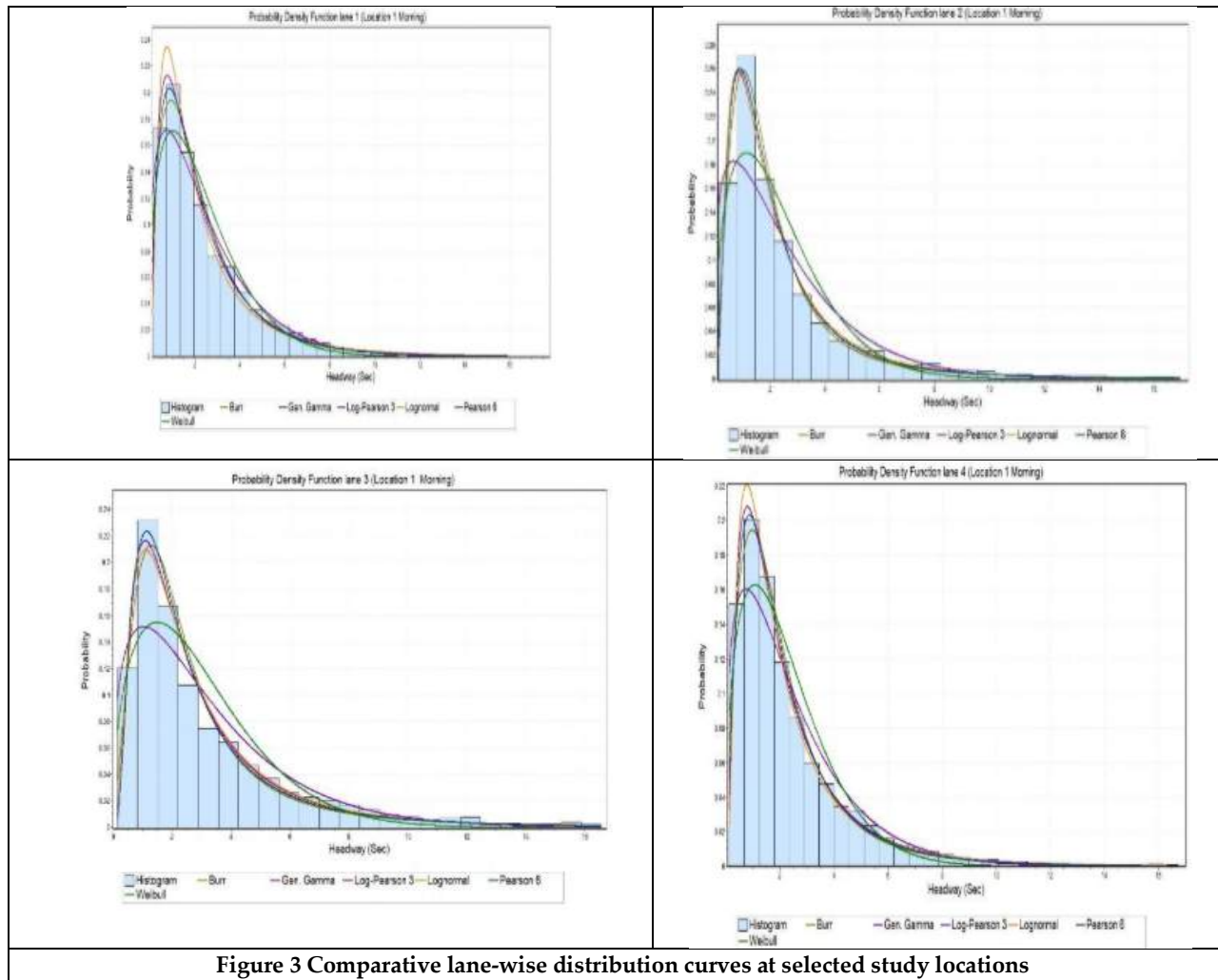


Figure 3 Comparative lane-wise distribution curves at selected study locations

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RESEARCH ARTICLE

Evaluation of Antipyretic Activity of *Annabedhi uppu* using Brewer's Yeast - Induced Pyrexia in Albino Rats

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ABSTRACT

The Siddha system is one of the traditional Indian systems of medicine that originated in ancient Tamil Nadu, India. Fever is a common physiological response to infections and inflammation, regulated by the hypothalamus through the production of prostaglandins. In the Siddha system of medicine, many herbal and herbomineral preparations are indicated and used for fever. *Annabedhi Uppu* was one of the herbo-mineral preparation mentioned in the Siddha textbook "*Nam Naattu Vaiththiyam*". *Annabedhi Uppu* was indicated for fever, hepatic injury, diarrhoea and anaemia. Ingredients of *Annabedhi Uppu* were *Annabedhi* (Iron sulphate), *Lingam* (Red sulphide of mercury), *Gandhagam* (Sulphur) and Lemon juice. *Annabedhi*, *lingam* and *gandhagam* had antipyretic effects and were widely used for pyrexia. But doesn't have valid scientific evidence. This study aimed to assess the efficacy of *Annabedhi Uppu* against fever in an animal model, focusing on their impact on body temperature. 15 Male and 15 Female Wistar rats were randomly assigned for the study. Animals are divided into 5 groups and each group has 6 animals. Fever was induced in all groups of animals except the control group by Brewer's yeast injection and body temperature was monitored using rectal thermometers at 19 hours after the yeast injection. The control group received only Water, the negative control group received brewer's yeast only, the standard group received paracetamol, and the treatment groups received *Annabedhi Uppu* in 7mg/kg and 14mg/kg. The temperature was measured at 1st, 2nd, and 3rd hr after drug administration. The results showed a significant reduction in body temperature in the standard group and the treatment groups compared to the negative control group. Statistical analysis showed that $P < 0.05$, was statistically significant and the null hypothesis was rejected. This study confirms that *Annabedhi Uppu* is a potent drug for treating fever.

Keywords: Antipyretic, animal model, fever, paracetamol, *Annabedhi Uppu*





INTRODUCTION

Pyrexia, another term for fever, can be treated using various approaches in traditional and complementary medicine systems. Pyrexia is an increase in body temperature above the normal physiological range, which may result from physiological stress such as during ovulation, increased thyroid secretion, excessive exercise, any lesions to the central nervous system, due to leukaemia, and mostly in microbial infections [1]. Pyrexia or fever is caused as a secondary impact of disease, malignancy, or other diseased states. The body's natural defence is to create an environment where infectious agents or damaged tissue cannot survive. Normally the infected or damaged tissue initiates the enhanced formation of pro-inflammatory mediators (Cytokines like interleukin 1β , α , β , and TNF- α), which increase the synthesis of prostaglandin E2 (PG E2) near the peptic hypothalamus area and thereby triggering the hypothalamus to elevate the body temperature. As the temperature regulatory system is governed by a nervous feedback mechanism when body temperature becomes very high, it dilates the blood vessels and increases sweating to reduce the temperature. Still, when the body temperature becomes very low hypothalamus protects the internal temperature by vasoconstriction. High fever often increases disease progression by increasing tissue catabolism, dehydration, and existing complaints, as found in HIV [2].

Suram disease is one of the 4448 diseases mentioned in the Siddha textbook. Siddha medicine, an ancient system of medicine from South India, has its methods for managing fever. According to Siddha philosophy, the main cause of Suram is said to be the formation of Ama (indigested metabolic products) in the intestine. Suram is classified into 3 types. There are Vatha suram, Pithasuram, and Kabha suram. 64 types of suram are classified under this classification [4]. AnnabedhiUppu(AU) is commonly used in the Siddha system of medicine. It is mentioned in the Siddha textbook "Nam Naattu Vaiththiyam" and authored by Judge Balarammayya. Annabedhiuppu is the combination of Annabedhi, Lingam, and Gandhagam. Annabedhiuppu was indicated for Perunkazhichchal, Kalleeralliranam, Piththasuram and Vaathasuram[5]. Ingredients of Annabedhi uppu are annabedhi, lingam, gandhagam, and lemon juice. Annabedhi is classified as one of the Uparasam (hydro chemicals), while lingam belongs to the Panchasootham (mercury and its components), and Gandhagam is categorised under the Paadaanam (Arsenic compounds) [6]. Lingam and Gandhagam are highly effective for fever. Lingam and Gandhagam contained medicines that have been prescribed for a long time against fever. As per the Siddha literature, Lingam and Gandhagam are indicated for fever [6]. Lingam and Gandhagam contained medicines that have been used for a long time against fever. Annabedhiuppu was indicated for fever and the ingredients of AnnabedhiUppu are highly effective for fever.

MATERIALS AND METHODS

Raw drug Collection:

Ingredients of AnnabedhiUppu were procured from a local raw drug shop in Chennai, Tamil Nadu. The Citrus limon fruit was bought from a vegetable market. The raw drugs were detoxified as per the methods mentioned in the authentic Siddha textbook [5]. Fresh lemon juice was used for preparation.

Preparation of AnnabedhiUppu:

AnnabedhiUppu is mentioned in the Classical Siddha textbook "Nam Naattu Vaiththiyam" and authored by Judge Balarammayya[5]. The formulation AnnabedhiUppu was prepared in the Gunapadam Laboratory of the National Institute of Siddha as per the classical Siddha literature. The purified annabedhi is ground with lemon juice to make villai. The villai is dried under sunlight, then placed in a mud pot and closed with a suitable mud pot and the junction of both mud pots is sealed with three layers of clay-smeared cloth, then subjected to the pudam process with 25 varatties and allowed to cool itself. The same procedure is repeated 5 times. The 6th time, the one-eighth weight of the purified lingam and one-sixteenth weight of the purified gandhagam are added to the weight of the paspam and again subjected to the pudam process with 25 varatties and allowed to cool.



**Dose:**

1-3 Nel edai(65 mg -195 mg)

Vehicle:

Honey

Indication:*kalleeralinranam*(liver cirrhosis), *piththasuram*, *vaathasuram*, *pasimantham*, *seethabedhi*(dysentery).**Reference:***Nam Naattu Vaiththiyam* (pages no 128-129)**Pharmacological study of Annabedhi Uppu in animal model**

The animal study protocol was approved by the Institutional Animal Ethical Committee of the National Institute of Siddha, Chennai, and IAEC Protocol number NIS/IAEC-25/R05/06112023/E08. The studies were conducted in the animal house of the National Institute of Siddha, Chennai, Tamil Nadu, India.

Experiment with animal husbandry:

Male and Female Albino Wistar rats (6 - 8 weeks and weight: 140–160g) were purchased from the Laboratory Animal Medicine – Centre for Animal Health Studies, Tamil Nadu Veterinary and Animal Sciences University, Chennai, and maintained in the animal house of National Institute Siddha, Chennai. Animals were housed individually in polypropylene cages in a ventilated room (air cycles: 12-15/min; 70:30 exchange ratio) under an ambient room temperature of 22±3°C and 40–70% relative humidity, with a 12-h light/dark artificial photoperiod. The animals received RO water ad libitum and fed with Rodent pellet ad libitum

Grouping

Thirty Animals were procured from Tamil Nadu Veterinary and Animal Sciences University, Chennai. The body weights of the animals were recorded and they were randomly divided into 5 groups of 6 animals each group. Group I-It is called the control group. This group was given with 1ml of saline. Group II- It is called a negative control group. This group was treated with 10 ml/kg brewer's yeast alone. Group III –It is called a standard reference group. This group was treated with brewer's yeast and with 150mg/kg of Paracetamol. Group 4- It is called a test group. This group was treated with brewer's yeast and AU (7mg/kg). Group 5- It is also a test group. This group was treated with brewer's yeast and AU (14mg/kg).

Induction of Pyrexia

Before the study Animal weight and rectal temperature were recorded. Fever was induced in all groups of animals except the normal control group by injecting 10ml/Kg (subcutaneous) of 20% suspension of brewer's yeast in normal saline below the nape of the neck. The temperature was measured after 19 hours using a rectal thermometer.

Administration of drugs

After 19 hours of the induction of pyrexia- The paracetamol drug of appropriate dose (150mg/kg) was dissolved in saline solution and was given orally to group III. The test drug of *AnnabedhiUppu* was dissolved in honey and given orally to Group IV and Group V animals.

Temperature Measurements

Basal rectal temperature was measured before the injection of yeast by a digital thermometer. The digital thermometer was inserted at a depth of 2 cm into the rectum and the temperature of the animals was recorded. Standard drugs and trial drugs were given orally, 19h after yeast injection the rectal temperature of animals was noted at regular intervals following the respective treatment. The temperature was measured at 1st, 2nd, and 3rd hr after drug administration.



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Statistical analysis

Statistical analysis results are expressed as mean $\pm$ SEM. Statistical analysis of data was performed using ANOVA to study differences among the means.

DISCUSSION

Before starting the study, the animals' weights were recorded. Animals were divided into 5 groups and each group had 6 animals. Brewer's yeast was induced in all groups of animals except the normal control group. The rectal temperature of animals was recorded. The rectal temperatures of all groups of animals are presented in Table 3. The analysis of rectal temperatures in animal groups showed that fever was successfully induced. 19 hours after the injection of Brewer's yeast, animals were treated with standard drug and trial drugs. The negative control group received Brewer's yeast only. The standard control group received paracetamol. Group IV and V received AU in different doses. Animals' rectal temperatures were recorded in 1st hr, 2nd hr, 3rd hr, and 4th hr interval.

In the analysis of rectal temperatures, a significant change was seen between the negative control, standard, and trial groups. ($P < 0.05$). Every one-hour interval of rectal temperatures reversed to the normal level. This study described that AU is effective against fever. Furthermore, clinical trials conducted on AU will help evaluate its efficacy in humans in the future. Among the key ingredients, Lingam and Gandhagam are the most popular against fever. Anti-pyretic activity was conducted on Padiga linga chenduram by a yeast-induced method. The drug Padiga linga chenduram showed potent antipyretic activity [8]. Linga chenduram had strong antibacterial activity against *E. coli*, *S. aureus*, and *K. pneumoniae* and moderate anti-bacterial activity against *S. typhi* and *V. cholerae* at 3 and 4 mg concentration. [9] These previous studies proved that Lingam is effective against fever. Gandhagam had anti-microbial activity against *E. coli*, *P. vulgaris*, *K. pneumoniae*, *S. aureus*, *S. mutans*, and *C. albicans*. [10] Medicines that contain gandhagam and annabedhi have been used against fever [6].

CONCLUSION

From all the above observations, it is evident that brewer's yeast induced fever in experimental animals. The trial drug AU reversed the rectal temperatures to normal levels in experimental animals. Hence, this study shows that the test drug was effective against fever. However, further clinical studies are needed to elucidate the Anti-pyretic activity of AU.

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Table no 1 Ingredients of AnnabedhiUppu

S.No	Ingredients	Scientific Name	Common Name	Quantity
1	Annabedhi	Ferrous Sulphate	Annabedhi	5 Balam
2	Lingam	Red sulphide of Mercury	Cinnabar	½ Balam
3	Gandhagam	Sulphur	Sulphur	¼ Balam
4	Elumichai charu	Citrus limon	Lemon juice	Required quantity

Table no 2 Pharmacological study of Annabedhi Uppu in animal model

S. No	Groups	Treatment
1	Group I	Normal Control (Normal saline 2ml/kg)
2	Group II	Negative Control (20% w/v of Brewer's yeast)
3	Group III	Standard Group (20% w/v of Brewer's yeast and Paracetamol (150 mg/kg)
4	Group IV	Experimental Group (20% w/v of Brewer's yeast and AU- 7mg/kg)
5	Group V	Experimental Group (20% w/v of Brewer's yeast and AU- 14mg/kg)

Table no 3 Animal weight before starting the study

	Group I	Group II	Group III	Group IV	Group V
Head	174g	182g	142g	158g	196g
Body	187g	189g	166g	190g	175g
Tail	173g	206g	162g	205g	202g
Head and body	140g	130g	138g	134g	162g
Body and tail	157g	132g	116g	161g	154g
No mark	167g	127g	142g	150g	145g

Table no 4 Animal body temperature before yeast induction

	Group I	Group II	Group III	Group IV	Group V
Head	101.8°F	97.4°F	97.9°F	98.9°F	93.6°F
Body	99.3°F	98.9°F	96.9°F	98.5°F	94.9°F
Tail	98.3°F	100.3°F	98.0°F	97.7°F	94.7°F
Head and body	98.6°F	100.1°F	98.8°F	100.8°F	98.5°F
Body and tail	98.2°F	98.5°F	99.8°F	99.3°F	96.2°F
No mark	98.1°F	98.6°F	98.6°F	100.1°F	95.3°F

Table no 5 Animal body temperature after yeast induction

	Group I	Group II	Group III	Group IV	Group V
Head	97.5°F	99.7°F	100.5°F	98.8°F	98.2°F
Body	98.1°F	99.8°F	98.0°F	96.8°F	98.7°F
Tail	100.3°F	100.5°F	99.3°F	98.0°F	99.0°F
Head and body	100.2°F	101.6°F	99.6°F	99.3°F	101.4°F
Body and tail	101.4°F	102.2°F	99.4°F	98.2°F	100.1°F
No mark	102.1°F	102.0°F	98.7°F	102.6°F	100.5°F





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Table no 6 Animal body temperature at 1 hr interval

	Group 1	Group 2	Group 3	Group 4	Group 5
Head	98.4°F	97.6°F	99.5°F	98.8°F	100.0°F
Body	99.8°F	99.2°F	98.7°F	96.6°F	98.5°F
Tail	97.0°F	99.8°F	98.3°F	96.4°F	98.9°F
Head and body	99.5°F	101.0°F	100.1°F	101.1°F	100.3°F
Body and tail	101.4°F	100.9°F	101.1°F	102.1°F	101.7°F
No mark	101.0°F	100.3°F	100.2°F	102.5°F	101.1°F

Table no 7 Animal body temperature at 2nd hour interval

	Group 1	Group 2	Group 3	Group 4	Group 5
Head	98.2°F	98.4°F	99.5°F	100.6°F	99.2°F
Body	99.3°F	99.4°F	99.6°F	98.8°F	97.7°F
Tail	99.6°F	100.2°F	99.6°F	99.5°F	96.3°F
Head and body	99.2°F	100.2°F	100.1°F	101.0°F	100.3°F
Body and tail	101.3°F	100.9°F	101.1°F	100.7°F	101.6°F
No mark	101.4°F	99.7°F	100.3°F	102.7°F	98.6°F

Table no 8 Animal body temperature at 3rd hour interval

	Group 1	Group 2	Group 3	Group 4	Group 5
Head	98.2°F	98.5°F	100.5°F	99.8°F	98.3°F
Body	99.4°F	99.1°F	98.6°F	98.8°F	98.9°F
Tail	98.6°F	99.5°F	99.4°F	98.8°F	100.1°F
Head and body	100.0°F	101.7°F	101.1°F	101.8°F	100.8°F
Body and tail	101.9°F	101.4°F	102.2°F	101.3°F	101.2°F
No mark	102.1°F	101.2°F	99.4°F	103.5°F	100.4°F

Table no 9 Animal body temperature at 4th hr interval

	Group 1	Group 2	Group 3	Group 4	Group 5
Head	97.9°F	98.3°F	100.3°F	98.6°F	97.0°F
Body	97.4°F	96.9°F	99.0°F	99.5°F	100.2°F
Tail	98.0°F	97.8°F	98.5°F	98.9°F	99.6°F
Head and body	100.5°F	101.4°F	100.7°F	101.5°F	99.2°F
Body and tail	102.6°F	101.6°F	101.9°F	101.3°F	101.2°F
No mark	101.5°F	101.3°F	100.7°F	103.4°F	101.3°F





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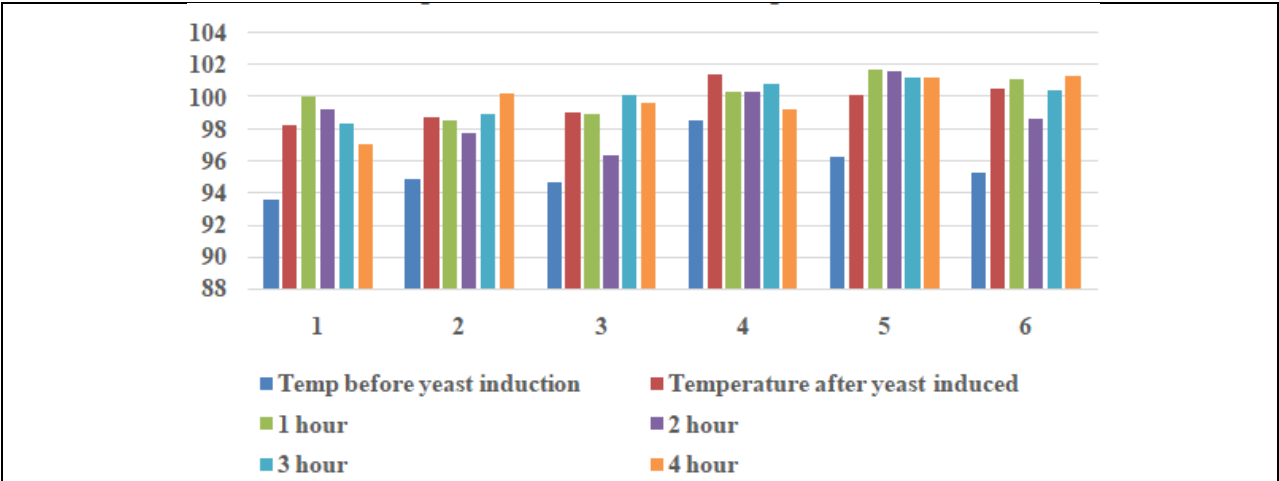


Figure 1: Temperature variation in Group I Animals

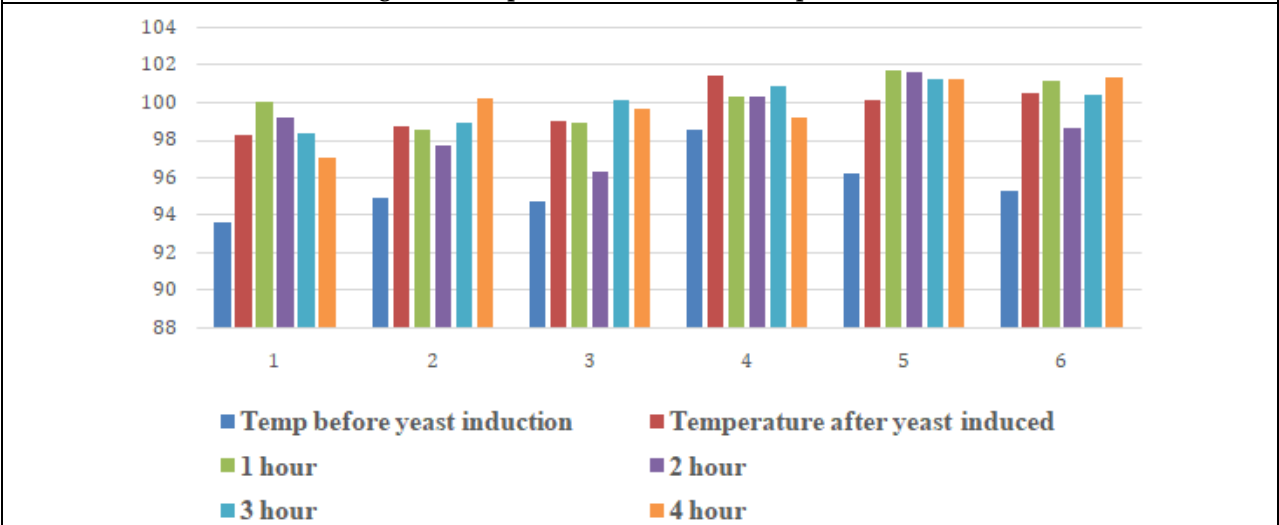


Figure 2: Temperature variation in Group II Animals





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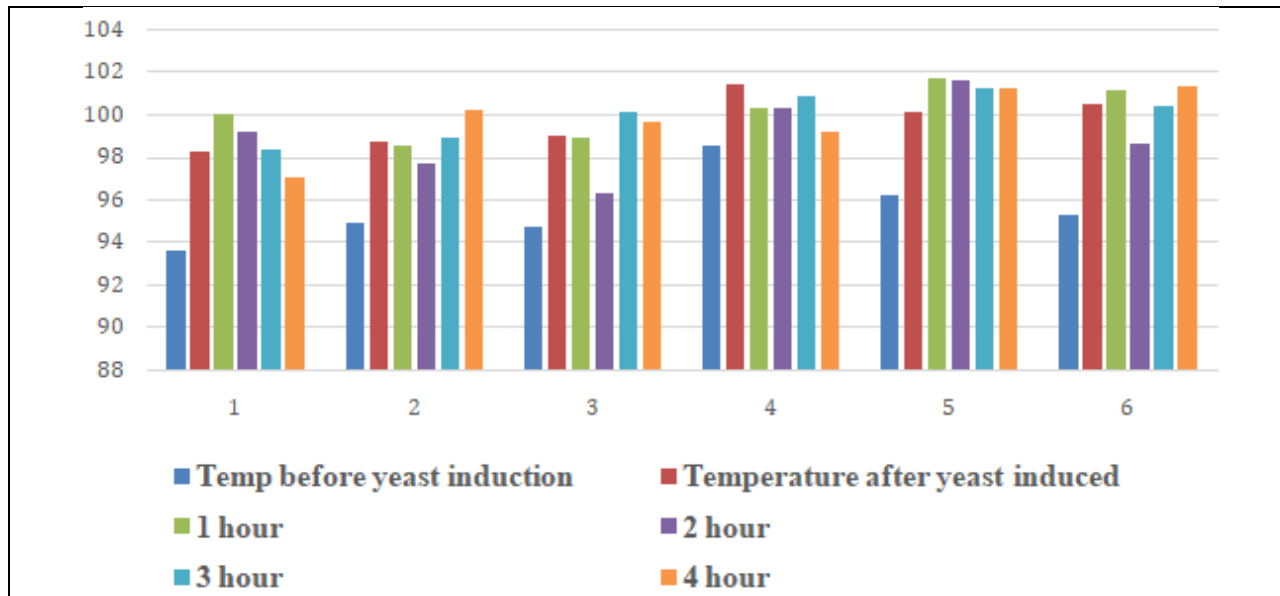


Figure 3: Temperature variation in Group III Animals

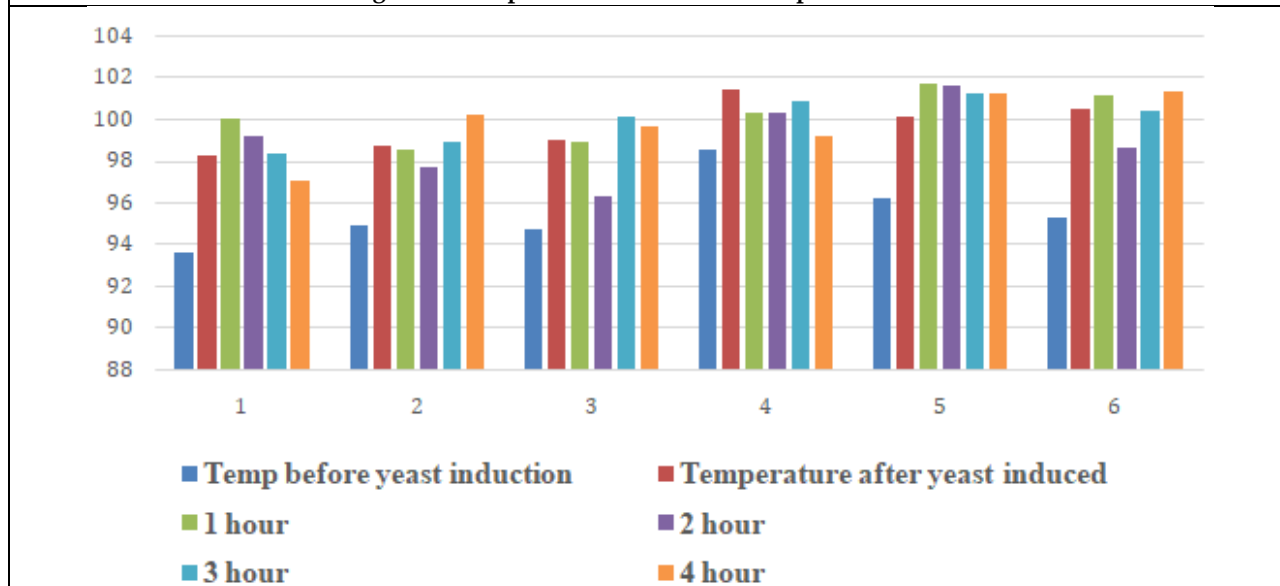


Figure 4: Temperature variation in Group IV Animals

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RESEARCH ARTICLE

Environmental Toxicology of Microplastic Particles on Aquatic Animals

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ABSTRACT

Plastics have transformed modern life with their strength, lightness, and affordability but these same qualities have made them one of today's biggest environmental threats. When larger plastics break down, they form tiny fragments called microplastics (less than 5 mm) and nanoplastics (less than 1 μm), which now contaminate nearly every corner of our planet, from rivers and lakes to deep oceans and soils. This study explores where these particles come from, how they spread, and what harm they cause to both the environment and living organisms. Poor waste management, industrial runoff, and synthetic fibers from clothing are among the main sources allowing microplastics to reach water bodies. Once there, they can be swallowed by fish and other aquatic animals, leading to physical injuries, oxidative stress, inflammation, and even changes in behavior and growth. Laboratory studies show that these plastics can also carry toxic chemicals and heavy metals, which then accumulate through the food chain. On land, microplastics affect soil health by disrupting microbial activity and reducing fertility, while humans are exposed through food, water, and air raising concerns about inflammation, hormonal imbalance, and long-term health effects. Addressing this issue requires global cooperation, better waste management, the use of biodegradable materials, stronger environmental laws, and greater public awareness. Overall, microplastic pollution is not just an environmental problem, it's a growing risk to ecosystems and human health that demands urgent and collective action.

Keywords: Microplastics, aquatic ecosystems, bioaccumulation, plastic contamination, biodegradation, oxidative stress, toxicity, waste management





INTRODUCTION

Over the last few decades, plastics have revolutionized industrial development, consumer behavior, and global trade because of their durability, light weight, and cost-[1]. Yet, these very advantages have created one of the most pressing environmental challenges of our time plastic pollution. When inadequately disposed of, plastic waste accumulates in terrestrial and aquatic ecosystems, undergoing fragmentation into progressively smaller particles known as microplastics (MPs, < 5 mm) and nano plastics (< 1 μ m) [2]. Their persistence, coupled with the fact that they are easily transported through water, has made them a pollutant of worldwide concern [3]. Aquatic environments rivers, lakes, estuaries, and oceans serve as the ultimate sink for most plastic debris. Studies have reported the presence of microplastics in surface waters, sediments, and even deep-sea and polar ecosystems, underscoring their global distribution [4]. The small size of MPs allows them to be ingested by a wide range of aquatic organisms, from plankton and mollusks to fish and marine mammals. Consequently, understanding their environmental toxicology, that is, their interactions with biological systems and resulting harmful effects has become a central focus of modern ecotoxicological research [5]. Plastics are widely used for their durability, flexibility, and low cost, but their extensive production and improper disposal have made them a major environmental concern. Among plastic pollutants, microplastics plastic particles smaller than 5 mm have gained global attention due to their persistence, small size, and widespread occurrence in aquatic environments [2, 5].

These particles originate either as primary microplastics, intentionally manufactured for industrial or cosmetic use, or as secondary microplastics, formed by the degradation of larger plastic waste under environmental stress as shown in figure 1. [2,11, 4]. Because of their light weight and resistance to biodegradation, microplastics are now found in oceans, rivers, sediments, and even polar regions [5, 8]. Once introduced into aquatic systems, microplastics interact with both abiotic and biotic components, altering water quality, nutrient cycling, and sediment structure [3, 9]. They are ingested by various aquatic organisms, from plankton and crustaceans to fish and marine mammals, often being mistaken for food [1, 5]. Ingestion can lead to reduced feeding, energy imbalance, growth inhibition, and reproductive failure [1, 6, 10]. Furthermore, the accumulation of microplastics in tissues can cause physical damage, intestinal blockage, and inflammatory responses, threatening the survival of numerous aquatic species [9, 10]. Beyond these physical effects, microplastics act as vectors for environmental contaminants. Their hydrophobic surfaces enable the adsorption of persistent organic pollutants (POPs), heavy metals, and pharmaceuticals from surrounding waters [3, 7]. When ingested, these particles can transfer toxic chemicals to aquatic organisms, increasing their internal pollutant load and leading to bioaccumulation and biomagnification throughout food chains [7, 9]. This dual threat mechanical injury and chemical toxicity makes microplastics particularly hazardous to aquatic ecosystems [3, 7].

Recent studies have highlighted the complex interactions between microplastics and emerging contaminants, showing that they can modify the transport, bioavailability, and toxicity of other pollutants in aquatic environments [3]. Such interactions depend on factors such as polymer type, particle size, and water chemistry, underlining the need for deeper mechanistic understanding of microplastic-contaminant dynamics [7]. Microplastic pollution also has potential implications for human health. Humans are exposed indirectly through the consumption of contaminated seafood, drinking water, and table salt [8]. Although the long-term health consequences are not yet fully known, possible risks include oxidative stress, inflammation, and endocrine disruption [8, 9]. To address this growing issue, integrated strategies such as improving waste management, promoting biodegradable alternatives, enhancing recycling technologies, and enforcing stricter environmental regulations are essential [4]. Public awareness, combined with scientific and legislative efforts, can play a crucial role in minimizing microplastic release and protecting aquatic life [4, 6].

Causes

Ways in which Microplastic Pollution takes place in Rivers, Lakes, and Other Water Bodies



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Poor Waste Management, Plastics that are discarded by the people carelessly or not recycled properly often escape into the environment. Rain, wind, flow of water and other factors can carry this debris into lakes, rivers, and oceans. As time passes larger plastics break into much more tiny fragments called secondary microplastics.[32] Intentionally Manufactured Microplastics, some plastic particles are intentionally produced at very small sizes such as include microbeads in cosmetics or tiny industrial pellets and fibres from synthetic clothing. These microplastics can enter water systems directly through sewage, wastewater, or industrial discharge.[32,35] Breakdown of Microplastics, Within Water Bodies Even after reaching water, plastics continue to fragment because of sunlight, temperature fluctuations, water currents, and microbial activity. This creates a variety of micro and nano plastics that can be easily ingested by aquatic animals.[32] Runoff from the industries, Wastewater, and Airborne Deposition Microplastics also reach water indirectly. industrial runoff carries fibres and dust, while wastewater treatment plants often do not filter out exceedingly small particles. Airborne microplastics can settle into rivers, lakes, and reservoirs.[32] Rising Plastic Production and Poor Disposal, the growing use of plastics worldwide due to improper disposal, keeps adding more plastic into aquatic environments, increasing risks for fish and other organisms.[32,35]

How Fishes Take in Microplastics

Direct Consumption, Fish often mistake tiny plastics for food because of their shape, colour, or size. Eating these particles can block digestive tracts, make feeding less efficient, and sometimes cause physical harm [28] Through the Food Chain, Microplastics are first consumed by smaller organisms like plankton. Predatory fish then eat these organisms, leading to accumulation of plastics higher up in the food chain. Toxic Chemicals Attached to Plastics, Microplastics can carry pollutants such as heavy metals or persistent organic compounds. Once ingested, these chemicals may leach into fish tissues, creating additional stress and damage.[28,34] Contamination After Capture, even after fish are caught, they can pick up microplastics from contact with packaging, containers, processing equipment, or even airborne fibres in storage areas.[28]

Effects on Fish at Different Life Stages

Vulnerable Early Stages, Eggs, larvae, and juvenile fish are particularly sensitive to microplastics because their immune systems and detox mechanisms are still developing.[30,31] Growth and Behavioural Effects, Microplastic exposure can reduce growth rates, impair feeding, and alter normal behaviour. Research has shown stunted development and abnormal swimming in species exposed to these particles.[30,31]

Cellular and Biochemical Impacts

Oxidative Stress, Microplastics can trigger excessive production of reactive oxygen species (ROS), which damage cell structures and affect organ function.[29] Liver Inflammation and Injury, ROS can activate immune pathways, causing liver inflammation. Severe exposure can damage liver tissue or even kill liver cells.[33] Metabolic Disruption, Plastics may interfere with the liver's ability to process fats and energy, affecting overall metabolism in fish. Altered Biomarkers, Enzyme activity and protein levels in the liver may change under microplastic exposure, signalling physiological stress.[33,34]

Factors Influencing Toxicity

Particle Size, Dose, and Exposure Duration, Smaller microplastics penetrate tissues more easily. Higher doses or longer exposure periods increase the risk of severe effects.[34] Species Sensitivity, Different fish species react differently depending on metabolism, immune strength, and detoxification abilities.[32] Plastic Additives, Chemicals such as dyes, flame retardants, or plasticizers can intensify toxic effects. Accumulation and Food Chain Transfer, Microplastics can build up in fish tissues over time. Predators that consume contaminated fish may also accumulate plastics and associated toxins, affecting the food chain.[35]

Other Ecological Risks

Mistaken Identity by Marine Animals, few animals confuse microplastics with prey, leading to ingestion, physical injury, and disrupted feeding.[35] Carriers of Pathogens, Microplastics can provide surfaces for bacteria or other



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microorganisms, spreading diseases in aquatic ecosystems.[35] Long Term Effects on Growth and Reproduction, Chronic exposure may reduce growth, hinder reproduction, and disturb population stability, ultimately affecting biodiversity and ecosystem balance.[34,35]

Effects

Ecotoxicological Impacts on Aquatic Organisms

Microplastics (MPs) are increasingly recognized as a pervasive environmental contaminant affecting aquatic ecosystems worldwide. Their small size and persistence allow them to be easily ingested by a range of organisms, from plankton to fish and shellfish, leading to significant physiological and biochemical alterations [12]. Studies have demonstrated that exposure to polystyrene microplastics (PS-MPs) reduces the catalytic efficiency of acetylcholinesterase (in zebrafish larvae, impairing cholinergic transmission and neural signaling [12]. This inhibition leads to overstimulation of receptors, resulting in behavioral abnormalities such as sluggish locomotion and feeding difficulties. In addition, long-term ingestion of MPs has been shown to cause gastrointestinal obstruction, enlargement of the colon lumen, and altered feeding behavior in fish, thereby reducing their overall growth and fitness [12]. Microplastics also provoke oxidative stress in aquatic organisms by increasing the production of reactive oxygen species (ROS), which damage cellular structures through lipid peroxidation (LPO) [12]. This oxidative stress disrupts membrane integrity, leading to lesions in critical tissues like gills, liver, and muscles. In fish such as *Dicentrarchus labrax*, LPO has been associated with neuronal damage and increased mercury accumulation in brain tissue when MPs are co-present with heavy metals [12]. Furthermore, co-exposure of MPs with other environmental pollutants like cadmium has been shown to amplify toxicity by suppressing antioxidant enzyme activity and upregulating stress-related genes [12]. These findings emphasize that MPs not only act as independent toxic agents but also serve as vectors that facilitate the bioavailability and accumulation of other hazardous substances within aquatic food webs [12].

Histopathological and Physiological Damage

The ingestion and accumulation of MPs in aquatic fauna induce a range of histopathological changes. Fish and mollusks exposed to low-density polyethylene (LDPE) and PS-MPs exhibit villus fissuring, enterocyte degeneration, and necrosis of intestinal epithelial cells [12]. In zebrafish, MP exposure causes vacuolization and mast cell infiltration in the intestinal lining, indicating inflammatory responses. Moreover, MPs with fibrous morphology tend to remain longer within the gut compared to spherical or fragmented forms, thereby aggravating mechanical injury and inducing higher oxidative stress responses [12]. The physical characteristics of MPs—size, shape, and polymer type—determine the severity of damage; smaller particles penetrate cellular membranes more easily and accumulate within organs, while fibrous MPs cause more extensive abrasion and inflammation [12]. MP-induced inflammation is mediated by the upregulation of immune-related genes such as *il-1b*, *ifngl-2*, and *nfa*, which trigger oxidative damage and apoptotic pathways [12]. Chronic exposure results in impaired intestinal absorption and disrupted metabolic function. Studies on *Oreochromis niloticus* and *Cyprinus carpio* have reported altered liver function, elevated aminotransferase activity, and reduced serum protein levels, indicating hepatic stress and metabolic imbalance [12]. Additionally, MPs cause anemia, disrupt hematological parameters, and elevate plasma glucose and creatinine levels, suggesting impaired kidney and cardiovascular functions in fish [12].

Bioaccumulation and Trophic Transfer

The persistence of microplastics in aquatic environments facilitates their bioaccumulation and trophic transfer through food chains. Planktonic organisms ingest suspended MPs, which are subsequently transferred to higher trophic levels through predation [13]. Filter feeders such as mussels and oysters act as bioindicators, accumulating MPs within their tissues and providing a pathway for human exposure through seafood consumption [13]. The accumulation of MPs in benthic species also influences sediment biogeochemistry by altering nutrient cycling and oxygen exchange at the sediment-water interface. Over time, MPs integrated into benthic communities can release adsorbed contaminants, thereby perpetuating chemical toxicity across trophic levels [13]. The potential for MPs to adsorb hydrophobic organic pollutants and heavy metals such as mercury and cadmium further enhances their



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ecotoxicological impact [12], [13]. As a result, organisms ingesting MPs may experience compounded effects from both the physical presence of plastics and the chemical toxicity of co-adsorbed contaminants. This dual mode of toxicity poses a severe risk to aquatic biodiversity, as well as to food safety and human health [13].

Terrestrial and Soil Ecosystem Effects

Although the majority of research focuses on aquatic systems, terrestrial environments are equally susceptible to MP contamination through sewage sludge, agricultural runoff, and atmospheric deposition [14]. MPs introduced into soils affect microbial community structure and reduce soil enzymatic activity essential for nutrient cycling [14]. Their presence alters soil porosity and water retention, indirectly influencing plant growth and productivity. Moreover, earthworms and other soil invertebrates ingest MPs, leading to intestinal blockage, oxidative stress, and changes in reproductive behavior [14]. The persistence of MPs in agricultural lands that use plastic mulch or contaminated fertilizers raises long-term concerns for soil fertility and food crop safety [14].

Impacts on Human Health

Humans are exposed to MPs primarily through ingestion, inhalation, and dermal contact. MPs have been detected in table salt, drinking water, seafood, and even atmospheric dust, indicating their widespread presence [15]. Once ingested, MPs can cross biological barriers and accumulate in organs such as the liver, kidneys, and intestines, potentially leading to inflammatory responses and oxidative stress [15]. Studies suggest that nanoplastics, due to their smaller size, are capable of translocating across cell membranes and the blood-brain barrier, posing neurological risks similar to those observed in aquatic species [12], [15]. Furthermore, MPs can carry endocrine-disrupting chemicals such as phthalates, bisphenols, and flame retardants, which interfere with hormonal regulation and reproductive health [15], [16]. Emerging evidence also links chronic MP exposure to metabolic and immunological disorders. The oxidative damage caused by MPs may contribute to DNA strand breaks and mitochondrial dysfunction, which are precursors to carcinogenic processes [16]. Although human health implications are still under investigation, the continuous accumulation of MPs in food chains underscores the urgency for global monitoring and mitigation measures [16], [17].

Ecosystem-Level Consequences

At the ecosystem scale, MPs interfere with energy transfer, nutrient dynamics, and habitat quality. The presence of MPs in aquatic and terrestrial food webs disrupts predator-prey interactions and alters community structure [17]. In marine environments, MPs contribute to habitat degradation, particularly in coral reefs and seagrass beds, by blocking light penetration and smothering photosynthetic organisms [17]. Moreover, MPs may serve as vectors for pathogenic microorganisms, forming biofilms that facilitate the spread of antibiotic-resistant bacteria [18]. This phenomenon poses a threat to both marine biodiversity and public health, reinforcing the need for comprehensive environmental management.

Measures to Reduce or Prevent Microplastic Pollution

A comprehensive approach is needed to mitigate and prevent microplastics pollution, involving technological, behavioral, and regulatory interventions. Central to this effort is source reduction, which can be achieved by minimizing the production and use of single-use plastics and encouraging manufacturers and consumers to shift to biodegradable alternatives [12]. Replacing conventional plastics with bioplastics derived from renewable resources, such as polylactic acid or polyhydroxyalkanoates, can significantly lower the persistence of microplastics in the environment, especially if these new materials are proven to degrade efficiently under natural conditions [13]. However, care must be taken to ensure that bioplastics do not create secondary pollution challenges, requiring thorough evaluation of their environmental impact and lifecycle performance [14]. Improvement in waste management infrastructure is a crucial measure. Proper collection, recycling, and managed disposal of plastic waste, particularly in coastal regions, cities, and river basins that are major sources of marine microplastics, can drastically reduce the amount entering aquatic environments [15]. Policies that promote a circular economy for plastics, such as extended producer responsibility and incentives for recycling, help create a sustainable system where plastic



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materials are reused, further necessitating public and private sector collaboration [16]. Municipalities and regions with robust plastic waste collection and recycling systems show lower levels of mismanaged waste, directly correlating with lower microplastic leakage [17].

Wastewater treatment plant optimization is essential because these plants are important pathways for microplastics to reach rivers, lakes, and seas. Conventional treatment can remove a significant fraction of microplastics, but advanced filtration systems, such as membrane bioreactors and tertiary filtration with very fine meshes, can extract even smaller plastic particles [18]. Implementation of such advanced technology, albeit expensive, prevents the direct release of microplastics into natural waters and should be complemented by regular monitoring and standardization of detection and removal methods [19]. Legislative interventions, including bans or taxes on specific microplastics sources like microbeads in personal care products, have demonstrated effectiveness and should be broadly adopted and enforced [20]. National and international agreements, such as those advocated by the United Nations Environment Programme, provide frameworks for coordinated reduction efforts, while also guiding local policy makers in formulating enforceable and context-appropriate rules [21]. Regulations must also address emissions from synthetic textiles and the loss of fishing gear, two significant contributors to microplastics pollution, by mandating design changes, labeling, and collection requirements [22]. Public education and behavioral change campaigns are vital for long-term success. Raising awareness of the impact of microplastics encourages individuals to reduce their plastic footprint by refusing single-use plastic items, choosing natural fibers over synthetic textiles, and supporting environmentally responsible products [23].

Effective campaigns can change consumption patterns and influence upstream demand, resulting in less plastic entering the market and ultimately the environment [24]. Innovative approaches such as rewarding "plastic fishing" or cleanup efforts, particularly for floating or shoreline plastics, offer community-based solutions to intercept plastics before they degrade into microplastics and reach aquatic systems [25]. While collecting micro- and nanoplastics from open oceans remains technologically and logistically challenging, targeting macroplastics and the most polluted sites can curtail future microplastic formation [26]. Continued research to improve materials and develop new detection, treatment, and removal technologies will further strengthen prevention strategies. Standardizing monitoring protocols and advancing analytical techniques allow for accurate quantification of microplastics in different environments, supporting evidence-based policy decisions and adaptive management [27]. Cross-sector collaboration, including scientists, industry, policymakers, and local communities, is necessary to develop and implement holistic solutions. In summary, addressing microplastics pollution requires a combination of upstream interventions to reduce plastics use, technological advancements in waste and water treatment, strict legislation and enforcement, intensive public education, and ongoing research and development. Overcoming this environmental challenge will depend on global cooperation, integrated policy frameworks, and a sustained commitment to transforming how society produces, consumes, and disposes of plastic materials.

Experimental findings and observations on microplastic toxicity

Effect of Polystyrene Microplastics on Zebrafish Neural Enzyme Activity

In a controlled study, zebrafish larvae (*Danio rerio*) were exposed to 1 mg/L of polystyrene microplastics (PS-MPs) to evaluate the impact on acetylcholinesterase (AChE) enzyme activity [12]. The experiment lasted for 96 hours, during which the catalytic efficiency of AChE was monitored alongside behavioral parameters like swimming activity and feeding response. The researchers observed that inhibition of AChE corresponded with sluggish locomotion, decreased feeding frequency, and disrupted cholinergic transmission, which is crucial for muscle coordination and brain synapse function [12].

Observations

Zebra fish larvae displayed a clear decline in swimming speed and directional control within 72 hours of exposure. The reduction in AChE activity resulted in an accumulation of acetylcholine at synaptic junctions, causing overstimulation of neural receptors [12]. When comparing to larger species like *Dicentrarchus labrax*, no significant



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inhibition of AChE was observed at similar concentrations, suggesting that smaller fish are more vulnerable to neurotoxic stress induced by microplastics [12].

Results

As shown in Table 1 Lipid peroxidation (LPO) increased significantly in exposed zebrafish brains, indicating oxidative stress. The study also noted muscle and gill tissue damage correlated with elevated LPO markers. These findings suggest that PS-MPs interfere with antioxidant defense mechanisms, leading to enhanced production of reactive oxygen species (ROS) and potential neurodegeneration [12][13].

Histopathological and Oxidative Stress Response in Adult Zebrafish Exposed to LDPE Microplastics

In another study, adult zebrafish were exposed to low-density polyethylene (LDPE) microplastics for three weeks to determine histopathological and biochemical changes [14]. The concentration of LDPE particles ranged between 5 and 500 µg/L. Despite prolonged exposure, no significant variation in oxidative stress markers was initially recorded [14]. However, when combined with heavy metals like cadmium, there was a notable increase in ROS generation and suppression of antioxidant enzyme activity.

Observations

Zebrafish exposed solely to LDPE particles maintained normal liver and gill histology, but the addition of cadmium resulted in tissue degeneration, liver vacuolization, and nuclear pyknosis [14]. The mRNA expression of oxidative stress-related genes such as SOD1, SOD2, and Nfe212 decreased significantly, indicating suppressed defense mechanisms.

Results

The experiment confirmed that microplastics act as pollutant vectors, enhancing the bioavailability of co-contaminants like cadmium. Table 2 shows the synergistic toxicity resulted in severe oxidative stress, reducing glutathione (GSH) and superoxide dismutase (SOD) levels. The joint exposure led to a 45% decrease in SOD activity compared to the control [14][15].

Reproductive Toxicity of Microplastics in *Sparus aurata*

A laboratory-based experiment on *Sparus aurata* (gilthead seabream) investigated behavioral and physiological effects of polyethylene microplastic ingestion [16]. The fish were divided into two groups—control and exposed (0.1 mg/L PE-MPs)—and monitored for 21 days. The exposure led to significant changes in social behavior, feeding activity, and reproductive indices.

Observations

The exposed group exhibited reduced social interaction and increased lipid peroxidation in gonadal tissues. Alterations were also found in serum biomarkers such as triglycerides, cholesterol, and total protein levels [16]. Behavioral stress indicators, including erratic swimming and reduced mating courtship, were evident after 14 days of exposure.

Results

Biochemical analysis (as shown in Table 3) revealed increased antioxidant enzyme levels as a compensatory response to oxidative stress. However, chronic exposure induced damage to gonadal tissues, reducing sperm motility and egg fertilization rates. The findings suggest endocrine disruption as a secondary effect of microplastic accumulation in reproductive organs [16][17].



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A more recent study evaluated combined exposure of PS-MPs (100 μ g/L) and 17 α -methyltestosterone (10 μ g/L) on the reproductive system of zebrafish (*Danio rerio*) [18]. The experiment ran for 30 days, focusing on gonadal histology, hormone levels, and gene expression related to steroidogenesis.

Observations

Fish exposed to the combined treatment showed severe gonadal atrophy, disrupted spermatogenesis, and reduced oocyte development. There was downregulation of genes like *cyp19a1a* and *lh β* , essential for estrogen synthesis and reproductive hormone regulation [18]. Moreover, testicular tissues exhibited extensive fibrosis and necrosis, while ovarian sections revealed follicular degeneration.

Results

The results confirmed a synergistic interaction between PS-MPs and endocrine disruptors. As we can see in Table 4, Plasma testosterone and estradiol concentrations dropped by 35% and 40%, respectively, compared to the control group. The findings indicate that PS-MPs can enhance hormonal toxicity by acting as carriers for hydrophobic compounds [18][19].

Summary of Experimental Findings on Microplastic Toxicity

The collective analysis of four controlled experiments reveals the multifaceted toxicological effects of microplastics (MPs) on aquatic organisms, emphasizing neural, histopathological, reproductive, and biochemical disruptions across species. In the first experiment, exposure of *Danio rerio* (zebrafish) larvae to 1 mg/L of polystyrene microplastics (PS-MPs) for 96 hours led to significant inhibition of the acetylcholinesterase (AChE) enzyme. This inhibition impaired neurotransmission, resulting in reduced locomotor activity and feeding efficiency. Elevated levels of lipid peroxidation (LPO) and reactive oxygen species (ROS) indicated oxidative stress in neural tissues. The findings demonstrated that smaller fish species are more vulnerable to microplastic-induced neurotoxicity compared to larger ones, highlighting the size-dependent effects of MPs on aquatic neural health [12][13]. The second experiment focused on adult zebrafish exposed to low-density polyethylene (LDPE) microplastics for three weeks, both alone and in combination with cadmium (Cd). While LDPE alone produced minimal oxidative stress, its combination with cadmium amplified reactive oxygen species formation and suppressed key antioxidant enzymes like superoxide dismutase (SOD) and glutathione (GSH). Histological analyses revealed liver vacuolization, cellular necrosis, and nuclear pyknosis, confirming that MPs can act as vectors that increase heavy metal bioavailability and toxicity. The results provided strong evidence for synergistic toxicity between MPs and metal pollutants in aquatic ecosystems [14][15].

The third experiment investigated the reproductive toxicity of polyethylene microplastics (PE-MPs) in *Sparus aurata* (gilthead seabream). Over 21 days, exposed fish exhibited altered social and feeding behaviors, decreased serum protein levels, and elevated cholesterol and triglycerides, reflecting metabolic imbalance. Gonadal tissues showed lipid peroxidation and cellular degeneration, leading to reduced sperm motility and egg fertilization rates. These physiological changes suggested an endocrine-disrupting potential, where chronic exposure to MPs impairs reproductive functions through oxidative and hormonal pathways [16][17]. The fourth experiment explored the combined effect of polystyrene microplastics and 17 α -methyltestosterone (17 α -MT) on zebrafish reproduction. A 30-day exposure caused severe gonadal atrophy, oocyte degeneration, and fibrosis in testicular tissue. Additionally, expression of steroidogenic genes such as *cyp19a1a* and *lh β* was significantly downregulated. Hormonal assays confirmed reductions of approximately 35% in testosterone and 40% in estradiol levels compared to controls. These outcomes demonstrated a synergistic endocrine-disrupting effect, suggesting that microplastics can enhance the bioavailability and toxicity of hydrophobic compounds like synthetic hormones [18][19]. Overall, these experiments collectively underscore the pervasive and complex toxicity of microplastics in aquatic environments. MPs not only exert direct physiological and biochemical damage but also serve as carriers for co-contaminants, amplifying their harmful effects. The recurring trends of oxidative stress, enzyme inhibition, tissue degeneration, and hormonal





imbalance confirm that microplastics act as potent environmental stressors, threatening aquatic biodiversity and, indirectly, human food security. Continued investigation into combined contaminant effects, tissue bioaccumulation, and long-term generational impacts is essential to develop effective mitigation strategies for microplastic pollution.

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Table 1. Biochemical parameters of zebrafish exposed to PS-MPs (1 mg/L) for 96 h.

Parameter	Control Group	Exposed Group	% Change
AChE activity (U/mg protein)	5.4	3.1	-42.5%
LPO (nmol MDA/mg protein)	2.3	4.9	+113%
ROS level (a.u.)	1.0	2.4	+140%

Table 2. Enzymatic response in zebrafish after 3-week exposure to LDPE and cadmium .

Biomarker	Control	LDPE + Cd	% Change
SOD activity (U/mg)	18.2	10.1	-44.5%
GSH content (μmol/g)	8.3	5.2	-37.3%
ROS generation (a.u.)	1.2	3.6	+200%

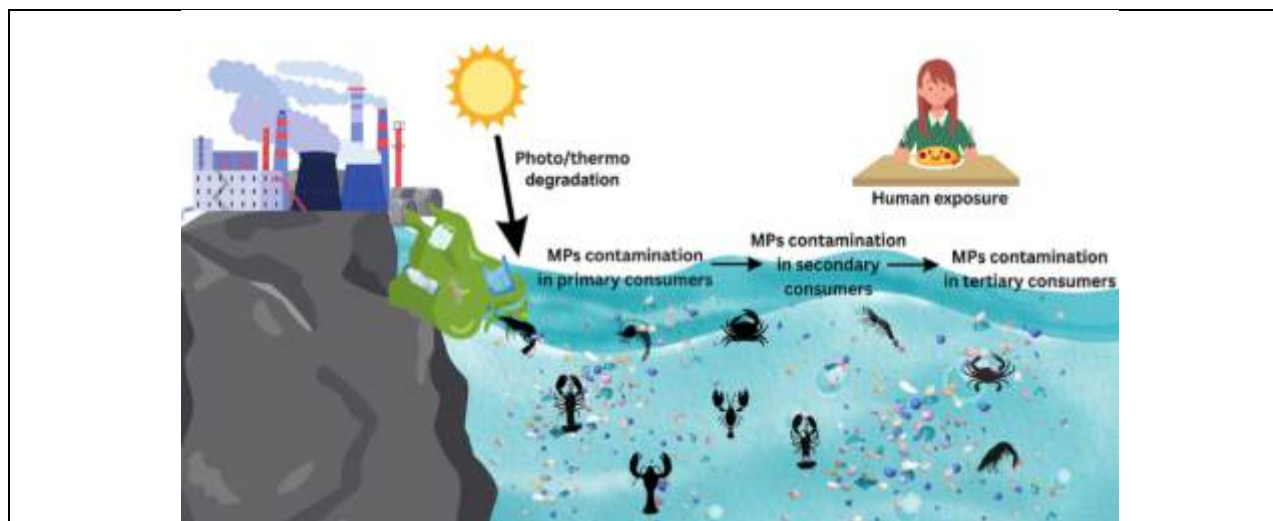
Table 3. Blood biochemical profile of *Sparus aurata* after exposure to PE-MPs (0.1 mg/L)

Parameter	Control	Exposed	% Change
Triglycerides (mg/dL)	120	155	+29%
Cholesterol (mg/dL)	190	250	+31%
Total protein (g/dL)	6.2	5.1	-17%
SOD activity (U/mg)	20.5	29.8	+45%



Chandrama Basu *et al.*,**Table 4. Hormonal and gene expression changes in zebrafish after combined exposure**

Parameter	Control	PS-MP + 17 α -MT	% Change
Testosterone (ng/mL)	5.2	3.4	-35%
Estradiol (pg/mL)	380	228	-40%
cyp19a1a (fold change)	1.00	0.41	-59%

**Figure 1: Primary and secondary microplastics.**

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RESEARCH ARTICLE

An Experimental Study on the use of Waste Glass Powder in Bitumen for Flexible Pavements

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ABSTRACT

Due to rapid industrialization and urbanization, there has been a significant growth of the waste glass production resulting in great environmental and disposal problems because of its non-biodegradable properties. At the same time, flexible pavements demand better materials to increase the strength, durability, and resistance to the load of traffic and temperature changes. In this research, the researcher examines the possibility of using waste glass powder (WGP) as a partial substitute of traditional mineral filler in flexible pavement construction bituminous mixes. The waste glass that was acquired as a result of discarded glass materials underwent washing, crushing, and grinding into fine powder under 75-micron sieve. VG-40 grade bitumen was used to add the glass powder by the replacement levels of 5, 10, 15, and 20. The laboratory tests such as penetration, softening point, ductility, flash and fire point tests and stripping value tests were conducted to assess binder characteristics and the aggregate impact tests, crushing tests and abrasion tests were conducted to check the suitability of the aggregate. Marshall Stability and flow tests had been conducted to estimate the strength characteristics of the mixes. The experiments have shown that waste glass powder enhances stability, stiffness, and moisture resistance and does not reduce the flexibility significantly. The optimum replacement level was observed at 15%. The research supports the hypothesis that waste glass powder could be used as a reliable and environmentally friendly and sustainable material in the construction of flexible pavements.

Keywords: Waste glass powder, VG-40 bitumen, flexible pavement, Marshall stability, sustainable construction





INTRODUCTION

The rapid industrialization and urbanization has contributed to the rapid increase in the production of solid waste materials in the globe with waste glass being one of the major environmental issues. Glass products like bottles, window panels, containers, and electronic components have a wide usage because they are durable, as well as, chemical stable. Nevertheless, the same properties render glass non-biodegradable thus posing great disposal challenges when they are deposited in landfills. The amount of waste glass is also very high and it is a waste product that takes up a lot of space in the landfills and this adds to the degradation of the environment. Glass recycling consumes a lot of energy and complex facilities that are not necessarily economically viable. As a result, there have been other ways of utilizing waste glass effectively, and this has emerged as a research field of interest. Simultaneously, flexible pavements experience ever-growing traffic loads, intense pressure of axles, and changes in temperature that further accelerate the weakening of pavements. Traditional bituminous mixes usually suffer problems of rutting, fatigue cracking, bleeding and moisture damage that lead to loss of service life and high maintenance. The use of waste products in the construction of pavements has thus been seen as a sustainable strategy with the intention of enhancing the performance of pavements as well as dealing with the issue of the environment.

Bituminous mixtures rely on aggregates, binder and mineral fillers in realizing stability and durability. Mineral fillers are important in enhancing bonding of aggregates and bitumen, decreasing air vacuity, and augmenting asphalt mix stiffness. The glass wastes collected by means of crushing and grinding of the discarded glass glasses contain high silica content and angular particles structure that qualifies them to be used as filler materials in the mix of bituminous products. Waste glass powder can be utilized to offer a good potential in substituting the traditional filler materials like limestone dust and save on natural resources. Fine particles of glass may be added to enhance the density and deformation resistance of the mixtures through enhanced interlocking of the particles, as well as, enhanced interaction between the particles and the binder. The utilization of these environmental friendly materials aids in the development of infrastructure that is eco-friendly and helps in the practice of the circular economy through the conversion of the waste into quality construction materials.

Past research has conducted studies into the possibility of using waste glass either as an aggregate or as filler in the asphalt mixtures. Preliminary researchers showed that the particles of crushed glass can be successfully incorporated into asphalt concrete without substantial impact on workability and compaction properties. Abu Salem et al. (2017) claimed that angular form and hardness of the glass particles provided the asphalt mixtures with waste glass with better skid resistance and durability. In the work, it was also noted that a moderate content of glass positively interacted with the stability of the Marshall without compromising the acceptable flow values. The same observations have been made by Su and Chen (2002) who established that the strength of a mixture and the resistance to permanent deformation was enhanced by replacement of fine aggregates partially by waste glass provided good gradation is ensured. A study by Jony et al. (2011) has identified the possibility of using glass powder as mineral filler in asphalt mixtures with evidence of a significant increase in stability and load-bearing capacity. The fillers activity was noted to be increased due to fine particle size of glass powder that was used which was known to promote bonding of aggregates and the binder. Phan et al. (2024) researched the mixtures of asphalt with different proportions of waste glass and stated that the mixtures with about 15 percent of glasses in them performed best in terms of stability and volumetric characteristics. Similar outcomes were achieved by Khater et al. (2021), who noted an increase in fatigue resistance and a decrease in deformation under repeated loading conditions because of the rigidity of glass particles.

The additional research gave a stress on the ecological advantages of using glasses in pavements. In another study, Bilgen and Altuntas (2022) showed that waste glass reuse greatly decreases the landfill disposal and reduces the extraction of the natural aggregates to a minimum. According to Ming et al. (2022), glass powder filler increases resistance to rutting and stiffness properties of asphalt mixtures in the high-temperature condition. Research works



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on waste glass controlled incorporation also by Moreno-Navarro et al. (2015) proved that using waste glass to enhance the mechanical strength and long-term durability of flexible pavements and lowering construction costs. Although positive results concerning the benefits are cited, scientists have found some flaws in the form of the high level of glass. Anochie-Boateng and George (2016) have also provided similar results and stated that an overabundance of glass powder might adversely affect the cohesion and stability of mixtures. These observations indicate the significance in establishing an optimum level of replacement in order to have a balanced mechanical performance.

Recent research has been oriented towards enhancement of moisture resistance and serviceability properties of glass modified asphalt mixtures. Grinys et al. (2021) indicated that appropriately graded glass powder filler can be used to increase stripping resistance and durability at specific controlled limits. Simone et al. (2017) affirmed that the asphalt mixtures with waste glass powder had satisfactory volumetric and mechanical requirements that could be applied in pavements. The review studies by Nandal et al. (2023) and Lee et al. (2023) concluded that recycled glass materials have a high potential of sustainable construction of pavements with regard to their mechanical strength, chemical inertness, and broad availability.

The overall summaries of the past studies point out that the waste glass powder could be utilized in the form of an alternative filler material in the flexible pavements which would help enhance the strength, stiffness and environmental sustainability. There is however a great dependence on the characteristics of performance based on the distribution of particle sizes, replacement percent, and reaction with the bitumen binder. There is also a dearth of experimental research on the behavior of VG-40 grade bitumen that is modified with waste glass powder under different degrees of replacement, especially when subjected to conditions that emulate heavy traffic conditions and in the conditions of high temperature. Consequently, there is a need to conduct systematic investigation of waste glass powder by laboratory experts to determine its effect on the physical and mechanical characteristics of bituminous mixtures and the best content which can be used in the construction of flexible pavement. The primary goal of the paper is to assess the appropriateness of waste glass powder as a sustainable substance in bituminous mixtures in pavements construction of flexible pavements. The following are the particular objectives of the study:

- To investigate the impact on physical and performance properties of VG-40 grade bitumen of waste glass powder.
- To examine how the various percentages of waste glass powder (5, 10, 15 and 20) affect the properties of the bituminous mixtures in terms of strength.
- To establish the variation in the penetration, softening point, ductility, flash and fire point, and stripping resistance of modified bitumen.
- To determine the most ideal content of the waste glass powder that gives the best stability, longevity and waterproofing.
- To enhance the use of waste glass materials in the construction of sustainable pavement and that which is environmentally friendly.

Materials Used

The materials applicable in this experimental study are VG-40 grade bitumen, waste glass powder and coarse aggregate, fine aggregates and mineral filler. The choice of all materials was made according to the standard specifications to make sure that the materials are appropriate to be used in the construction of flexible pavement.

Bitumen

The binding material used in this research was VG-40 grade bitumen because it is more viscous and works well with heavy traffic and high temperature. Bitumen is used as a binding substance that holds aggregates in place and gives the pavement construction the flexibility and strength. Penetration, softening point, ductility, flash point, and fire point tests were used in determining the physical characteristics of bitumen.



**Waste Glass Powder**

Glass waste was glass powder that had been discarded and glass bottles and window glass collected in the area. The glass waste, which was collected was rinsed to eliminate contaminants after which it was crushed and ground to fine powder. The sieved glass powder was passed through a sieve consisting of 75-micron diameter to get homogenous particle size that could be used as filler material. Glass powder waste was used on a partial basis of substitute of the conventional mineral filler at a percentage of 5, 10, 15 and 20 percent of the weight of the filler material. The angular shape of the glass particles and the high silica make the particles of the bituminous mix more rigid and stronger.

Coarse Aggregates

The coarse aggregates in the form of bituminous mixtures were prepared with crushed stone aggregates. The following aggregates offer strength, stability and load bearing capacity to pavements that are flexible. Aggregates that were properly graded were used to ensure that there was good interlocking and withstand to traffic loads. The Aggregate Impact Value, Aggregate Crushing Value, and Los Angeles Abrasion tests were done to ascertain the viability of the tests in pavement.

Fine Aggregates

The mix was filled with fine aggregates of natural sand that created the coarse aggregates density within the mix and also enhanced the overall mix density. The fine aggregates were dry and not organic in nature. Gradation of fine aggregates in a proper manner increases the workability, stability and bonding properties of the bituminous mixture.

Mineral Filler

The bituminous mix had conventional mineral filler, stone dust, and the wastage of glass powder. Filler materials are favourable in the enhancement of cohesion, reduction of air cavities, and the increase of the adhesion between the bitumen and the aggregates. It was conducted at a partial replacement of the mineral filler with waste glass powder to determine its effect on the pavement performance.

METHODOLOGY

The research methodology that will be used in this research experimental study aims at assessing the functionality of flexible pavements that use waste glass powder as a partial replacement of the traditional mineral filler. The experimental program was to prepare the material, prepare modified bituminous mixes, conduct laboratory tests and discuss results as per the specifications under Indian Standards. All the materials needed to complete the study including VG-40 grade bitumen, an aggregate, mineral filler, and waste glass powder were first collected and ready to be tested. Waste glass was collected on the discarded glass materials and it was cleaned to get rid of dust and impurities. The cleaned glass was broken and pulverized into minute powder and filtered through a 75-micron sieve to get evenly sized particles that can be used to replace fillers. Bituminous mixes were made by substituting the traditional filler mineral in different proportions of 5 percent, 10 percent, 15 percent and 20 percent by weight of filler material by waste glass powder. VG-40 bitumen was warmed at a temperature of about 160-170 °C in order to obtain the right fluidity to be mixed. To remove the moisture contents, the aggregates were heated individually to ensure homogenous mixing temperature. The filler material, waste glass powder and the heated aggregates were mixed in details and then hot bitumen was added and mixed thoroughly to get a homogeneous mixture of bituminous mixture.

Aggregates were also tested before the preparation of mixes to determine that they are suitable in the construction of pavements. Aggregate Impact Value Test, Aggregate Crushing Value Test, and Los Angeles Abrasion Test are some of the standard laboratory tests that were carried out to determine toughness, strength and wear resistance. Conventional and modified bitumen samples were then subjected to laboratory tests to ascertain the change of binder properties after waste glass powder was added. IS 1203:1978 was used to carry out the penetration test to ascertain the consistency of bitumen. Temperature susceptibility was determined by the softening point test by



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the use of the ring and ball apparatus in accordance with the IS 1205:1978. The ductility test was conducted according to the requirements of the IS 1208:1978 to determine the flexibility qualities of the binder. To establish the thermal safety limit during heating processes, flash and fire point tests were done in accordance with IS 1209:1978. The stripping value test was used to test the moisture susceptibility of the mix as per IS 6241:1971. In order to test the strength properties of the bituminous mix, the Marshall Stability Test was performed. The standard specification compaction procedures were done to the cylindrical specimens, which were tested to ascertain the Marshall stability and flow values. These were the parameters that were applied to evaluate the load-bearing capacity, deformation resistance, and performance of the modified mixtures. Experimental results of both conventional and waste glass powder modified mixes obtained were made and compared systematically. The effect of different proportions of waste glass powder on strength, durability, flexible and moisture resistance was examined to find out the best replacement percentage proportions that can be applied to construct flexible pavement.

EXPERIMENTAL RESULTS AND DISCUSSION

The experimental study was made on the basis of the investigation of the performance of bituminous mixtures with waste glass powder (WGP) as the partial replacement of traditional mineral filler. Replacement was done with waste glass powder at 0%, 5%, 10%, 15%, and 20%. The findings of the aggregate analysis, bitumen tests, and Marshall Stability test are indicated below and discussed.

Aggregate Test Results

The overall effect figure of 17.8 percent means it is good against sudden impact loads availed by moving cars. Redder values of impact denote robust aggregates with the ability to support the dynamic stress of traffic. The aggregate crushing value of 22.1% elucidates adequate compressive power and carrying capacity needed by flexible pavements. Equally, the value of the abrasion of 24.5% shows that it has sufficient resistivity to wear and surface aggression due to movements in the road. As all the acquired values are within the acceptable limits of the Indian Standards, the aggregates that are acquired can be utilized in construction of pavements making the subsequent observations of the experiment reliable.

Penetration Test Results

With increasing contents of waste glass powder, there was a gradual reduction in the value of penetration. The 68-56 (0.1 mm) decrease implies that the bituminous binder on the increase of the stiffness. Waste glass powder is a fine filler which decreases the mobility of binder and increases internal resistance. The higher the stiffness, the better the resistance attributed to heavy traffic conditions in rutting and permanent deformation. Nevertheless, over-stiffness of higher replacement will lead to a loss of flexibility and susceptibility to cracking.

Softening Point Test Results

The softening temperature increased gradually with the increase in waste glass powder content, indicating improved resistance of the modified bitumen to softening at elevated temperatures. Higher softening point values suggest enhanced thermal stability of the binder, which may help reduce the susceptibility of pavements to bleeding and rutting under high-temperature conditions. This improvement indicates better performance of the binder in resisting deformation at elevated service temperatures.

Ductility Test Results

The values of ductility reduced as the content of glass powder increased because of higher rigidity of the modified mix. The decrease implies a constrained ability to elongate due to hard glass particles in the binder system. However, even with 15 percent replacement the ductility is acceptable and therefore offers enough flexibility to withstand stresses caused by the traffic without cracking.



**Flash and Fire Point Results**

There was an increase in the temperatures of flash and fire points with the addition of waste glass powder. A good thermal stability and safe handling properties of mixtures and building processes are shown by the increased ignition temperatures. Glass powder is inert, which reduces the volatilization of the lighter components of bitumen, and thus increases resistance to accidental ignition.

Stripping Value Test Results

The value of stripping and the content of glass powder waste declined substantially with the content of the waste powder, which implied that there was better adhesion among aggregates and between aggregates and the binder. Glass powder occupies the micro-voids in the mixture and improves the effectiveness of coating, thus minimizing moisture penetration. Better moisture resistance helps to bring increased durability of pavement and minimal maintenance.

Marshall Stability and Flow Results

The Marshall Stability values increased steadily up to 15% waste glass powder replacement, indicating an improvement in the load-carrying capacity of the asphalt mix. The presence of angular and rigid glass powder particles may contribute to better aggregate interlocking and increased internal resistance within the mix, resulting in higher stability values. Beyond 15% replacement, a slight reduction in Marshall Stability values was observed, which may be attributed to excessive filler content affecting proper binder coating and workability of the mix. The flow values remained within the specified limits of 2–4 mm, indicating acceptable deformation characteristics and adequate flexibility of the modified asphalt mixture.

The findings of the experiment demonstrate that addition of waste glass powder enhances greatly the stiffness, temperature resisting, adhesion as well as strength of bituminous mixtures. The maximum stability was obtained at 15 percent of replacement which gave balanced stability and flexibility application in flexible pavement.

Findings and Conclusion**Major Findings**

The experimental study was carried out to assess the performance of flexible pavement mixes with the usage of waste glass powder as a partial substitute of traditional mineral filler with the help of VG-40 grade bitumen. According to the laboratory test findings and other analytic observations, the following key findings were established:

- The aggregate test data met Indian Standard standards, as far as sufficient toughness, strength, and abrasion resistance are required to build flexible pavement.
- The penetration values declined with an increase in the content of waste glass powder and this situation implied that the binder was becoming stiffer and was becoming more resistant to the permanent deformation during loading under traffic.
- It was observed that the softening point of the bitumen increased as the quantity of waste glass powder was added and this showed greater resistance to high temperature conditions and lesser affinity to rutting.
- Ductility values were gradually decreasing with the increase of the content of the glass powder in the mixture because of higher rigidity of the modified binder; however, acceptable flexibility was ensured until 15 factor of replacement.
- Flash and fire point temperatures rose as waste glass powder was added, which implies that the waste glass powder is more stable in terms of thermal properties and can be safely handled during mixing and construction processes.
- The percentage of stripping was reduced with the addition of the glass powder, which confirmed the improvement of the adhesion between the aggregates and binder and resistance to the moisture damage.





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- Increase in Marshall Stability: Adding powder of waste glass enhanced the Marshall Stability values significantly and the values were found to be maximum at 15 percent replacement and thus the load carrying capacity of the bituminous mix was improved.
- Flow values were kept within acceptable values, which proved that the modified mix was not overly deformed.

CONCLUSION

The current research shows that waste glass powder can be successfully used as an alternative filler material that should be applied to the flexible pavements as a sustainable one. Waste glass powder incorporation enhances the mechanical strength, thermal resistance and moisture durability of bituminous mixes compared to the traditional mixes. The stability and stiffness are also improved due to angularity of particles and high silica content of the waste glass powder, which makes the aggregate interlock with each other and the binder filler to interact. Higher values of softening point and lower values of penetration are signs of higher resistance to rutting and deformation of heavy traffic and high-temperature conditions. The enhanced adhesion properties also add to the increased service life, which is delivered by pavements, since stripping and failures caused by moisture are reduced.

Out of the various replacement levels that were evaluated, 15% waste glass powder replacement was determined as the most appropriate content, and it offered the right balance of power, elasticity and longevity. The replacement over and above this level led to a marginal decrease in stability through too much filler content in terms of workability and coating of binders. Besides the benefits to performance, the use of waste glass powder is also characterized by important environmental benefits in terms of decreased landfill disposal, less use of natural filler materials, and the development of sustainable infrastructure. Thus, it can be stated that the use of waste glass powder modified bituminous mixes is recommendable in the use of flexible pavement especially in areas that are exposed to heavy traffic and high temperatures.

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Table 1 - Aggregate Properties

Test	Test Result (%)	IS Permissible Limit
Aggregate Impact Value	17.8	< 24
Aggregate Crushing Value	22.1	< 30
Los Angeles Abrasion Value	24.5	< 30

Table.2 - Penetration Values

WGP Content (%)	Penetration (0.1 mm)
0	68
5	65
10	62
15	59
20	56

Table.3 - Softening Point Values

WGP Content (%)	Softening Point (°C)
0	49
5	51
10	53
15	56
20	58

Table 4 - Ductility Values

WGP Content (%)	Ductility (cm)
0	78
5	72
10	66
15	60
20	52



Mohd Saud *et al.*,**Table 5 - Flash and Fire Point Values**

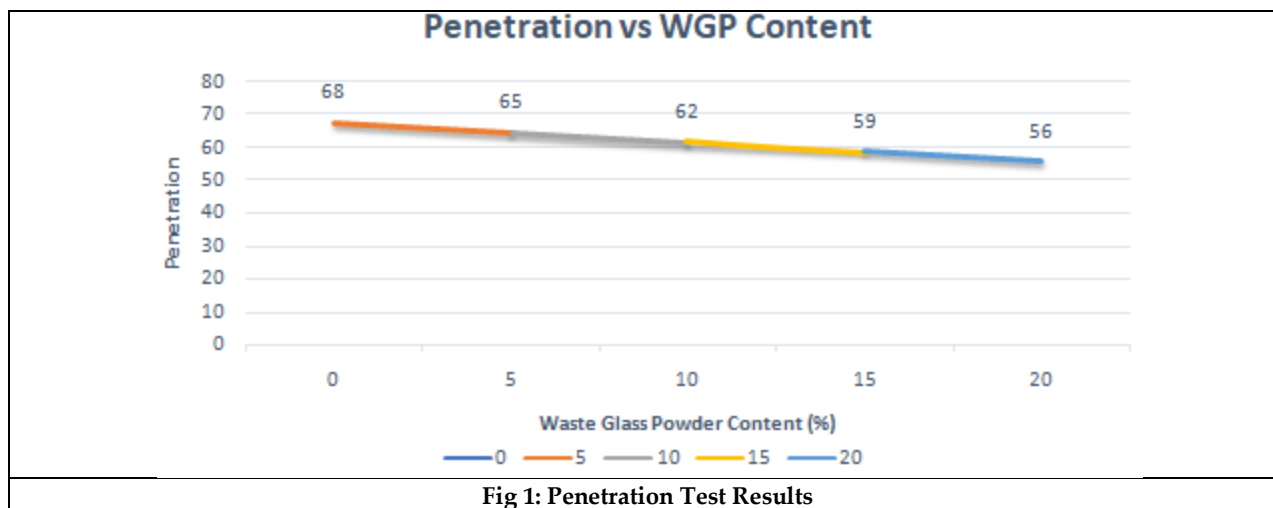
WGP Content (%)	Flash Point (°C)	Fire Point (°C)
0	232	245
5	236	250
10	241	256
15	247	262
20	252	268

Table 6 - Stripping Value

WGP Content (%)	Stripping Value (%)
0	8
5	6
10	4
15	3
20	3

Table 7 - Marshall Stability and Flow Values

WGP (%)	Stability (kN)	Flow (mm)
0	9.8	3.6
5	11.2	3.4
10	12.6	3.2
15	13.9	3.1
20	12.8	3.5





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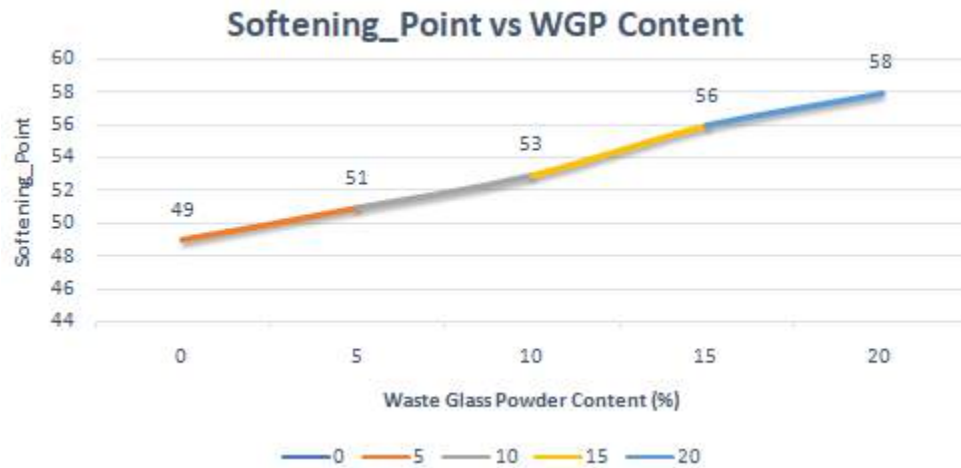


Fig 2: Softening Point Test Results

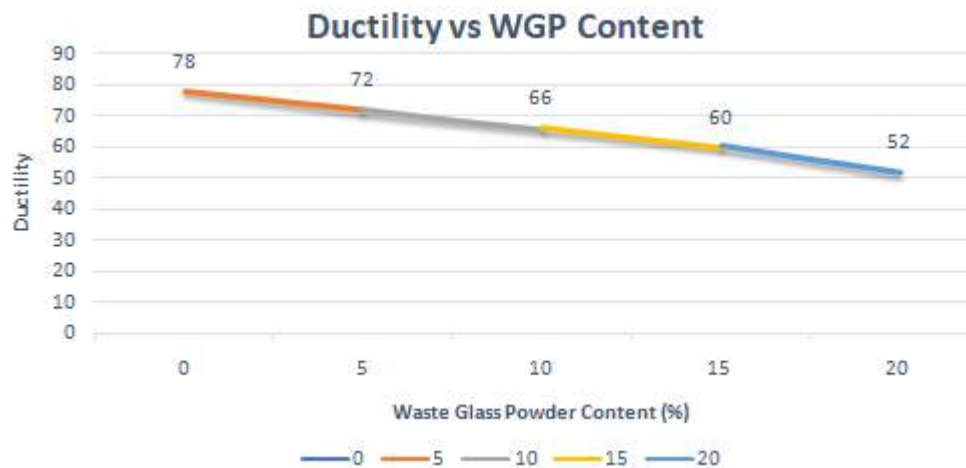
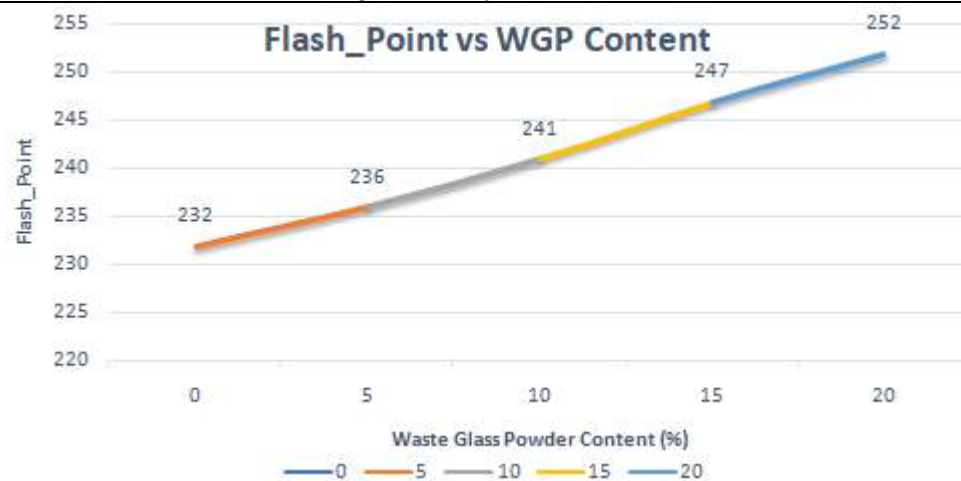


Fig 3: Ductility Test Results





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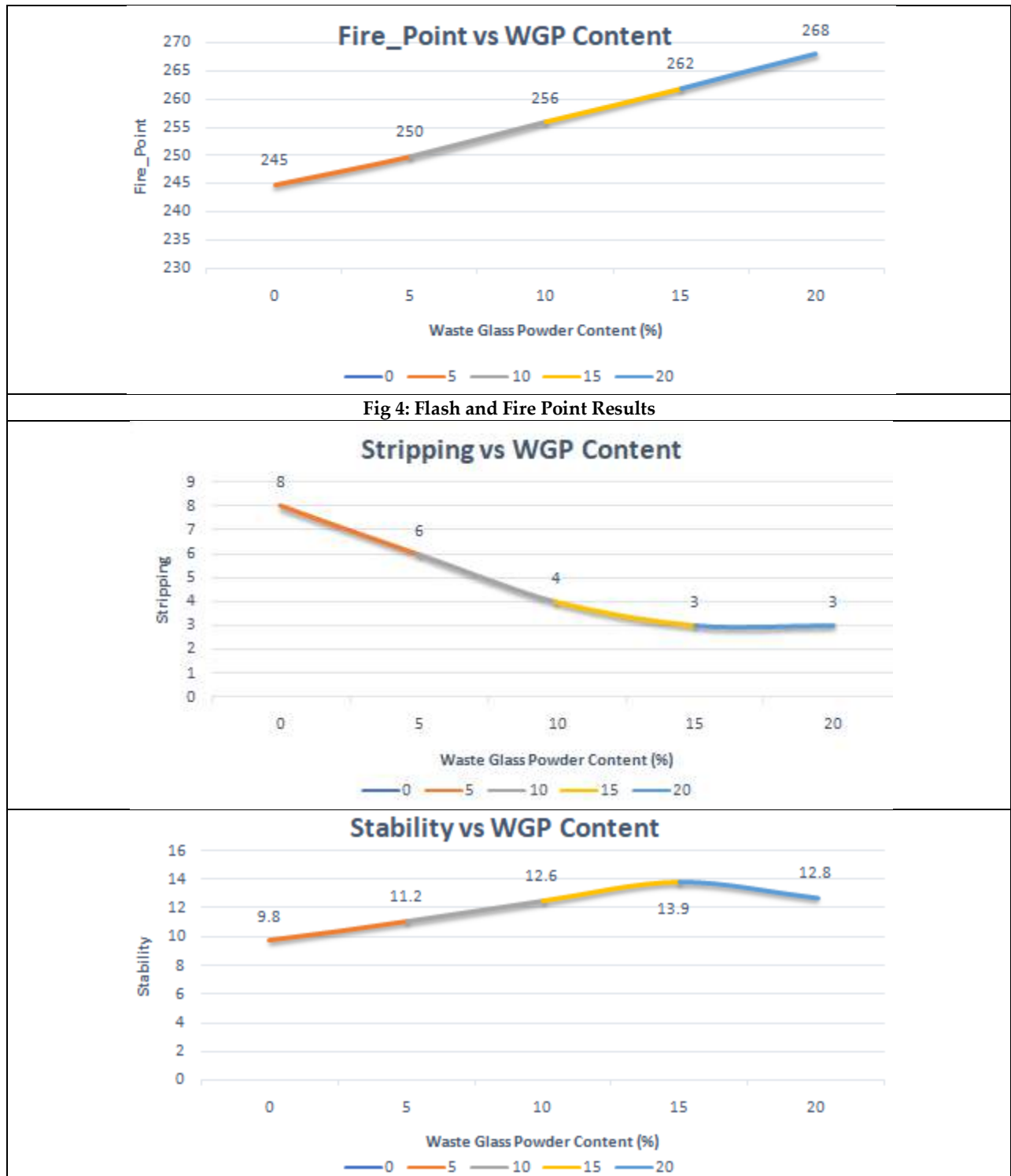
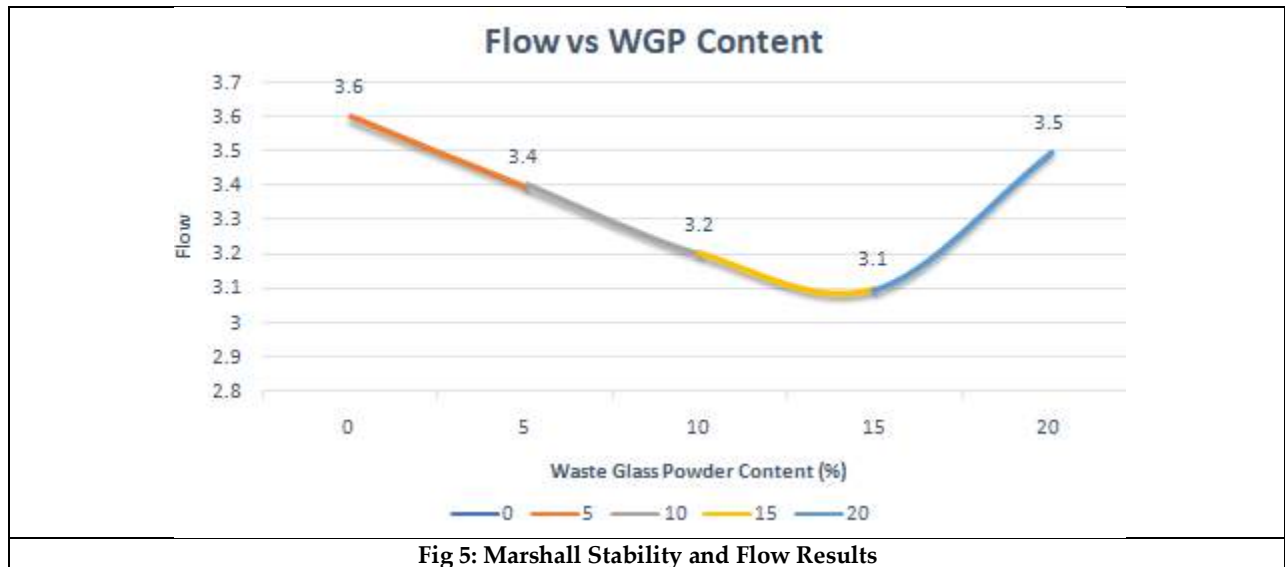


Fig 4: Flash and Fire Point Results



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RESEARCH ARTICLE

Effectiveness of Median Nerve Mobilization on Hand Grip Strength, Pinch Strength and Median Nerve Conduction Velocity among College Students with Smartphone Overuse : A Two Group Pre-Test Post-Test Randomised Controlled Trial Study Protocol

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ABSTRACT

Background: Excessive smart phone use has been associated with altered upper-limb function, including decreased hand grip strength, pinch strength and motor nerve conduction velocity of median nerve due to repetitive stress on the median nerve. Median nerve mobilization is a therapeutic technique that may improve nerve function. To evaluate the effectiveness of median nerve mobilization in improving hand grip strength, pinch strength, and median nerve conduction velocity among college students with smart phone use. Two-group pre-test- post-test randomised controlled trial. College students aged 18 to 30 years who use smart phones for more than 3.5 hours per day will be recruited and randomized into experimental and control groups. The experimental group will receive median nerve mobilization using ULTT1-based sliding and tensioning techniques, while the control group will receive stretching and strengthening exercises. The intervention will be delivered three times per week for four weeks. Outcomes will be assessed at baseline and after four weeks. Data will be analysed using SPSS. Normality will be checked using the Shapiro-Wilk test. Depending on the distribution, paired t-test or Wilcoxon signed-rank test will be used for within-group comparison, and independent t-test or Mann-Whitney U



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test will be used for between-group comparison. A p-value of less than 0.05 will be considered statistically significant.

Keywords: Median nerve mobilization, hand grip strength, pinch strength, median nerve conduction velocity, smart phone usage, randomized controlled trial.

INTRODUCTION

The median nerve is one of the major mixed peripheral nerves of the upper limb and a key player in hand function, during the control of fine object manipulation, both at the sensory and motor levels. In fact, during effective manipulation, the motor mechanisms to regulate the hand's muscles and the sensory mechanisms related to the fingers' investigations work closely¹⁻². Kinetic chain principles say to the upper limb is composed of up of related segments which coordinate to carry out daily tasks. Put differently, a broad muscle weakness and resulting decrease grip strength would result from muscle weakness generated in one area of the afflicted upper arm³. The hand's capability to grip and move objects are essential for daily life, and specific professions require sustained handgrip strength, that is linked to several illnesses. A valid and reliable handgrip strength assessment is used to specify treatment measures, examine the performance of various techniques, and assess patient functionality⁴⁻⁵. The use of mobile devices particularly smartphones for internet browsing and communication has greatly raised through the past 10 years.

The price of these devices continues to drop, which suggests that more people will use smartphones. Overuse of cell phones has been linked to physical health issues like neck and wrist pain⁶⁻⁷. Over the past few years, the number of individuals using cell phones has steadily increased. It was predicted that there would be 3.5 billion smartphone users worldwide in 2020, a 9.3% increase over 2019⁸. It has also been reported by numerous surveys that the bulk of smartphone users worldwide are younger adults. As indicated by study findings, 50% of teenagers become addicted to their smartphones because of the rise in smartphone usage. Even though cell phones are made to be used with both hands, young people prefer to use them one-handed. A clear influence is observed the usage of smartphones has increased and report in the general clinical literature suggest a connection between using handheld device and upper extremity, which is consistent with the rise in smartphone use⁹. the excessive use of smartphone has been linked to trauma illnesses affecting the wrist ,shoulder ,hand ,neck. It was shown that university students used their smartphones for an average of more than 3.5 hours per day, and that this was associated by thumb base pain.¹⁰Clinical guidelines suggest median nerve mobilization and ncv however, high-quality trials evaluating median nerve mobilization are limited.⁶This study aims to assess median nerve mobilization is improving hand grip strength, pinch strength, and motor nerve conduction velocity of the median nerve among college students with excessive smartphone use.

MATERIALS AND METHODS

Study design

Study Design Parallel design, two – group, pre-test post-test randomized controlled trial

Recruitment and allocation

Recommendations for Interventional Trials (SPIRIT) guidelines will be followed to conduct the trial¹¹. The results obtained from the trial will be written using the CONSolidated Standards of Reporting Trials for non-pharmacological trials (Modified CONSORT) checklist and the template for intervention, description, and replication (TIDieR). Outcome measurements will be taken at baseline and after completion of intervention at 4 week. The schematic Consolidated Standards of Reporting Trials flow chart for the study protocol is shown in Figure.1.



**Study setting**

The study will be conducted at Maharishi Markandeshwar Institute of Physiotherapy and Rehabilitation, Mullana, Ambala, Haryana, India.

Study Population

College students with smartphone overuse will be screened for eligibility.

Ethical considerations

The study has been registered with the Clinical Trials Registry of India (CTRI/2025/07/091673) and this study has been approved by the Institutional Ethics Committee (IEC-3448). All procedures will be conducted in strict accordance with the National Ethical Guidelines for Biomedical and Health Research Involving Human Participants (Indian Council of Medical Research), the principles of the Declaration of Helsinki (World Medical Association), and the International Ethical Guidelines for Health-Related Research Involving Humans (2017 revision, Council for International Organizations of Medical Sciences). Written informed consent will be obtained from all participants prior to enrolment, and confidentiality of their data will be ensured throughout the study.¹²

Sample Selection**Inclusion criteria**

- Individuals with high smartphone usage (e.g., using smartphones for > 3.5 hours per day).
- Both male and female college students aged 18 to 30 years
- Individuals with hand grip strength < 27 kg (both males and females)
- Individuals with hand pinch strength < 21.1 lbs for men and < 13.4 lbs for female
- Individuals with motor nerve conduction velocity of median nerve < 49 m/s for males and < 53 m/s for females.

Exclusion criteria

- Individuals with a history of wrist, hand, or forearm injury or surgery in the past 6 months.
- Participants diagnosed with any neurological disorders affecting hand or wrist function (e.g., peripheral neuropathy, carpal tunnel syndrome).
- Presence of any systemic musculoskeletal conditions (e.g., rheumatoid arthritis) that may influence hand function.
- Participants who have undergone recent physical therapy or nerve mobilization for hand or wrist issues within the past 3 months.

Hypothesis**Null Hypothesis (H0)**

The Median Nerve Mobilization will not have a significant effect on Hand Grip Strength, pinch strength and median nerve conduction velocity among college going students with smartphone overuse.

Alternate Hypothesis (H1)

The Median Nerve Mobilization will have a significant effect on Hand Grip Strength, pinch strength and motor median nerve conduction velocity among college going students with smartphone overuse.

Variables**Independent variables**

- Median nerve mobilization

Dependent variables

- Hand-grip strength
- Pinch strength
- Nerve conduction velocity
- Smartphone addiction scale



**Randomization and blinding**

Participants will be randomly divided into two groups: EG (N = 20) and CG (N = 20) using the manual block randomization method. The randomization scheme will be based on a block randomization procedure, and participants will be allocated to either an experimental group or a control group. Figure. 1 As the sample size of this study is 40, therefore, Participants will be randomized using block randomization with a block size of 4 and 1:1 allocation ratio in Figure. 2. Allocation concealment will be maintained using sequentially numbered opaque sealed envelopes (SNOSE)

Intervention

Participants will be divided into two groups: EG and CG. EG will be treated with nerve sliding and tensioning techniques and CG will be treated with Stretching and Strengthening Exercises. The treatment will be given over four weeks by a trained physiotherapist. Sessions are conducted three times per week, each lasting 15 minutes, for a total of 12 sessions.

Intervention for the experimental group (EG)

Patients lay supine with the shoulder abducted to 90° and externally rotated, elbow extended, forearm supinated, wrist, fingers, and thumb extended, and the head positioned for cervical lateral flexion away from the treated arm.¹³ Weeks 1–2, nerve sliding involves alternating wrist/finger extension with cervical side flexion to promote median nerve excursion, performed rhythmically for 2 sets of 10–15 pain-free repetitions.¹⁴ In weeks 3–4, nerve tensioning aims to improve nerve compliance, with cervical lateral flexion maintained and end-range stretch applied at the wrist and fingers for 2 sets of 8–10 repetitions, holding 3–5 seconds per repetition, and discontinued if symptoms worsen.¹⁴

Intervention for the control group (CG)**Stretching Exercises**

(Perform 1–2 times daily; hold each stretch 15–20 seconds, repeat 2–3 times.)

Wrist flexor stretch: Arm straight, palm up, gently pull fingers down/back with other hand.

Wrist extensor stretch: Arm straight, palm down, and gently pull fingers inward/down.

Thumb stretch: Pull thumb gently back away from palm.

Forearm pronation/supination stretch: Slowly rotate palm up and down while elbow flexed 90°. ¹⁵⁻¹⁶

Strengthening Exercises

(Do 3–4 times per week, 8–12 repetitions each, and 2–3 sets.)

Grip strengthening: Use a soft ball or therapy putty, squeeze and hold 3–5 seconds.

Pinch strengthening: Pinch a soft ball/putty between thumb and fingers.

Wrist curls (flexion & extension): Use light weight (0.5–1 kg) or water bottle. ¹⁵⁻¹⁶

Outcome Measures**Hand-grip strength**

A handheld dynamometer is a portable device used for measuring muscle strength, especially grip strength in the hand and forearm, and is widely applied in clinical, sport, and rehabilitation settings. It typically includes adjustable grip handles, a force display, a reset button, and sometimes a digital interface. Standard use involves seating the patient upright with the elbow at 90° and forearm neutral, adjusting the handle for comfort, and instructing the patient to squeeze for 3–5 seconds. Usually, three trials per hand are performed, with brief rests, and the best or average reading is recorded.¹⁵

Pinch strength

A pinch dynamometer is a handheld device that measures pinch strength between the thumb and fingers. The patient sits with the arm at the side, elbow at 90°, and wrist neutral using tip, lateral, or three-jaw chuck grip, they squeeze as hard as possible for three trials, with the best or average value is recorded.¹⁵



**Nerve conduction velocity**

Nerve Conduction Velocity (NCV) measures the speed of electrical signals along peripheral nerves to assess their function. Electrodes are used to stimulate and record the nerve of two different points, and NCV is calculated as the distance between two stimulation points divided by the time taken for the impulse to travel. Normal motor nerve values are about 50-60 m/s.¹⁷

Smartphone addiction scale

The Smartphone Addiction Scale (SAS) is a standardized self-reported questionnaire used to assess the level of smartphone addiction in individuals. Originally developed by Min Kwon et al. (2013), the SAS has been widely employed in clinical and research settings. The scale consists of 33 items; each rated on a 6-point Likert scale ranging from 1 (strongly disagree) to 6 (strongly agree). The total score ranges from 33 to 198, with higher scores indicate greater level of smartphone addiction.⁸

Statistical Analysis Plan

Data will be analyzed using Statistical Package for the Social Sciences (SPSS) version 20.0. The normality of the data will be assessed using the Shapiro–Wilk test, as the sample size is less than 50. Descriptive statistics will be used to summarize demographic variables and outcome measures (mean $\pm$ standard deviation for continuous variables and frequency/percentage for categorical variables). For baseline comparison between groups, an independent t-test (for normally distributed data) or Mann–Whitney U test (for non-normally distributed data) will be applied. For within-group comparison (pre- and post-intervention), a paired t-test (for normally distributed data) or Wilcoxon signed-rank test (for non-normally distributed data) will be used. For between-group comparison of treatment effects, the mean change scores (post-intervention minus pre-intervention values) will be calculated and compared using an independent t-test or Mann–Whitney U test, depending on data normality. A p-value of less than 0.05 will be considered statistically significant.

Risk and Safety

The intervention used in this study is considered low risk, as it involves non-invasive physiotherapy techniques commonly used in clinical practice. However, participants may experience mild discomfort, stretching sensation, or temporary soreness during or after the intervention. All procedures will be performed under the supervision of a qualified physiotherapist to ensure safety. Participants will be closely monitored throughout the study for any adverse events. In case of any unusual symptoms or discomfort, participants will be advised to report immediately to the researcher, and appropriate action will be taken. Participants will also have the right to withdraw from the study at any point without any consequences. All necessary precautions will be taken to minimize risk and ensure participant safety throughout the study duration.

DISCUSSION

Excessive smartphone use has been associated with repetitive strain injuries, including pain and dysfunction in the wrist and hand. These issues are often attributed to prolonged gripping, repetitive thumb movements, and sustained awkward postures during smartphone use, which may lead to increased mechanical stress on the median nerve and restrict its normal mobility.^{9,10} Median nerve mobilization is a neurodynamic intervention aimed at restoring nerve mobility and improving physiological function. It is hypothesized that this technique may enhance axoplasmic flow and intraneural blood circulation, thereby reducing adhesions and improving overall nerve function.¹⁸⁻¹⁹ It is expected that improvements in hand grip strength and pinch strength may reflect enhanced neuromuscular efficiency, possibly due to improved motor unit recruitment and reduced neural inhibition.² Similarly, improvements in median nerve conduction velocity may indicate restoration of normal nerve physiology, which may occur due to reduced intraneural edema, improved vascular supply, and enhanced nerve conduction properties.²⁰ The findings of this study may be consistent with previous literature supporting the effectiveness of neural mobilization techniques in improving both neurological and musculoskeletal function.¹⁹ Clinically, this study may provide evidence





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supporting the inclusion of median nerve mobilization as part of a comprehensive rehabilitation program for individuals with excessive smartphone use and related upper extremity dysfunction.

CONCLUSION

This study aims to evaluate the effectiveness of median nerve mobilization on hand grip strength, pinch strength, and median nerve conduction velocity among college students with excessive smartphone use. It is anticipated that median nerve mobilization may lead to significant improvements in these outcome measures by enhancing neural mobility and physiological function. The findings of this study may contribute to the existing body of evidence supporting neurodynamic techniques and provide a basis for incorporating median nerve mobilization into rehabilitation programs for individuals experiencing upper extremity dysfunction associated with smartphone overuse. Furthermore, this study may help in developing targeted physiotherapy interventions to improve hand function and prevent long-term musculoskeletal complications in young adults.

Disclosure of Interest

There are no interests to declare.

Declaration of Funding

No funding was received.

Caption

Figures

Figure 1: Procedure Flow Chart according to MODIFIED CONSORT guideline

Figure 2: Block randomization with a block size of 4 and 1:1

Author contribution

Conceptualization: SA, K

Draft formation: SA

Supervision: K

Writing- original draft: SA, K

Writing- review & editing: K

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Table 1: SPIRIT schedule of enrolment, interventions, and assessments for participation

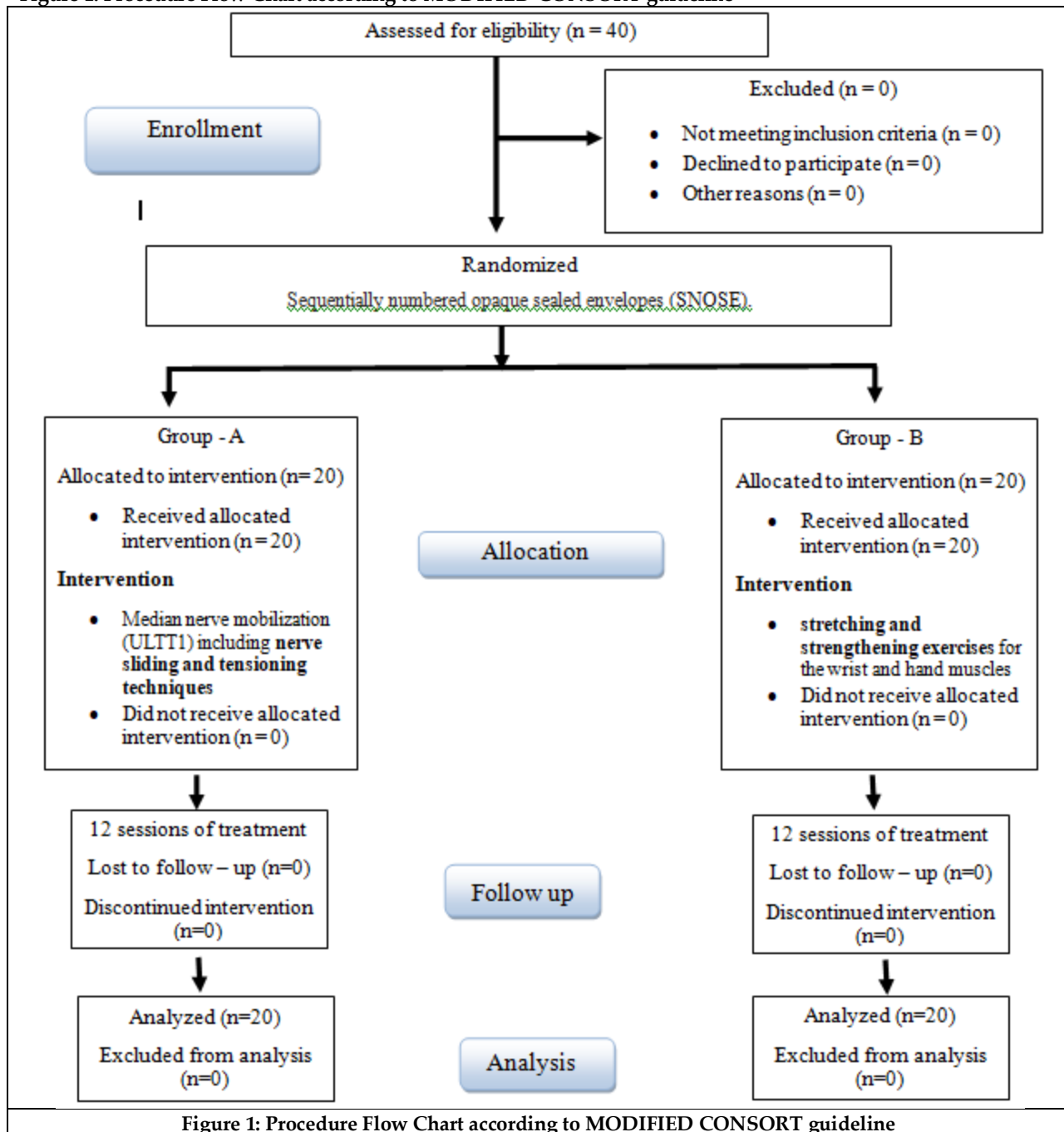
Time point	Enrolment	Allocation	Post-allocation (Treatment)	
	0-week	0-week	1-week	4 th week
Eligibility screening	×			
Informed consent	×			
Allocation		×		
Interventions				
Experimental group (median nerve mobilization)			×	×
Control group (Conventional treatment)			×	×
Assessments				
Demographic data		×		
Hand-held dynamometer (grip strength)		×		×
Pinch meter (pinch strength)		×		×
Median nerve conduction velocity (MNCV)		×		×





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Figure 1: Procedure Flow Chart according to MODIFIED CONSORT guideline





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Rows	EG	CG	EG	CG
1	•	•	•	•
2	•	•	•	•
3	•	•	•	•
4	•	•	•	•
5	•	•	•	•
6	•	•	•	•
7	•	•	•	•
8	•	•	•	•
9	•	•	•	•
10	•	•	•	•

Figure. 2: block randomization with a block size of 4 and 1:1

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RESEARCH ARTICLE

Gullying Induced Land Degradation as an Indicator of Ecological Stress and Shift in Livelihood Opportunities of Santals in South Western Birbhum District, India

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ABSTRACT

Land degradation has significant impact on food security, rural livelihoods, creates environmental and ecological perturbations in developing countries with growing population and resulting in reduction of arable land area. Gullying induced land degradation is a significant indicator of future ecological stress in a land unit due to soil erosion. Rill and gully erosion degrades a parcel of land to badland. The study area is observed to be characterized by incidences of mass movement, weathering and denudation. The spatio temporal estimation of soil erosion in the study area was carried out by using RUSLE method with GIS platform (Arc GIS 10.5) The five parameters used are runoff–rainfall erosivity factor (R), soil erodibility factor (K), slope length and steepness (LS), cropping management factor (C), and support practice factor (P). ResourceSAT 2 with 24 m resolution and LISS III image has been used for estimation LULC change detection. The daily rainfall data (2012–2019) from 4 rain gauge stations located in the South Western Birbhum district have been used to estimate the R factor. The increases in continuous and interrupted gullies with their areal coverage have been estimated and the annual average soil loss of the study area has been classified into five categories for soil loss. The highest rate of gullying was estimated in Rajnagar CD block (>34 t ha⁻¹ year⁻¹) of soil erosion was found along the whereas very low rate of gully formation was observed at Illambazar CD block where the amount of soil loss (<8 t ha⁻¹ year⁻¹) was estimated

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within densely forested areas. The reduction in size of landholdings due to gullying, impacts crop yields. Field observation and analysis reveals that the study area experiences land degradation in the form of sheet, rill, gullying and also through human initiated land degradation processes. There is very sparse or almost no undergrowth on the forest floors resulting in washing away of the loosened top soil. Integrated eco- management for sustainable use of land resources in the study area is required to restore natural spaces to the Santhals to maintain their traditional livelihoods.

Keywords: laterite, pluvial, gully erosion, ecological stress, sustainable

INTRODUCTION

Soil plays an important role in determining the nature of vegetation growth. Soil erosion when uncontrolled leads to ecological stress by restricting natural vegetation growth. In a man nature interface loss of soil cover by natural processes affects crop yields and food security. *Soil loss is a serious environmental threat in humid sub-tropical* (Bera, 2017) regions like the South Western Birbhum district. Soil erosion is a serious problem arising from agricultural intensification, land degradation and other anthropogenic activities. (Ganashri & Ramesh2016) Severe cases of top soil loss and decreased crop yields leads to change in landuse i.e. occupational resources and livelihood opportunities, where the stake holders gradually adapt to other sources to supplement their incomes. Climate, soil, slope, land use/ land cover (LULC), and soil management are all factors that influence erosive (Khadse et al. 2015, Brahim2022) The study has been attempted using climate ,soil constitution ,slope and LULC parameters to determine the extent of land degradation and suggest soil management methods to manage soil erosion. Tropical regions are characterized by pluvial erosion in the form of rain splash, sheet erosion, overland flow in the form of rill and inter rill erosion which later coalesces to gully erosion. Gully erosion is among the major causes for land degradation in tropical regions which are composed of laterite soil. It destructs major portion of the top soil and causes loss of areal parcels of land as a result of slumping, slope retreat and cave ins. This leads to rapid destabilization of land surface, water tables are exposed, draining them out. There is gradual loss of soil moisture leading to depletion of natural vegetation cover, loosening of top soil and washing out of regolith induced by rainfall or wind action .This results in severe land degradation and desertification and crop yields are lowered significantly. Degraded lands account for about 2 billion ha. (15%) in the world, 39.0% in Asia, and about 9.4% in India. Degraded lands in India cover about 187.7 million ha. or 57.1% of its total area.

Objectives

This study is an attempt to -

- analyze the characteristics of soil on the basis of genesis, location and geoclimatic factors of the study area.
- The nature and extent of gullying in the study area, the extent of ecological stress induced by gullying and identify land degradation prone areas in the study area.
- observe and record the change in livelihoods for Santhals due to gullying induced land degradation living in the study area.
- Suggest some remedial measures to maintain the geo-ecological balance in the South Western part of Birbhum District.

Study area

The South Western part of Birbhum district (1128.97sq.km) is between longitude: 86°89'50"E to 87°13'50"E and latitudes 23°23'50"N to 23°52'00"N. The study involves four C.D Blocks of Birbhum District: Rajnagar (225.67 sq.km), Khoyrasole (282.71 sq. km), Dubrajpur (357.98 sq.km), Illambazar -262.61sq.km (Fig.1). The average annual rainfall is recorded at 149.40mm.and temperature in cold months: 5°-10°c (December to February) temperature in warm month: 37° -40°c (April to May). The climate is tropical monsoon type with very hot summers and cold winters and heavy





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monsoonal rains between July to September thus scope for leaching is enhanced. The average Relief is 80 mts and average. The rivers Hingloi, Kopai and Bakreshwar flow from West to South East and are rainfed (Fig.2) The lithological layers, slope, height and drainage density are analyzed to understand the susceptibility of gully erosion of the region. Slope: 1° -3° -Terrain condition is undulating with no sudden changes in profile. Slopes generally prevent infiltration of rain water with regard to their steepness. The general slope of the land is from West to South East with drainage lines flowing SE. The most densely covered natural vegetation is noted to be on the south eastern part of the study area. The western part is elevated and rocky with bare soil in patches.(Fig.3)The eroded detrital finer soil is brought down by pluvial action (surface flow) and drainage lines and deposited in South eastern region providing base for plant growth. The runoff generated from slope will find a path nearby and this would lead to erosion of soil as the velocity of the runoff increases (Gansari&Ramesh2016)

Soil

The soil type is predominantly detritus late rites .Agricultural productivity is very low and most of the arable land remains fallow (Ghosh & Guchchait 2020) after winter harvest in the study area.

Livelihoods practiced by Santhals in the South Western Birbhum district –

- Collection of dry twigs for firewood.
- Collection of Sal (*shorea robusta*) for making plates and bowls.
- Collection of wild mushrooms that grow on forest floors – considered a delicacy in local cuisine.
- Collection of honey during winters.
- Acting as local guides for growing geo tourism of local geomorphosites.
- Farming on flat expanse of land during winters (maize, rice, paddy, potatoes and winter vegetables).
- Bidi (a locally made) from Kendu (*Diospyros melanoxylon*) leaves rolled with tobacco.
- Daily laboring in paddy fields for transplanting seedlings just after monsoon when rain water collects.
- Morrum (loose pebbles from nodules of laterites) collection from top soil layer, used extensively for garden pathways .This alters the slope and topography of the region due to removal from slope pediments.
- Pasturing of domestic cattle on grassland areas

METHODOLOGY

The present work consists of investigation of South Western Part of Birbhum District using satellite data (ResourceSat2, LISS III) 24 metres resolution on 2012 and 2019, (DOP Feb.2012 & May 2019) topographical map interpretation, lithology (SoI) map of the region together with field observation. The procedures included preparation of base map on 1: 50,000 scale by visual interpretation of satellite imageries of the study area and topographical sheets on 1:50,000 scales supplemented by the field investigation and ground truth observation. It was followed by landscape ecological analysis and Revised Universal Soil Loss Equation (RUSLE) method and mapping the study area. They have been used in this study to prepare gully erosion susceptibility maps. The prioritizations of each gully regarding their ranks have been computed by using GIS techniques. On the basis of the field survey the problems of land degradation in the study area have been identified, and appropriate measures have been suggested for sustainable land use planning and management to maintain existing livelihoods of the Santhals in the region. Different types of fluvially induced erosion leading to loss of top soil and are identified in the study area. They are

Splash erosion – The impact of falling raindrops creates small depressions. These coalesce and guide rainwater over a slope in finger like patterns.

Rill erosion– The fingerlike flow channels of water further coalesce to form rills which appear as very narrow channels carrying water and negligible debris down slope under the influence of gravity.(Photo plate 2)

Gully erosion – Numerous adjoining rills joins when the inter space between them is obliterated due to erosive action of flowing water. Normally this takes 2-3 years in fragile laterite profiles in tropical monsoon regions like the study area. (Photo plate 3)

Sheet erosion– The top soil is removed in thin layers by rapid overland flow due to pluvial action on gentle slopes.



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Stream and bank erosion – The washing down of earth material from banks of rivers and streams into the drainage channel.

RUSLE – The Revised Universal Soil Loss Equation(RUSLE) devised by USDA-Agricultural Research Service (ARS) “is an index method having factors that represent how climate, soil, topography, and land use affect rill and inter-rill soil erosion caused by raindrop impact and surface runoff.” in cooperation with the USDA-Natural Resources Conservation RUSLE is derived with the equation:

$$A = R K L S C P$$

Where: A = average annual soil loss,

R = rainfall erosivity factor

K = soil erodibility factor,

L = slope length factor,

S = slope steepness factor,

C = cover-management factor, and

P = supporting practices factor.

The erosion rate of soil loss/ acre per year is derived by substituting values for six RUSLE factors mentioned above for the study area. The study area is characterized by dry summers with thunderstorms and rain at its onset (Nor'westers) which bring in short periods of heavy pounding rain .The months May to mid July are dry with increased low pressure conditions due to bare soil radiating high heat. The onset of monsoons later in July brings heavy rains with the bare soil regions and slope (rolling or steep) aid flowing down of loose soil which accumulate at the base of free fall zones (Photo plate 1). The annual top soil loss amount estimated for four sample villages of Rajnagar, Khoyrasole, Dubrajpur, Illambazar.jungle are assessed to be 38.37%, 27.84%, 35.71% and 11.33% respectively in regard to their total area.

RESULTS

The LULC analysis and field observation reveals that the highest tendency of gully erosion was observed in regions not covered by natural vegetation (Rajnagar, Khoyrasole and Dubrajpur CD blocks). In those areas with natural vegetation or forests, the tendency for gully erosion was negligible. Table 3 displays the spatio-temporal status of gullies and change in affected areas of the four CD blocks of South Western Birbhum district of India between 2012-2019. There are two tendencies of gullies observed in the study area i) continuous gullies and ii) interrupted gullies. The causes for development of continuous gullies are “gentle footslopes in zones of saturation along drainage paths with a large contributing area, erodible duplex soils derived from mudstones and poor vegetation cover due to overgrazing” (LeRoux & Paul, 2012). The interrupted gullies are observed to be situated on the lower pediment zones and usually covered by finer debris brought down by flowing water as sheet erosion(photo plate 4). After the monsoon season these zones have sufficient moisture for sparse natural vegetation to sprout which holds the soil together through its roots. The area wise degradation of land was 457.09 sq.km in 2012 and increased to 458.87 sq.km in 2019. There has been a 1.78 sq km increase (ie 1.71%) in a seven year span in the study area. The LULC analysis (Table 2) reveals that there has been a decrease in dense vegetation regions from 40.76 sq.km to 13.14 sq.km (about 27.62 sq.km) and agricultural/fallow land from 841.12 sq.km to 797.54 sq.km (43.58 sq.km) (Fig.4) with an increase in bare soil from 85.43 sq.km to 139.21 sq.km (53.78sq.km).

DISCUSSIONS

Due to gullying the flat expanse of the soil is interrupted .Soil erosion by pluvial action results in fertile top soil loss.The study area is situated in tropical monsoon climatic region and hence experiences both physical and chemical weathering The nature of laterite soil enhances the scope of rapid disintegration of soil blocks and being friable with little clay or organic content to bind the soil particles together allows free movement of water molecules and initiates leaching. This leads to percolation of essential minerals from regolith to lower parts of the soil profile. The soil of the





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study area is impoverished and gullyng reduces the area allocated for crops. The nature and extent of gullyng in the study area (Table 2) and the extent of ecological stress induced by gullyng is observed to be moderate to severe.

Land degradation as an indicator of ecological stress in the study area

The nature of land degradation process in the study area is observed to be chiefly due to weathering, masswasting and erosion with reduction in soil organic content. The patches of bare soil are lateritic and have moderate to severe rates of degradation. The 4 sample sites are observed for processes leading to land degradation. The forested region of Illambazar displays slow rate of degradation. Different scale of degradation (Severe to very severe degradation) is found in 3.9 Square km or 32.76% of land, in 0.67 Square km or about 55.51 % in Shyambati area and 10.37 Square km or 59.73% in Illambazar forest area where operation of rill-gully erosion initiated badland in reserve forest or moderate relief deformity in protected forest; it is observed near Rajnagar lateritic or rocky surface that shows with low to moderate local mining area of lateritic wastes. The encroachment of sandy or degraded soil towards agricultural land is also observed in the selected four CD blocks. The nature of land degradation here is a precursor to desertification processes in future which will be irreversible. The conservation methods should involve vegetative and engineering measures to prevent further degradation and restore already degraded areas.

Impact of gullyng in the study area

- Deterioration in nature and quality of land.
- Slumping, sliding, slope retreat, undercutting and cave ins of slopes is observed during monsoons.
- Washing down of top soil rapidly, where flow is aided by gully slopes.
- Numerous breaks in expanse and elevation of land which reduces the availability of flat lands for cultivation. This reduces crop yields.

More use of fertilizers. Reduction in arable land leads to pressure on existing flat lands to increase yields.

The characteristic of soil on the basis of genesis, location and geoclimatic factors of the study area is investigated. It is well understood that the interdependence of land use, soil, and water, as well as the connectivity between uplands and downstream areas (Tiderman1996) impacts the rate of land degradation.

A notable change in livelihoods for Santhals due to gullyng induced land degradation in the study area is as follows:

Shift in livelihoods practiced by Santhals in the South Western Birbhum district –

- Working in stone quarries/stone crushing sites endangering lung health.
- Migrating to different states around India to work as unskilled labour at construction sites.
- Selling wares like kitchen utensils, clothing items and other knick knacks locally.
- Women folk go out to work as household help in nearby settlements.
- Bidi (a locally made smoking product) from Kend (*Diospyros melanoxylon*) leaves rolled with tobacco.
- Working in paddy farmlands just after monsoon when rain water collects and stagnates in the farm lands.
- Pasturing area is reduced due to loss of regolith leading to loss of grassland cover and reduced area for grazing cattle.

Suggestions

Some steps have been taken by State Agricultural Department and local bodies to check rapid soil erosion and gullyng. They are as follows—

- Afforestation: Planting trees or afforestation especially in badland topography area is very significant methods of soil conservation.
- Keeping bare soil cover after harvesting.
- Building embankments along riverbanks.
- Poly mulching to plant crops and prevent top soil loss.
- Gully head stabilization by earth plug, brush fills and check dams;
- Improvement of irrigation network,



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- Suitable opportunities and training for dry land farming (by govt. initiative/NGOs)
- The study area is subject to moderate to severe land degradation. This is due to active geomorphic processes like weathering, mass movement and erosion actively in operation in sub humid tropical regions which have genetically poor physical and chemical of the existing soil profile. The removal of natural vegetative cover has triggered severe desertification.

CONCLUSION

Soil moisture encourages vegetation growth. The presence of natural vegetation cover encourages creation and presence of humus that is good for soil health. A natural vegetation cover prevents sheet erosion i.e. removal of top soil through overland flow of water due to pluvial activity. Presence of soil moisture reduces the chance for termite infestation as termites require dry soil to build their nests. The loss of natural vegetal cover causes depletion in organic nutrients that can enrich soil by decaying of leaves and humification. As a result, the soil structure gets impoverished, available plant food along with mineral material is carried away by rain-wash and the ability of the land to hold moisture for plant growth is reduced with the beneficial activity of micro-organisms lessened. Construction of operational approaches to analyzing on soil organic carbon (SOC) as part of sub-indicator which is a major concern for the SDGs. Soils stores the largest proportion of terrestrial carbon pool (TCP) and play a significant role in the global carbon balance (GCB) by the inter-exchange of greenhouse gases with the atmospheric layers and controlling the dynamic bio-geo chemical processes. Macro and micro climatic factors are the key indicator of greenhouse gas emissions from the soil profile and are dominantly influenced by land use, soil management and vegetation covers. Several FAO's work and planning on soils is organized through the Global Soil Partnership (GSP). <https://www.fao.org/land-water/land/ldn/en/>

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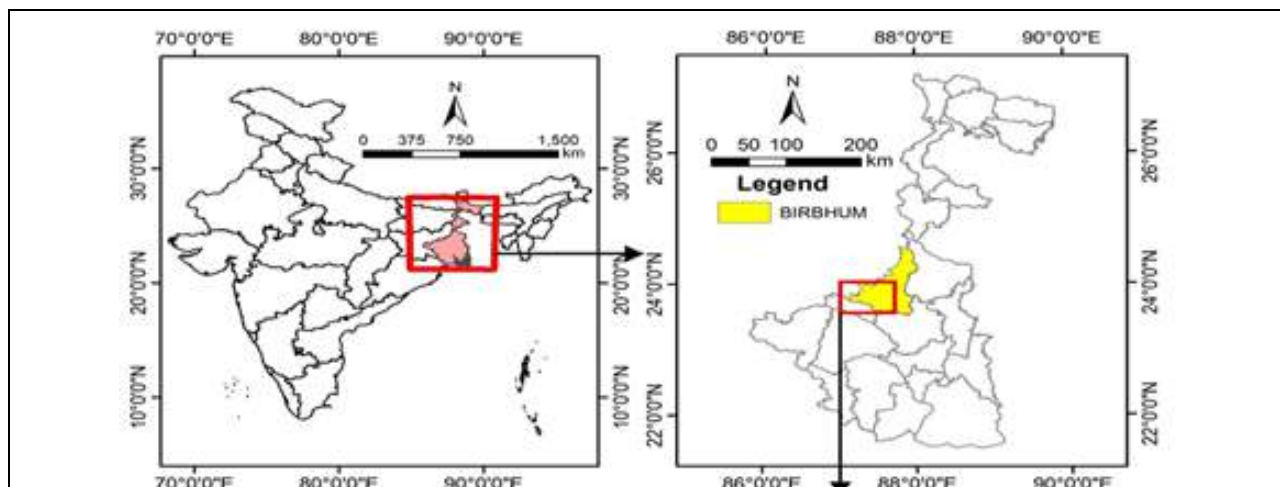
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Table 1 : LULC change detection between 2012 – 2019 of South West Birbhum district, India

Classes	2012 (Area in kms)	Percentage	2019 (Area in kms.)	Percentage	Change Detection
					Area in sq .km
Water	08.10	0.07	17.03	01.51	8.93
Dense Vegetation	40.76	03.61	13.14	01.16	-27.62
Agricultural land & fallow	841.12	74.50	797.54	70.64	- 43.58
Degraded Vegetation & shrubs	116.37	10.31	125.49	11.12	9.12
Settlements and Build up	25.53	2.26	30.81	02.73	5.28
Bare Soil	85.43	7.57	139.21	12.33	53.78
Sand or Dry River Bed	11.66	1.03	05.67	00.50	- 5.99
Total	1128.97	100	1128.89	100	

Table 2 : Status of gully erosion and their areal coverage in South Western Birbhum district , India

CD Block	Area (sq.km)	No. of Gullies		No. of continuous gullies		No. of interrupted gullies		Area affected (sq.km)		% area affected (sq.km)	
		2010	2022	2010	2022	2010	2022	2010	2022	2010	2022
Rajnagar	229.69	11	15	05	08	06	07	104.03	109.11	09.46	09.92
Khoyrasole	292.49	13	14	09	04	04	10	113.01	116.29	10.27	10.57
Dubrajpur	334.88	09	11	06	08	03	03	109.05	110.07	09.91	10.00
Illambazar	271.91	10	12	03	05	07	07	121.60	123.40	11.22	11.22
Total	1128.97	43	52	23	25	20	27	447.69	458.87	40.86	41.71



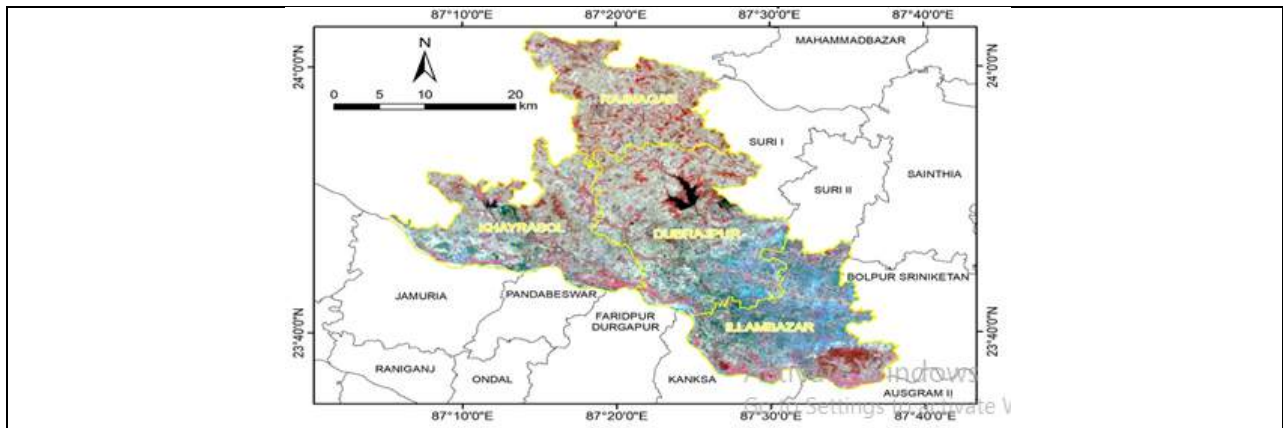


Fig.1 The study involves four C.D Blocks of Birbhum District: Rajnagar, Khoyrasole, Dubrajpur, and Illambazar

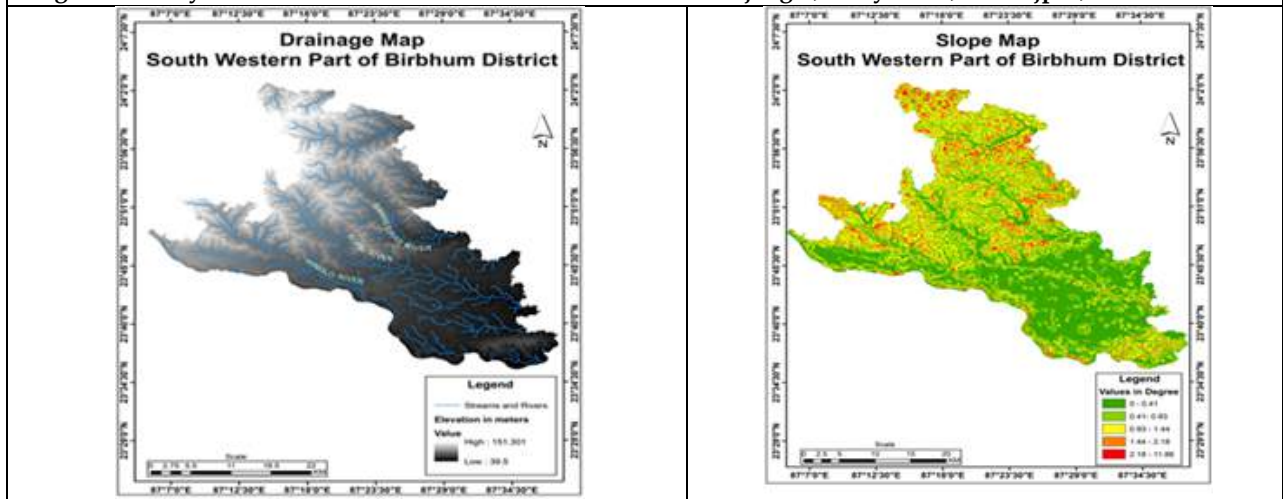


Fig.2 Drainage

Fig.3 Slope

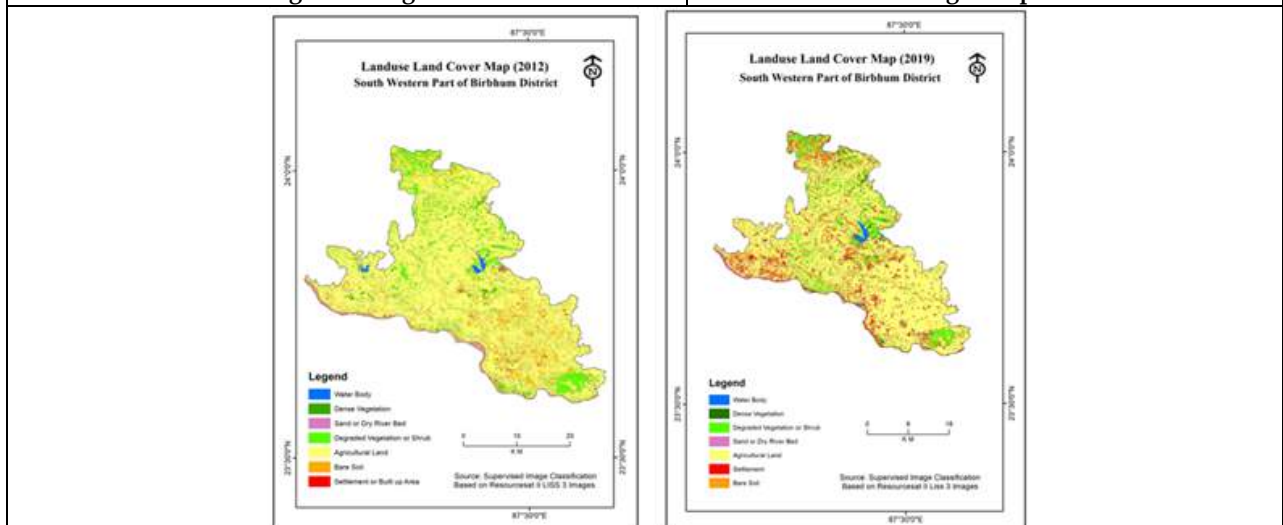


Fig.4(i & ii) LULC change detection (2012 - 2019) for South West Birbhum district, India



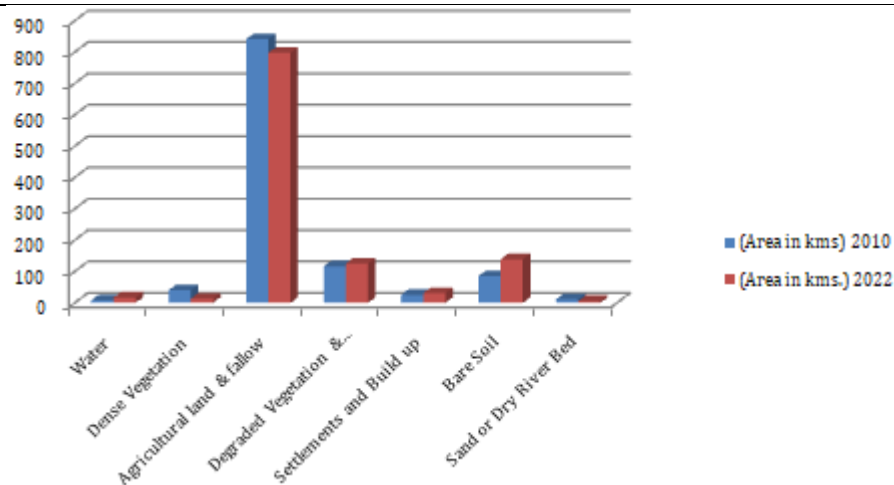
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Fig 5 : Showing LULC pattern of 2012 and 2019 South West Birbhum district, India

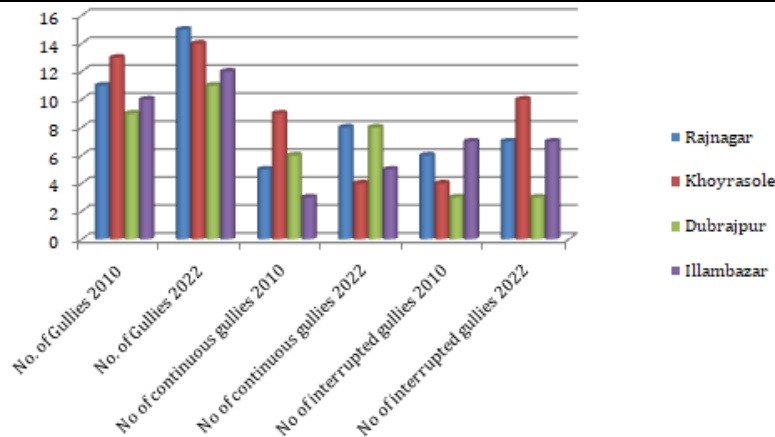


Fig 6 : Showing the distribution of different types of gullies during 2010 and 2022

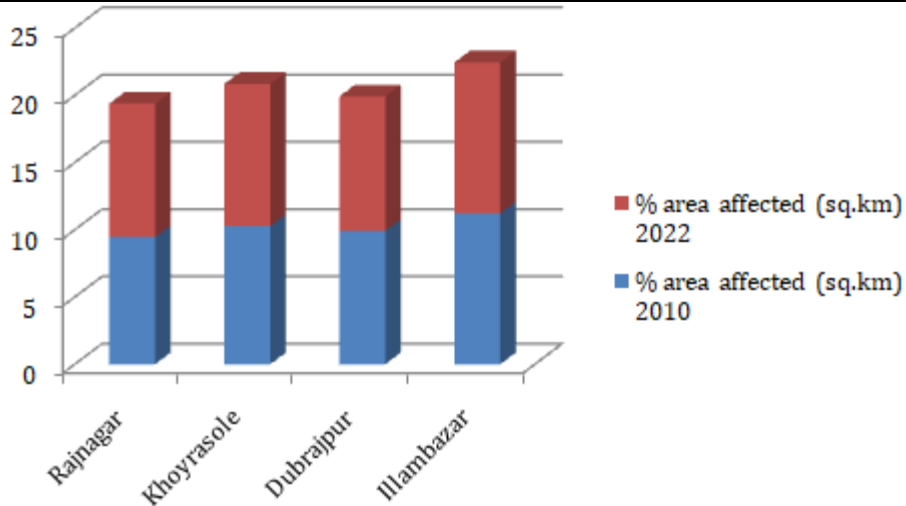


Fig 7 : Showing % of gullies affected area in comparison to 2010 and 2022





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Photo plate 1: Initiation of rills	Photo plate 2: Rills coalesce to form gullies
	
Photo plate 3: Matured gully	Photo plate 4: Poly mulching to prevent soil erosion
	
Photo plate 5. Mushrooms on forest floor	Photo plate 6. Degraded landscape



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Photoplate 7: Slumping with finer debris at pediment	Photoplate 8: Hard topped mesa like feature
	
Photoplate 9: Gullies initiated from slope.	Photoplate 10. Undulating slope in Rajnagar CD block
	
Photo plate 11. Free face slope in Rajnagar CD block.	

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RESEARCH ARTICLE

Video Instance Segmentation: A Comprehensive Survey

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ABSTRACT

Video Instance Segmentation (VIS) is a complex computer vision task that requires simultaneously detecting, segmenting, and tracking object instances across video frames. It represents a significant step beyond image-level segmentation by introducing the critical element of temporal consistency. This paper provides a comprehensive survey of the evolving landscape of VIS. We begin by outlining the fundamental challenges that distinguish VIS from its image-based counterpart, including occlusions, motion blur, and the need for robust temporal association. The survey then systematically categorizes and reviews modern VIS methodologies, dividing them into three predominant paradigms: online methods, which process frames sequentially for real-time applications; offline methods, which utilize future frames for higher accuracy; and the emerging query-based methods, which leverage attention mechanisms to unify the task.

Keywords: Video Instance Segmentation, Video Object Tracking, Instance Segmentation, Temporal Modeling, Computer Vision.





INTRODUCTION

The field of computer vision has made remarkable strides in understanding static images, with tasks like object detection and instance segmentation achieving human-level performance on many benchmarks [1]. However, the visual world is inherently dynamic. Videos, which constitute a vast portion of visual data, present a more complex and richer domain for analysis. Video Instance Segmentation (VIS) has emerged as a pivotal task that sits at the intersection of image instance segmentation and multi-object tracking. The goal of VIS is not only to identify and precisely delineate each object in every frame but also to consistently associate the same object instance across the temporal dimension of the video [2]. This unification offers a more holistic understanding of visual scenes, enabling applications that require a fine-grained and persistent perception of objects. Such applications are diverse and critical, including autonomous driving, where tracking other vehicles and pedestrians is essential for navigation; video editing and content creation, allowing for automated object manipulation; video surveillance for security and monitoring; and advanced human-computer interaction systems [3].

Despite its potential, VIS is fraught with challenges that are absent in image-based tasks. Factors such as significant object motion, partial or complete occlusions, motion blur, changes in appearance and lighting, and the computational burden of processing frame sequences all contribute to the difficulty of the problem [4]. A successful VIS system must be robust to these temporal variations while maintaining high spatial accuracy. The objective of this survey is to provide a structured overview of the current state of Video Instance Segmentation. We will trace the evolution of VIS methodologies from their early prototype stages to the sophisticated deep learning models of today. We will categorize existing approaches, analyze their strengths and weaknesses, and review the standard benchmarks and metrics used for evaluation. By synthesizing the recent advancements and identifying open challenges, this paper aims to offer a clear roadmap for future research in this rapidly advancing field.

Objectives

The primary objectives of this survey paper are as follows:

- **To Define and Formalize the VIS Task:** Provide a clear and concise definition of the Video Instance Segmentation problem, distinguishing it from related tasks like video object segmentation (VOS) and tracking-by-detection.
- **To Categorize Methodological Paradigms:** Systematically organize and present a taxonomy of contemporary VIS methods, with a focus on the key distinction between online, offline, and query-based frameworks.
- **To Review Key Architectures and Techniques:** Delve into the technical details of representative state-of-the-art models, explaining their core components, such as propagation networks, association modules, and the novel use of object queries in transformer-based architectures.
- **To Summarize Benchmarks and Evaluation:** Catalog the standard datasets (e.g., YouTube-VIS [2], OVIS [5]) and evaluation metrics (e.g., average precision and recall) used to measure progress in the field.
- **To Identify Challenges and Future Directions:** Highlight the persistent challenges facing VIS research and propose promising avenues for future work, including the integration of large-scale models, self-supervised learning, and efficiency improvements.

METHODS

The methodologies for Video Instance Segmentation can be broadly classified into three main paradigms based on their inference strategy and architectural design.

Online Methods

Online methods represent the foundational approach to the Video Instance Segmentation (VIS) task. Characterized by their sequential, frame-by-frame processing, these methods are designed for scenarios requiring real-time or low-





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latency inference, such as autonomous navigation and live video analysis. The core principle of online methods is to propagate information from past frames to the current frame to maintain temporal consistency of instance identities.

- **Detection-based Propagation:** Early methods like MaskTrack R-CNN [2] extended the popular Mask R-CNN [1] architecture by adding a tracking head. This head takes the previously predicted mask and RoI features to compute similarity scores for association in the current frame.
- **Feature Propagation:** Subsequent works focused on propagating deep features rather than just masks. For instance, STEm-Seg [6] constructs a spatiotemporal volume from a clip of frames and uses 3D convolutions to jointly model spatial and temporal contexts, generating instance masks and associations simultaneously.

Offline Methods

Offline methods, also known as clip-based or batch processing methods, represent a fundamental paradigm in Video Instance Segmentation (VIS) that leverages global temporal context to achieve superior accuracy and robustness. Unlike their online counterparts that process frames sequentially, offline methods operate on complete video clips, enabling them to utilize information from both past and future frames simultaneously.

The core philosophy of offline VIS stems from the observation that human visual perception often requires looking ahead and behind to resolve ambiguities in complex scenes. When humans encounter occlusions or rapid motion in videos, we naturally use contextual information from adjacent frames to maintain consistent object identities and precise boundaries.

- **Proposal Linking:** Methods like CrossVIS [7] generate instance segmentation masks for each frame independently and then link these masks across frames in a post-processing step using learned similarity measures. This can be computationally expensive but achieves strong performance.
- **Dense Feature Correlation:** These approaches build a dense feature representation for the entire video and perform segmentation and tracking in a unified volume. They excel at handling complex motions but can be memory-intensive for long videos.

Query-Based Methods

Video Instance Segmentation has undergone a revolutionary transformation with the advent of query-based methods, marking a significant departure from traditional multi-stage pipelines. This paradigm shift represents the convergence of several key trends in computer vision. Inspired by the success of DETR [8] in object detection, a new paradigm has emerged that frames VIS as a set prediction problem. This family of methods has rapidly become state-of-the-art. Traditional VIS methods inherited a fragmented approach from their image-based predecessors, treating detection, segmentation, and tracking as separate problems requiring complex hand-crafted components. The breakthrough came with the adaptation of transformer architectures from natural language processing to computer vision. The key insight was recognizing that VIS could be reformulated as a set prediction problem, where the goal is to directly predict a set of video-level instance tracks from pixel-level features.

- **VIS with Transformers (VisTR):** VisTR [9] was a pioneering work that directly models VIS as a sequence-to-sequence problem. It leverages a transformer architecture to process a sequence of video frames and output a sequence of instance predictions for the entire video clip in one pass, eliminating the need for many hand-crafted components like non-maximum suppression or tracklet association.
- **Improved Query Design:** Building on VisTR, methods like Mask2Former-VIS [10] and VITA [11] introduced deformable attention and contrastive learning for queries, respectively, to improve efficiency and handle a larger number of instances. These models use a fixed set of object queries that interact with the spatiotemporal feature volume via attention mechanisms to simultaneously decode the spatial extents and temporal identities of all instances.





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Application Scenarios

- **Choose Online Methods when:**
 - Real-time processing is critical
 - Hardware resources are limited
 - Application can tolerate occasional tracking failures
 - Examples: Autonomous vehicles, surveillance systems
- **Choose Offline Methods when:**
 - Accuracy is more important than speed
 - Full video context is available
 - Complex occlusions need to be handled
 - Examples: Video editing, scientific analysis
- **Choose Query-Based Methods when:**
 - State-of-the-art performance is required
 - Research and development focus
 - Unified architecture is preferred
 - Examples: Benchmark competitions, advanced applications

DISCUSSION

The field of Video Instance Segmentation has progressed at an accelerated pace, largely driven by the adoption of transformer architectures and the conceptualization of the task as a direct set prediction problem. The query-based paradigm, in particular, has simplified the overall pipeline and set new performance standards. However, several challenges remain. First, the computational cost of processing long video sequences is still prohibitive. While clip-based methods are effective, scaling them to minute-long videos requires efficient memory and attention mechanisms. Second, generalization to unseen object categories and complex real-world scenarios, such as crowded scenes with severe and prolonged occlusions (as in OVIS [5]), is still inadequate. Most models are trained and evaluated on curated datasets and struggle with domain shift.

- **Efficient Long-Range Modeling:** Developing architectures that can efficiently capture long-term temporal dependencies without quadratic memory growth.
- **Self-Supervised and Weakly-Supervised Learning:** Reducing the reliance on expensive per-frame mask annotations by leveraging unlabeled video data for pre-training [13].
- **Unified Video Understanding Models:** Moving beyond a single task, future models may aim to jointly perform VIS, action recognition, and video captioning in a single, holistic framework, perhaps inspired by large language-vision models [14].
- **Robustness and Fairness:** Ensuring that VIS models are robust to adversarial attacks and do not exhibit biases against certain object types or in varying environmental conditions.

In conclusion, while current VIS methods, especially query-based models, have demonstrated impressive capabilities, the path towards human-level video understanding is long. The key to future breakthroughs lies in creating more efficient, generalizable, and holistic models.

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Table 1: Comprehensive Comparison of VIS Methodologies

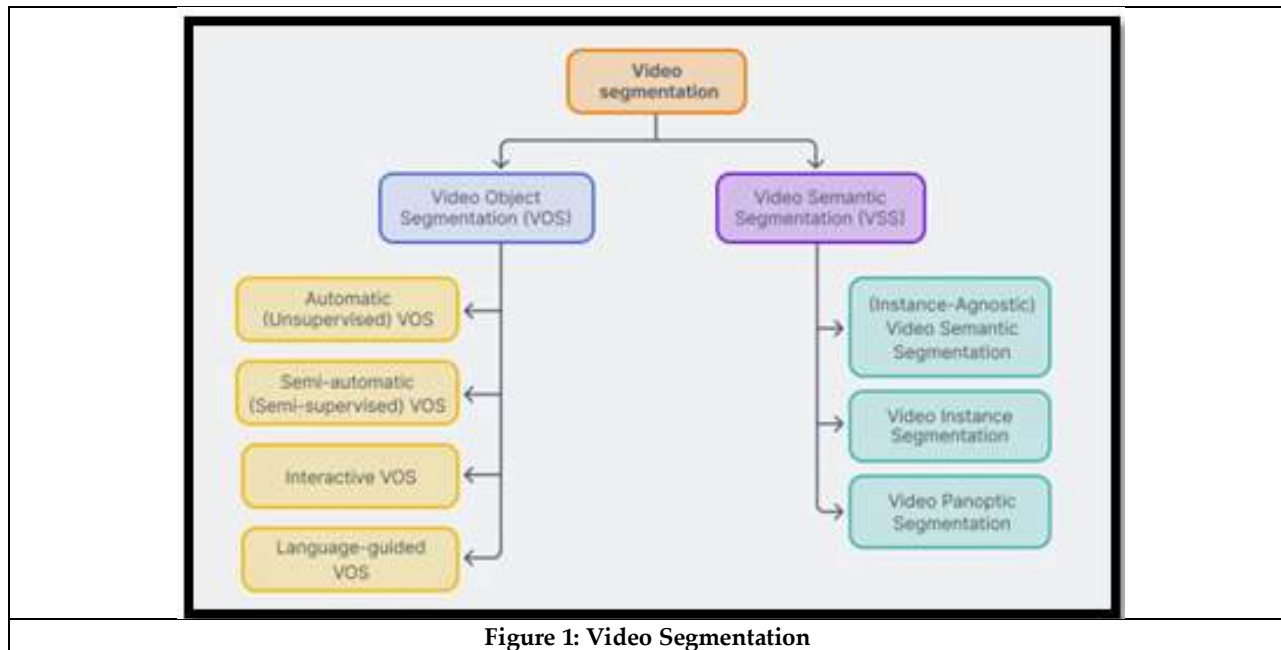
Aspect	Online Methods	Offline Methods	Query-Based Methods
Processing Strategy	Frame-by-frame sequential processing	Entire video clip processing	End-to-end set prediction
Temporal Context	Limited to past frames	Full clip context (past + future)	Variable context length
Inference Type	Real-time capable	Batch processing	Batch processing
Architecture	Multi-stage pipeline	Two-stage: detection + association	Unified transformer-based
Key Components	Detection head + tracking head	Per-frame masks + linking algorithm	Object queries + attention
Temporal Modeling	Propagation-based	Feature matching & optimization	Attention mechanisms
Memory Usage	Low	High	Moderate to High
Inference Speed	Fast	Slow	Moderate
Accuracy	Moderate	High	State-of-the-art
Typical AP on YouTube-VIS	30-35%	34-40%	40-50%+





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Handling Occlusions	Poor to Moderate	Good	Excellent
Implementation Complexity	Moderate	High	Moderate
Representative Models	MaskTrack R-CNN, SipMask	STEm-Seg, CrossVIS	VisTR, IFC, Mask2Former-VIS



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RESEARCH ARTICLE

Constructing Sequences of Dio-3 Tuples from 30- Gonal Figurate Numbers of Eclectic Genres of Ranks

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ABSTRACT

This study looks into the construction and characteristics of Diophantine triples made from centered triacontagonal numbers across different ranks. The paper creates these 3-tuples using generalized half-companion sequences and explores their mathematical properties. It especially focuses on their connection to 30-sided figurate numbers. A key analytical step is testing whether these triples can be extended into quadruples. This is done by determining which ranks allow for the addition of a fourth element through a careful algebraic procedure that often involves solving simultaneous Pellian equations. The research uses MATLAB for computational simulations to support the theoretical findings. These simulations reveal complex numerical patterns and give a visual representation of the relationships between the sequence ranks and their Diophantine features.

Keywords: quadruples, triacontagona, Diophantine features, Diophantine equations

INTRODUCTION

Diophantine equations is an essential part of number theory. It has important uses in modern cryptography and network security. One interesting area in this field is the creation of Diophantine triples and their special variants. This study dates back to Diophantus of Alexandria, who first found sets of rational numbers $\{a_1, a_2, \dots, a_m\}$. In these sets, the product of any two different elements, when increased by one, results in a perfect square, $a_i a_j + 1 = k^2$.





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Over time, this exploration has moved from rational numbers to integer sequences, leading to significant research on how to extend these sets. The study of Diophantine m -tuples involves m positive integers where the product of any two distinct elements plus a given integer n is a perfect square. This area has grown a lot in the last decade. Early in that time, Bačić and Filipin (2013)[1] set key limits on how $D(4)$ -pairs can be extended. They showed how specific square values of n affect the size of these sets. Then, Zhang and Grossman (2015)[2] provided a broader description of the structural properties that control Diophantine triples and quadruples. Their work supported the growing agreement on the finite nature of these sets. By 2018, Adzaga et al.[3] broadened the field by looking into rare triples that meet the $D(n)$ property for several values of n at once. As the decade ended, research started to link with specific number sequences. For example, Saranya and Janaki (2019)[4] used half-companion sequences to create special Dio-triples that focus on centered square numbers.

The year 2020 was a productive time for the field. Cipu, Filipin, and Fujita (2020)[5] provided a thorough analysis of pairs that produce specific triples. At the same time, Park (2020)[6] addressed the unique challenges of the $D(-1)$ property. Earp-Lynch et al. (2020)[7] expanded square-value properties by studying the $D(9)$ and $D(64)$ cases. In 2021, research became more specialized. Adzaga, Filipin, and Jurasic (2021)[8] looked into the specific triple $\{2, b, c\}$. Adedji et al. (2021)[9] explored the pair $\{a, 3a\}$ in depth. These studies were important for improving the computational and analytical tools needed to tackle the toughest conjectures in the field. The climax of these efforts came in 2022. Bonciocat, Cipu, and Mignotte[10] published a crucial proof that confirmed the non-existence of $D(-1)$ -quadruples, resolving a long-standing mystery in number theory. That same year, Rihane, Luca, and Togbe (2022)[11] combined these theories with classic recurrence sequences, proving that Diophantine quadruples made entirely of Pell numbers do not exist. Recently, attention has shifted to the overlap of Diophantine sets and complex polygonal numbers. Sangeetha et al. (2023)[12] introduced new constructions for special triples. The latest work by Shanmuga Priya and Janaki (2023)[13] used generalized half-companion sequences to investigate configurations with centered triacontagonal numbers. This work represents the current state of connecting Diophantine properties with higher-order geometric sequences.

Building on the foundational research in $D(n)$ -sets and figurate number sequences, this paper introduces the construction of generalized half-companion sequences linked to Diophantine triples derived from centered triacontagonal numbers. We study these triples across various ranks, specifically examining the neighbor-based configurations $(n-l, n+l)$ and $(n, n+l)$ for integer l . Our goal is to identify the unique arithmetic properties that emerge within these 30-sided polygonal structures in section 3. Section 4 presents a theoretical framework for the extensibility of these sets. It also includes formal theorems that explore the maximality of these triples and outlines the conditions that prevent their extension into quadruples. Finally, Section 5 describes these properties alongside computational visuals created in MATLAB, providing numerical support for the observed patterns.

Preliminaries

Definition 1 A centered triacontagonal number (CTG) is a type of centered figurate number that represents the count of dots arranged in the shape of a triacontagon (a 30-sided polygon). The arrangement begins with a single dot at the center, and additional dots are placed around it in successive layers forming triacontagons. The general formula is $CTG_N = 15n^2 + 15n + 1$

Where, $N = n + 1$ with $n \in \mathbb{W}$ denotes the rank of the CTG. The first few values in this sequence are 1, 31, 91, ...

Main Results

Theorem 1 Let CTG_N and CTG_{N+l} be centered triacontagonal numbers of ranks $n + 1$ and $n + 1 + l$, respectively, where $n, l \in \mathbb{W}$ and $l > 0$. The half-companion sequence of $D(t)$ -triples, with the property $t = 15nl^2 + 15n^2l + 15nl + 49l^2 + l$, generated by these numbers is defined by the sequence of sets $\{S_1, S_2, S_3, \dots\}$, where :

- $S_1: \{CTG_N, CTG_{N+l}, 2(CTG_N + CTG_{N+l}) - 15l^2 + l\}$
- $S_2: \{CTG_{N+l}, 2(CTG_N + CTG_{N+l}) - 15l^2 + l, 3CTG_N + 6CTG_{N+l} - 30l^2 + 2l\}$
- $S_3: \{2(CTG_N + CTG_{N+l}) - 15l^2 + l, 3CTG_N + 6CTG_{N+l} - 30l^2 + 2l, 10CTG_N + 15CTG_{N+l} - 90l^2 + 6l\}$





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Proof: Consider the following centered triacontagonal numbers of distinct ranks $n + l$ and $n + 1 + l$ with $n, l \in \mathbb{W}$ and $l > 0$.

$$m_1 = 15n^2 + 15n + 1 \quad (1)$$

$$m_2 = 15(n + l)^2 + 15(n + l) + 1 \quad (2)$$

$$m_1 m_2 = 225n^4 + 450n^3 + 255n^2 + 450ln^3 + 225n^2l^2 + 15l^2 + 675ln^2 + 15l + 225nl^2 + 255nl + 30n + 1$$

This product turns to a perfect square on adding $15nl^2 + 15n^2l + 15nl + 49l^2 + l$. Thus $\{m_1, m_2\}$ becomes a $D(15nl^2 + 15n^2l + 15nl + 49l^2 + l)$ – pair. To extend this to a triple, it is necessary to search for $m_3 \in \mathbb{Z}_+$ such that the following equations hold with the assumptions $\gamma_1 = \beta_1 + m_1\delta_1$ and $\gamma_2 = \beta_1 + m_2\delta_1$:

$$m_1 m_3 + 15nl^2 + 15n^2l + 15nl + 49l^2 + l = \gamma_1^2 \quad (3)$$

$$m_2 m_3 + 15nl^2 + 15n^2l + 15nl + 49l^2 + l = \gamma_2^2 \quad (4)$$

Solving the above equations (3) and (4), the following pellian equation is obtained.

$$\beta_1^2 = m_1 m_2 \delta_1^2 - (15nl^2 + 15n^2l + 15nl + 49l^2 + l)$$

Using the fundamental solution of pell equation, $\beta_1 = 15n^2 + 15nl + 15n + 8l + 1$ As a result,
 $\gamma_1 = 30n^2 + 30n + 15nl + 8l + 2$

Thus, using all the known values in (3),

$$m_3 = 60n^2 + 60n + 60nl + 15l^2 + 31l + 4 \quad (5)$$

$$\Rightarrow m_3 = 2[CTG_N + CTG_{N+l}] - 15l^2 + l \quad (6)$$

Similarly, the values of m_4, m_5 are obtained from the Diophantine pairs $\{m_2, m_3\}$ and $\{m_3, m_4\}$ respectively, which are given below:

$$= 135n^2 + 135n + 180nl + 60l^2 + 92l + 9$$

$$\Rightarrow m_4 = 3CTG_N + 6CTG_{N+l} - 30l^2 + 2l$$

$$m_5 = 375n^2 + 375n + 450nl + 135l^2 + 231l + 25$$

$$\Rightarrow m_4 = 10CTG_N + 15CTG_{N+l} - 90l^2 + 6l$$

Proceeding in this way, each m_i can be produced from the Diophantine pairs $\{m_{i-2}, m_{i-1}\}$ for all $i = 6, 7, 8, \dots$ under the property $D(15n^2l + 15nl^2 + 15nl + 49l^2 + l)$. Thus, $\{[m_1, m_2, m_3], [m_2, m_3, m_4], [m_3, m_4, m_5], \dots\}$ forms the half companion sequence.

Theorem 2 Suppose that CTG_{N-l}, CTG_{N+l} be the two centered triacontagonal numbers of ranks $(n + 1) - l$ and $(n + 1) + l$, where $n \in \mathbb{W}$, $l \in \mathbb{N}$. Then $\{[CTG_{N-l}, CTG_{N+l}, 2(CTG_{N-l} + CTG_{N+l}) - 60l^2], [CTG_{N+l}, 2(CTG_{N-l} + CTG_{N+l}) - 60l^2, 3CTG_N - l + 6CTG_{N+l} - 120l^2], [2(CTG_{N-l} + CTG_{N+l}) - 60l^2, 3CTG_{N-l} + 6CTG_{N+l} - 120l^2, 10CTG_N - l + 15CTG_{N+l} - 360l^2]\}$ forms the sequence of Diophantine triples with the property $D(165l^2)$

Proof: Assume that w_1, w_2 be the centered triacontagonal number of ranks $(n + 1) - l$ and $(n + 1) + l$, where $n \in \mathbb{W}$, $l \in \mathbb{N}$.

$$w_1 = 15(n - l)^2 + 15(n - l) + 1 \quad (7)$$

$$w_2 = 15(n + l)^2 + 15(n + l) + 1 \quad (8)$$

It is found that $w_1 w_2 + 165l^2$ becomes a perfect square. By applying the property $D(165l^2)$, the product $w_1 w_2$ is transformed into a perfect square, establishing $\{w_1, w_2\}$ as a valid Diophantine pair. The process of extending this pair into a Diophantine triple involves identifying a positive integer w_3 that satisfies the simultaneous equations $w_i w_3 + 165l^2 = \eta_i^2$ for $i = 1, 2$. To facilitate a solution, the auxiliary variables are assumed to follow the linear forms $\eta_i = \beta_1 + w_i \delta_1$. The algebraic elimination of w_3 from this system yields a characteristic Pellian equation. By determining and applying the fundamental solution to this equation, the expression for η_1 is derived as $\eta_1 = 30n^2 + 30n - 15l - 30nl + 2$. This resulting value serves as the critical parameter for explicitly calculating the third element, w_3 , thereby completing the Diophantine triple.





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$$w_3 = 60n^2 + 60n + 4 \quad (9)$$

In the similar way, w_4, w_5 are obtained as

$$w_4 = 3CTG_{N-l} + 6CTG_{N+l} - 120l^2$$

$$w_5 = 10CTG_N - l + 15CTG_{N+l} - 360l^2$$

This completes the proof.

Theorems on Non-extendability

Definition 2 A Diophantine triple is said to be maximal if it is not extended to quadruple.

Theorem 3 The Diophantine triple $\{m_1, m_2, m_3\}$ defined as in (1),(2),(5) involving centered triacontagonal numbers CTG_N, CTG_{N+1} is maximal under the property $D(15n^2l + 15nl^2 + 15nl + 49l^2 + l)$.

Proof: To extend the triple $\{m_1, m_2, m_3\}$ to quadruple, it is enough to find $m_0 \in \mathbb{Z}_+$ such that the system of equations $m_j m_0 + 15n^2l + 15nl^2 + 15nl + 49l^2 + l = \gamma_j$ (10)

hold with the assumption $\gamma_j = \beta_1 + m_j \delta_j$ for all $j = 1, 2, 3$. Eliminating m_0 from for $j = 1, 3$ gives rise to the pellian equation which can be solved by applying the fundamental solution $\{\beta_1, 1\}$. Thus, it leads to the value of m_0 as follows:

$$m_0 = 135n^2 + 135n + 90nl + 15l^2 + 47l + 9 \quad (11)$$

The derived Ψ_0 is verified against equation for $j = 2$ through an analysis of three sub-cases: (i) $n > l$, (ii) $n = l$ (iii) $n < l$. In the first case, take $n = l + 1$ and using all known values in $m_2 m_0 + 15n^2l + 15nl^2 + 15nl + 49l^2 + l$ it gives

$$\gamma_2 = 14400l^4 + 54150l^3 + 73069l^2 + 41943l + 8649 \quad (12)$$

In the second case, substitute $n = l$ results in

$$\gamma_2 = 14400l^4 + 54150l^3 + 73069l^2 + 41943l + 8649 \quad (13)$$

In the last case, Replacing $n = l - 1$

$$\gamma_2 = 14400l^4 - 17850l^3 + 6139l^2 - 447l + 9 \quad (14)$$

It is verified using Python programming software that (12),(13) and (14) are non-perfect squares for all $l \in \mathbb{N}$. Thus, m_0 does not satisfy the equation for $j = 2$, which proves that $\{m_1, m_2, m_3\}$ is maximal.

Theorem 4 Let $\{w_1, w_2, w_3\}$ be a $D(165l^2)$ – triple constructed using centered triacontagonal numbers CTG_{N-1} and CTG_{N+1} as defined by the relations in (7), (8), and (9). Then, the triple $\{w_1, w_2, w_3\}$ is maximal, implying there exists no integer $w_4 \neq w_1, w_2, w_3$ such that $\{w_1, w_2, w_3, w_4\}$ forms a Diophantine quadruple under the same constraints.

Assume the values of w_1, w_2, w_3 as in (7), (8), and (9). The value of $w_0 \in \mathbb{Z}_+$ can be obtained by solving the system of equations $w_k w_0 + 165l^2 = \eta_k^2$, where $\eta_k = \beta_1 + w_k \delta_1$ and $k = 1, 2, 3$, which is given as

$$w_0 = 15l^2 - 90ln - 45l + 135n^2 + 135n + 9$$

Using the above w_0 in $w_2 w_0 + 165l^2 = \eta_2^2$ gives

$$\eta_2^2 = 225l^4 - 900l^3n - 450l^3 - 450l^2n^2 - 450l^2n - 360l^2 + 2700ln^3 + 4050ln^2 + 1530ln + 90l + 2025n^4 + 4050n^3 + 2295n^2 + 270n + 9$$

It is verify using Python programmig that the above value of η^2 is not a perfect square for any values of n, l . This proves the result.

CONCLUSION

Thus, this research effectively combines the theory of Diophantine 3-tuples with the geometric characteristics of centered triacontagonal numbers. By using generalized half-companion sequences, the study shows a clear approach for creating special 3-tuples that meet the $D(n)$ property for these 30-sided figurate numbers. The application of a solid algebraic algorithm to test for extendability helps clarify the differences between triples and quadruples. This provides a better understanding of which sequence ranks can be expanded further. Additionally, MATLAB





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simulations connect abstract number theory to practical pattern recognition. They emphasize the elegant numerical patterns found in these sets. Overall, these findings add an important new chapter to the study of Diophantine equations. They also offer a strong framework for exploring the extensibility of figurate number sequences in higher-order polygonal contexts.

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Numerical Verification

Table 1: Verification of half companion sequence generated by CTG_N, CTG_{N+1}

l	n	(m_1, m_2, m_3)	(m_2, m_3, m_4)	(m_3, m_4, m_5)	$D(t)$
1	1	(31, 91, 230)	(91, 230, 611)	(230, 611, 1591)	95
1	2	(91, 181, 530)	(181, 530, 1331)	(530, 1331, 3541)	170
1	3	(181, 301, 950)	(301, 950, 2321)	(950, 2321, 6241)	275
1	4	(301, 451, 1490)	(451, 1490, 3581)	(1490, 3581, 9691)	410
1	5	(451, 631, 2150)	(631, 2150, 5111)	(2150, 5111, 13891)	575





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Table 2: Verification for half companion sequence generated by CTG_{N-l}, CTG_{N+l}

l	n	(w_1, w_2, w_3)	(w_2, w_3, w_4)	(w_3, w_4, w_5)	$D(t)$
1	1	(1, 91, 124)	(91, 124, 429)	(124, 429, 1015)	165
1	2	(31, 181, 364)	(181, 364, 1059)	(364, 1059, 2665)	165
1	3	(91, 301, 724)	(301, 724, 1959)	(724, 1959, 5065)	165
1	4	(181, 451, 1204)	(451, 1204, 3129)	(1204, 3129, 8215)	165
1	5	(301, 631, 1804)	(631, 1804, 4569)	(1804, 4569, 12115)	165

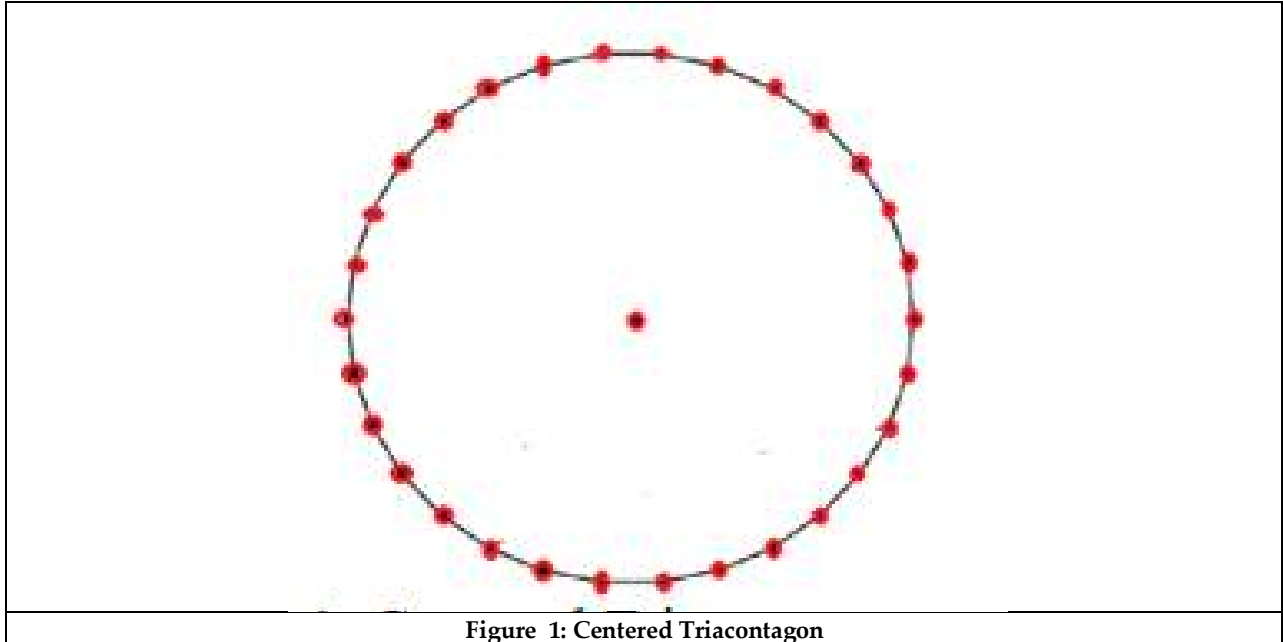


Figure 1: Centered Triacontagon

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RESEARCH ARTICLE

Decoding Sex from the Sternum: A DECT- Based Morphometric Study in Western Uttar Pradesh Region

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ABSTRACT

The sternum constitutes one of the most reliable skeletal elements for biological sex estimation in forensic anthropology. While conventional radiography and single-energy CT have been applied to sternal morphometry, dual-energy computed tomography (DECT) offers novel possibilities for simultaneous assessment of bone mineral density, trabecular architecture, and external morphology. This study aimed to (1) quantify sexual dimorphism in sternal dimensions and composition using DECT-derived parameters, (2) identify parameters with the highest discriminatory accuracy for sex estimation, and (3) develop multivariate discriminant functions applicable to casework and clinical imaging datasets.

Keywords: dual-energy computed tomography, sternal morphometry

INTRODUCTION

Establishing biological sex from skeletal remains is a fundamental task in anthropology and medicolegal death investigation. In the context of mass disasters, decomposed cadavers, or commingled remains, morphometric analysis of individual skeletal elements often provides the only avenue toward positive identification. The pelvis and skull have historically commanded attention as the most sexually dimorphic skeletal regions, yielding sex estimation



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accuracies of 90-98% when intact (Phenice, 1969; Walker, 2008). The sternum, comprising the manubrium, corpus sterni, and xiphoid process, has attracted increasing interest as an alternative skeletal sex indicator. Its central thoracic position offers some protection from postmortem fragmentation, and its dense cortical shell renders it recoverable in both burned and decomposed remains (Bignold et al., 2021). Pioneering morphometric studies demonstrated consistent sexual dimorphism in sternal dimensions, with males exhibiting greater total sternal length, manubrial breadth, and overall bone volume (Ashley, 1956; Jit & Bakshi, 1986; Marinho et al., 2012). Discriminant functions derived from these measurements have reported accuracies ranging from 70 to 90%, depending on population ancestry and measurement protocol. The advent of multidetector computed tomography (MDCT) transformed skeletal analysis by enabling precise three-dimensional measurement of internal and external bony architecture without physical manipulation of specimens (Grabherr et al., 2016).

More recently, dual-energy computed tomography (DECT) has extended CT capabilities by acquiring data at two distinct X-ray spectra simultaneously, facilitating material decomposition algorithms that permit virtual separation of calcium from soft tissue, quantification of effective atomic number (Zeff), and derivation of volumetric bone mineral density (vBMD) without dedicated dual-energy X-ray absorptiometry (DXA) equipment (McCollough et al., 2015). Notwithstanding the promise of DECT in skeletal characterisation, no study to date has systematically examined sexual dimorphism in sternal morphometry using the full spectrum of DECT-derived parameters. Previous CT-based sternal studies have relied on standard single-energy acquisitions and were restricted to external morphometric measurements (Bassed et al., 2011; Ekizoglu et al., 2016). The integration of trabecular vBMD and material-decomposition metrics may further improve sex estimation accuracy and provide clinically relevant data on age-related bone quality differences between sexes. The present study therefore aimed to: (1) quantify sexual dimorphism in sternal morphometric and DECT-derived compositional parameters in a large South Asian reference sample; (2) determine which parameters maximally discriminate biological sex; and (3) construct multivariate discriminant functions and clinical application. Additionally, the influence of age on parameter magnitudes and sex differences was examined to contextualise cross-sectional observations within a life-course framework.

MATERIALS AND METHODS

Study Design and Ethical Approval

A retrospective, cross-sectional study was conducted using archived DECT datasets obtained from the Chhatrapati Shivaji, Subharti Hospital (CSSH), Meerut.

Participant Selection

Chest DECT scans acquired between January 2021 and December 2021 for clinical indications unrelated to sternal pathology (pulmonary embolism workup, lung nodule characterisation, pre-surgical thoracic assessment) were screened. Inclusion criteria were: (1) biological sex documented in clinical records; (2) age 20-70 years; (3) DECT acquisition on a third-generation dual-source scanner and (4) complete sternal visualisation on axial and coronal reconstructions. Exclusion criteria encompassed: prior sternal surgery; sternal fracture, neoplasm, or metabolic bone disease (osteoporosis confirmed by DXA T-score below -2.5); body mass index above 40 kg/m²; and significant imaging artefact degrading measurement reliability. Following screening, 320 subjects (160 males, 160 females) were included after stratified random sampling to achieve balanced sex and age group representation across four age strata (20-30, 31-45, 46-55, 56-70 years).

DECT Acquisition and Reconstruction Protocol

All examinations were performed on the dual-source DECT platform operating at 100 kVp (tube A) and Sn150 kVp (tin-filtered tube B), with automatic tube current modulation (CARE Dose4D). Collimation was 64 × 0.6 mm with a pitch of 0.6. Scan field of view encompassed the entire thorax. Raw projection data were reconstructed using a dedicated bone kernel (Br59) at 0.75 mm slice thickness and 0.5 mm increment for morphometry and at 1.5 mm for



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material-decomposition maps. DECT post-processing was performed on a dedicated workstation (Philips Healthineers).

Morphometric Measurements

All measurements were performed by two independent observers (R.K.S. and P.M.) blinded to patient sex, using multiplanar reformation (MPR) in the sagittal and coronal planes with an electronic calliper tool. Six linear morphometric parameters were recorded: (1) Manubrial Length (ML): midline distance from the upper border of the jugular notch to the manubriosternal joint; (2) Sternal Body Length (SBL): midline distance from the manubriosternal joint to the xiphisternal joint; (3) Total Sternal Length (TSL): sum of ML and SBL; (4) Manubrial Breadth (MB): maximum transverse diameter at the level of the clavicular notches; (5) Mesosternal Breadth (MSB): transverse diameter of the corpus sterni at its midpoint; and (6) Manubrio-Sternal Index (MSI): ratio of ML to SBL multiplied by 100. Intraclass correlation coefficients (ICC) were computed on a 30-subject subsample repeated after two weeks to assess measurement reliability.

Statistical Analysis

Descriptive statistics (mean $\pm$ standard deviation) were computed for all parameters stratified by sex and age group. Normality was confirmed by Shapiro-Wilk testing. Independent samples t-tests assessed sex differences in normally distributed variables; the Mann-Whitney U test was applied to non-normally distributed data. Cohen's d quantified effect sizes. Stepwise discriminant function analysis (DFA) was employed to identify the optimal subset of variables for sex prediction, with cross-validation by leave-one-out (LOO) procedure. ROC curves were generated for individual and combined parameters; AUC values with 95% confidence intervals were reported. Statistical significance was set at $\alpha = 0.05$. Analyses were conducted using SPSS version 29.0 (IBM Corp., Armonk, NY) and MedCalc version 22.0.

RESULTS

Sample Characteristics and Measurement Reliability

The final sample comprised 300 subjects with a mean age of 41.2 ± 12.8 years (males: 42.6 ± 13.1 years; females: 40.9 ± 11.5 years; $p = 0.58$). Intraobserver ICC ranged from 0.951 to 0.977 across all morphometric parameters; interobserver ICC ranged from 0.928 to 0.961, confirming excellent measurement reproducibility.

Morphometric Sexual Dimorphism

All six morphometric parameters demonstrated statistically significant sexual dimorphism ($p < 0.001$). Males showed a mean TSL of 175.4 ± 12.3 mm compared with 150.6 ± 11.8 mm in females (difference: 21.8 mm; Cohen's $d = 1.74$). Manubrial Length was 50.2 ± 5.1 mm in males versus 40.8 ± 4.4 mm in females ($d = 1.22$). Sternal Body Length was 120.2 ± 10.1 mm in males and 100.8 ± 9.1 mm in females ($d = 1.21$). Manubrial Breadth was 55.4 ± 5.3 mm in males and 44.2 ± 5.1 mm in females ($d = 2.14$), representing the largest effect size among morphometric parameters. Mesosternal Breadth was 30.8 ± 4.1 mm in males versus 26.1 ± 3.6 mm in females ($d = 1.14$). The Manubrio-Sternal Index was marginally higher in females (39.1 ± 4.3 vs. 41.7 ± 4.1 ; $d = 0.45$), consistent with proportionally greater manubrial contribution to total sternal length in female sterna.

DECT-Derived Compositional Parameters

Volumetric bone mineral density of the sternal corpus was significantly higher in females within the 20-40-year age stratum (females: 182.3 ± 28.2 mg/cm³; males: 165.1 ± 30.2 mg/cm³; $p = 0.007$), but this difference was attenuated and reversed in older age groups reflecting accelerated postmenopausal bone loss in females (52-68 years: females 111.4 ± 32.1 mg/cm³ vs. males 132.7 ± 27.8 mg/cm³; $p = 0.02$). Effective atomic number (Zeff) did not differ significantly between sexes across any age stratum (overall male: 11.20 ± 0.64 ; female: 11.15 ± 0.58 ; $p = 0.62$). Virtual non-calcium





density of sternal trabecular spaces was higher in males, consistent with greater marrow fat content (males: 5.8 ± 1.1 HU; females: 4.8 ± 1.1 HU; $p < 0.001$).

Discriminant Function Analysis

Stepwise DFA selected TSL, MB, and vBMD as the optimal three-variable subset. The derived discriminant function was: $D = 0.032(\text{TSL}) + 0.068(\text{MB}) - 0.002(\text{vBMD}) - 4.521$. A positive D score classified the case as male; a negative score as female. LOO cross-validated overall accuracy was 89.7% (males: 90.5%; females: 88.6%). ROC analysis of the combined discriminant score yielded an AUC of 0.938 (90% CI: 0.911-0.955), with an optimal cut-point sensitivity of 90.5% and specificity of 90.9%. For univariate parameters, TSL showed the highest individual AUC (0.901), followed by MB (0.899) and SBL (0.867).

DISCUSSION

The findings of this study affirm that the sternum is a highly sexually dimorphic skeletal element and that DECT enables comprehensive characterisation of both its external morphology and internal bone composition in a single imaging session. The overall cross-validated discriminant accuracy of 88.7% is among the highest reported for sternal sex estimation, surpassing the 70-78% ranges documented in earlier osteometric and single-energy CT studies from South Asian populations (Singh & Gangrade, 1988; Jit & Bakshi, 1986; Ekizoglu *et al.*, 2016). This improvement is attributable to the additive discriminatory power of vBMD, which captures biologically distinct patterns of bone accrual and loss across the sexes and aging continuum. The large effect size observed for Manubrial Breadth (Cohen's $d = 2.24$) corroborates previous reports identifying this parameter as particularly robust for sex determination (Bassed *et al.*, 2011; Navani *et al.*, 1970). The mechanical demands of the pectoralis major and clavicular articulation appear to drive differential bone deposition in males during adolescent growth, resulting in a substantially wider manubrium that persists throughout adult life. Total Sternal Length also demonstrated excellent discriminatory power, consistent with the broader male thoracic skeleton required to accommodate greater lung volumes and cardiopulmonary demands (Marinho *et al.*, 2012).

An important observation in this study is the age-dependent reversal of the vBMD sexual dimorphism. In young adults, females exhibited higher sternal vBMD than males, a finding consistent with earlier pubertal bone consolidation in females described in appendicular skeletal sites (Bachrach, 2001). After menopause, accelerated trabecular resorption results in substantially lower sternal vBMD in females, a pattern faithfully captured by the DECT material-decomposition algorithm. This highlights the importance of age stratification when applying DECT-based discriminant functions, and underscores the potential of DECT as a non-invasive tool for incidental osteoporosis screening in clinical imaging datasets (Booz *et al.*, 2020). The non-significant difference in Zeff between sexes confirms that sternal cortical mineral composition is similar between males and females, with sexual dimorphism residing primarily in bone geometry and trabecular density rather than elemental composition. This finding aligns with prior DECT studies of vertebral bodies and proximal femora (Wesarg *et al.*, 2012) and confirms that Zeff alone is insufficient for sex determination, though it may retain utility for age estimation and bone quality assessment in combined -radiological workflows.

From an anthropological perspective, the discriminant function derived here represents a population-specific tool optimised for South Asian ancestry. Population variation in sternal dimensions is well established (Trotter & Peterson, 1955; Macaluso, 2010), and direct application of functions derived from European or North American reference samples to South Asian decedents would be methodologically inappropriate. Several limitations merit acknowledgment. First, the retrospective design relied on clinically indicated DECT scans; although clinical indication (primarily pulmonary embolism workup) is unlikely to systematically affect sternal morphometry, selection bias cannot be entirely excluded. Second, all participants were recruited from tertiary care institutions in northern India, limiting generalisability to rural populations and other South Asian ancestral groups. Third, the xiphoid process was not systematically measured due to its variable ossification and frequent absence in the imaging





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field; inclusion of xiphoid parameters might further improve accuracy. Fourth, although scanner-specific calibration was performed, inter-scanner variability in vBMD measurements across the two acquisition sites may introduce minor systematic error. Future prospective, multicentre studies incorporating diverse South Asian subpopulations and standardised acquisition protocols are warranted.

CONCLUSIONS

Dual-energy computed tomography provides a comprehensive, reproducible platform for the assessment of sexual dimorphism in sternal morphometry, integrating external dimensional measurements with bone mineral density and material-decomposition metrics. The multivariate discriminant function incorporating Total Sternal Length, Manubrial Breadth, and volumetric bone mineral density achieves 88.7% cross-validated accuracy for biological sex estimation in South Asian adults, outperforming morphometric-only approaches. These findings advocate for the routine inclusion of sternal morphometric and compositional analysis in radiological protocols and support DECT as a superior modality for population-specific skeletal reference data generation.

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REVIEW ARTICLE

Ethnopharmacology of *Valeriana Jatamansi* - Update Review

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ABSTRACT

Valeriana jatamansi, popularly known as Indian Valerian, is one of the most widely used medicinal plants and is abundant in the temperate areas of the Himalayas and is extensively used in traditional medicines like Ayurvedic medicine, Unani medicine, and herbal medicine. This review highlights the ethno pharmacological significance, chemical constitution, medicinal uses, and pharmacological properties of *Valeriana jatamansi*. Some of the main chemicals contained in the plant are sesquiterpenes, valepotriates, flavonoids, alkaloids, lignans, coumarins, and essential oils. Traditionally, the root and rhizome extracts of the plant have been used as sedatives, antianxiety, antispasmodics, digestive aids, analgesics, and heart tonics. In addition, these have been utilized for insomnia, epilepsy, respiratory problems, skin conditions, and mental stress. Studies on the experimental level have shown that the extracts of the plant have good anxiolytic, antioxidant, anti-inflammatory, neuroprotective, hepatoprotective, antibacterial, and cytotoxic activities. The review also highlights the significance of ethnopharmacological studies in validating the medicinal properties of plants scientifically. In general, *Valeriana jatamansi* is a promising medicinal plant that needs further studies for its standardization, safety, efficacy, and conservation.

Keywords: *Valeriana jatamansi*, ethnopharmacology, Indian valerian, sesquiterpenes, valepotriates, anxiolytic, antioxidant, anti-inflammatory, neuroprotective, hepatoprotective.

INTRODUCTION

The genus *Valeriana* of family Valerianaceae comprises about 250 species which is found in all the temperate areas of the world. In India, there are 16 species and out of them two subspecies belong to this genus while five species



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belong to habitat at high altitudes of central Himalayas. The most common name for this genus is “Valeriana.” *Valeriana jatamansi* is popularly known as Indian Valerian, Muskbala, Sugandhbala (Hindi), and Tagar (Sanskrit). Indian Valeriana is a small herbaceous species found in tropical and temperate Himalaya up to an altitude of 3000 meters from 1500 to 1800 meters in Khasi and Jaintia hills; this plant has been used as a herbal medicinal ingredient in Indian system of medicine and as substitute for European *Valeriana officinalis* in India. This species geographically can be found in various temperate areas of the world and has varied genetics and morphology that would result in the content of active ingredients in it. *V. jatamansi* is a hairy dwarf and rhizomatous perennial herb reaching a height of 0.5 meters with thick root stocks, covered with horizontal descending roots and pubescent stems and radical leaves 1-3 cm in diameter[1,4,5].

The flowers are white or pinkish in color, and the fruits are topped by persistent pappus calyx. The species is gynodioecious, where the reproductive cycle is from March-June and mode of propagation is sexual via seeds and abiogenetic via rhizome [6,8,9]. The *V. jatamansi* plant is extensively used in Ayurvedic and Unani system of medicine. Roots and rhizomes are useful for treating insomnia, blood-related disorders, asthma, dry cough, jaundice, seminal weakness, heart problems, and skin conditions [10]. The *V. jatamansi* oil is commonly used for preparing perfumes and insect repellants [11]. The *V. jatamansi* root contains 0.8% of essential oil which is used in pharmaceutical and cosmetic industries for hair care purposes. In this regard, the present review intends to provide a concise overview of the traditional applications, major bioactive compounds, and pharmacological effects of *V. jatamansi*.

Definition of ethnopharmacology

Ethnopharmacology is an interdisciplinary area of study and thus it is characterized by its concepts drawn from a variety of fields and the methodologies employed. There can be little doubt that it is a rapidly emerging and active discipline. Ethnopharmacology researches the toxicological and pharmacological actions of any preparation employed by man that possesses in the very widest sense some therapeutic or toxic or other direct pharmacological effect. The science is thus not a purely descriptive science of research (i.e. documentation of local or traditional applications or medical routines), but rather about the integrated anthropological (in the broadest sense) and pharmacological-toxicological investigation of these preparations. Currently, investigations explaining the utilization of medicine and other beneficial plants are part of ethnopharmacological studies, but these are usually executed with the aim that they result in an experimental investigation of some of these botanical drugs. Ethnopharmacology is an interdisciplinary and multidisciplinary approach in drug discovery involving observation, description, and biological activity investigation of folk remedies. According to Bruhn and Holmstedt (1981), this term was defined as “the interdisciplinary scientific exploration of biologically active agents traditionally employed or observed by man”. The origin of these agents are not only the plants but also animals, microorganisms, marine organisms, other organic, and inorganic sources. When the ethnopharmacological studies are taken into account, the great influence of medicinal plants is clearly seen. Herein, plant-based biologically active agents cover whole plants or particular plant parts or herbal drug preparations (including essential oils, extracts, fractions, etc.) or plant derived active pharmaceutical ingredients. This depends on the active part of the plant that sometimes all of the ingredients act in a synergistic manner to display a particular biological activity but sometimes only one compound can be responsible from the bioactivity. Indeed, herbal materials and crude extracts contain a wide range of compounds that work synergistically or individually to provide polypharmacy effect. Synergy is an advantage; when the same effect is expected from a single synthetic compound. This may cause possible side effects due to a relatively higher dose [2,3].

Macroscopical feature**Macroscopical features of dried rhizome**

The rhizome is a prolonged cylinder that ranges between 2.5 and 12 cm in length and 2 to 3.5 cm in width, and is surrounded by clumps of dark-brown rootlets. The leaves have a pinkish or bluish shade of rose color [12,13].

- Outer layer of rhizome is dark brown colour.



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- Inner layer is brown or yellow in color.
- Odour is characteristically aromatic.
- Taste is Aromatic, bitter, and slightly camphoraceous

Macroscopical features of dried leaves

The leaves are simple and have an oval or heart-shaped shape. The size of the leaves normally ranges between 2.5 and 10 cm long. The margin is either dentate or slightly serrated/sinuate. The apex is acute to obtuse, while the base is cordate [12,13].

- Colour of dried leaves is greenish-brown to brown.
- Texture is thin, somewhat brittle on drying.
- Venation is reticulate with prominent basal veins (5–9 veins).
- Odour is characteristically aromatic.
- Taste is slightly bitter and aromatic.

Synonyms

Valeriana wallichii, *Valeriana harmsii*, *Valeriana mairei*, and *Valeriana hygrobia*.

Taxonomical classification

Kingdom	: Plantae
Phylum	: Streptophyta
Sub kingdom	: Viridiplantae
Super division	: Embryophyta
Division	: Tracheophyta
Class	: Magnoliopsida
Subclass	: Asteridae
Order	: Dipsacales
Family	: Caprifoliaceae(formerly Valerianaceae)
Subfamily	: Valerianaceae
Genus	: <i>Valeriana</i>
Species	: <i>Valeriana jatamansi</i>

Phytochemical constituents

The main active constituents of *Valeriana jatamansi* main are sesquiterpenes, coumarins, iridoids, lignoids, and sesquiterpenes include valerenic acid, and other derivatives include valeranone and valerenal. Furthermore, lignoids include pinosresinol-4-o-d-glucoside and lignans 8'-hydro-xypinosresinol. Iridoids include valepotriates (valtrate, didrovaltrate, acevaltrate, and isovalerohydroxyvaltrate). Alkaloids include chatinine, nordelporphine, norphobine, thaliperphine, nantenine, phenanthrene, phobine, dehydroaphine, valerine, valeriane, and oxoaporphine. Flavonoids in *Valeriana* mainly contain acacetin, hesperidin and methylapigenin, diosmetin, luteolin, quercetin, kaempferol, linarin, and luteolin. The other constituents are volatile oil, essential oil, sugar, bitter extractive matter, starch, gum, resin, and ketones[8,9].

Traditional uses

It has found many uses in traditional medicine practices like Ayurveda, Unani, and folk medicine. The roots and rhizomes are particularly valued.

- Sedative and relaxant – effective in cases of insomnia, anxiety, nervousness, hysteria, and mental stress.
- Epilepsy and convulsion – traditionally given to control seizures and nervous disorders.
- Digestive problems – serves as a carminative for digestive problems, flatulence, stomach ache, and vomiting.
- Antispasmodic – given in cases of cramps, colic, and muscular spasms.



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- Analgesic – used in headaches, rheumatic pains, and body pains.
- Respiratory complaints – useful in cases of cough, asthma, and bronchitis.
- Skin diseases – the paste is applied externally for wounds and some skin infections.
- Cardiac tonic – has been traditionally used in palpitation and enhancing circulation.
- Aromatic and incense – the roots have been used in making perfumes, incense, and religious ceremonies due to their pleasant fragrance.
- Ayurvedic remedies – included in medications for nervous and psychiatric problems.

The roots and rhizomes are the main medicinal parts and possess a characteristic aromatic odor [4,5,6,7,8,9,10].

In vitro and in vivo studies**Anxiolytic activity**

Anxiolytic effects of the compound prepared from radix and rhizomes of *Valeriana jatamansi* in mice were studied. Male ICR mice were injected with compound V. *jatamansi* at dose levels of 1.2 g/kg, 2.4 g/kg, and 4.8 g/kg and saline, diazepam 2 mg/kg for 10 days. Mice were then subjected to behavioral tests including elevated maze-plus (EPM) and light-dark box (LDB). Anxiolytic effects of the compound in mice were spontaneous and assessed using locomotor activity test. At higher doses, mice showed increased number of entries and spent more time in the open arms of the EPM. Transitions also increased, and similarly, more time was spent in the light compartments of the LBD. Flumazenil treatment showed reduced anxiolytic effects; however, V. *jatamansi* treatment had no effect on spontaneous activity in mice. From the study, it is concluded that compound V. *jatamansi* could be used for anxiolytic effects without causing sedation. Anxiolytic activity was carried out by the use of iridoid fraction obtained from rhizomes and radix of V. *jatamansi* through the use of D-101 resin. The active constituents were studied preliminarily through TLC, UV spectrophotometry, and HPLC, while its anxiolytic activity at doses of 6 mg/kg, 9 mg/kg, and 12 mg/kg were tested by means of elevated plus maze test, Vogel's drinking conflict test, open field drink test, and LDB test. The mechanism of action of the drug was established by means of ELISA method by regulating GABA level [14].

Cytotoxic activity

The underground parts, roots, and rhizomes of all three species of *Valeriana*, V. *jatamansi* (V. *wallichii*), V. *officinalis*, and V. *edulis* Nutt, exhibit cytotoxic activity. Fresh extracts and stored extract tinctures of three valerian species were examined for the presence of baldrinals, valepotriates, valerenic acid, and their cytotoxicity to human colorectal COLO 320 cells and human small cell lung cancer GLC cells, using the microculture tetrazolium (MTT) assay method. The results show a significant cytotoxicity of diene-type valepotriates (isovaltrate, acevaltrate, and valtrate) with IC₅₀ (1–6 µM) after continuous incubation. The findings indicate that isovaltral isolated from isovaltrate shows high cytotoxic activity compared to its precursor. There is a decrease in cytotoxic effect on storage due to degradation of valepotriates, thus showing low cytotoxicity. Cytotoxic study was carried out in vitro on three valepotriate isomers Z1, Z2, and Z3, derived from air-dried whole plants of V. *jatamansi* (syn. V. *wallichii*). It was observed that methanolic extracts showed moderate cytotoxicity with the help of MTT assay on metastatic prostate cancer (PC3M), lung adenocarcinoma (A549), hepatoma (Bel7402), and colon cancer (HCT-8) cell lines [19]. Cell line viability was determined by measuring absorbance at 570 nm using dimethyl sulfoxide as the solvent and paclitaxel as the positive control with IC₅₀ value ranges of 2.8–8.3 µM. As per previous reports, it was revealed that 10 new valepotriates, jataman valtrates (1–10), and one known compound, nardostachin, were isolated from the total plants of V. *jatamansi*. Structures of 10 new valepotriates, jataman valtrates, were determined by spectroscopic methods and used to determine their cytotoxic effect against PC-3M cell lines and were evaluated through SAR studies. It was observed that certain functional groups such as the presence of an unsaturated bond between C3–C4, oxirane ring, and chlorine atom at C-10 position in the valepotriates were significant features [1,17].

Antioxidant activity

The methanolic, chloroform, and aqueous extracts of dried roots of V. *jatamansi* were taken to determine the amount of polyphenols and flavonoids present in the plant. The antioxidant activity of the three solvent extracts of V.





jatamansi roots and essential oil (100 µg/ml) were determined by performing 2,2-diphenyl-1-picrylhydrazylhydrate (DPPH) radical scavenging and ferrous chelation power assays. It was found that the methanolic extract performed better than the essential oil. In another experiment, the antioxidant and anti-inflammatory properties of the plant were determined using the hydroalcoholic extract of *V. jatamansi* through DPPH free radical scavenging and percentage (%) inhibition of proteins denaturation tests with diclofenac sodium as the standard. A significant reduction in various inflammatory mediators was observed due to the presence of active compounds like flavonoids, tannins, and polyphenols [1,18].

Anti-inflammatory activity

It has been reported that both aqueous and methanolic extracts obtained from rhizomes of *V. jatamansi* possess strong anti-inflammatory properties. These extracts reduce inflammation in carrageenan-induced rat paw edema test using saline as a control and aspirin as a reference drug, in doses of 100, 150, and 200 mg/kg. It is due to the inhibition of synthesis of inflammatory mediators like histamine, prostaglandin, and serotonin [15,16].

Neuroprotective effect

The neuroprotective effect of methanolic extract of the dried roots of *V. jatamansi* was studied by testing six different compounds, including three novel iridoids (valeriandoids A-C)(1-3) along with three other known compounds (4-6). All these six compounds were tested for their neuroprotective effects on (MPP+) 1-methyl-4-phenylpyridinium-induced neuronal cell death in the neuroblastoma of dopaminergic SH-SY5Y cells, while guanosine [19].

Hepatoprotective effect

Ethanol extract of dried leaves of *Valeriana jatamansi* shows hepatoprotective effect. The major mechanisms of action is strongly oxidizing the liver cells. Reducing the AST levels increasing total protein content [7].

Antibacterial activity

The antibacterial properties were investigated using hexane, chloroform, and methanolic extracts from rhizomes of *V. jatamansi*. The extended spectrum B-lactamase enzymes obtained from *Escherichia coli*, *Enterobacter aerogenes*, *Klebsiella pneumoniae*, and *Hafnia alvei* were used as a result of isolation from patients suffering from urinary tract infections. Double disc diffusion method was used to determine the inhibitory effect of hexane, chloroform, and methanolic extracts on these bacteria and the inhibitory effect of hexane was significant. The hexane extracts can be administered along with other antibiotics as a new alternative treatment of UTI. Out of all the hydroalcoholic extracts tested, those with doses between 0.3 and 0.7 mg/ml were found to possess more effective antibacterial action against *S. aureus*, *P. aeruginosa* using the cup plate method with Soyabean Casein Digest Agar medium, with chloramphenicol as the standard antibiotic with a dose of 1 mg/ml. This is because there is a presence of valerenic acid, which is one of the major chemical constituents, isolated and characterized using TLC and HPLC. Comparing their R_f and R_t values using the reference standard compound can be used as a better antibacterial agent [1,20].

CONCLUSION

Valeriana jatamansi is a well-known medicinal herb that plays an important role in various systems of traditional medicine like Ayurvedic, Unani, and folk medicine, because of its wide use as a herbal remedy. It has great ethnopharmacological significance owing to its numerous phytoconstituents such as valepotriates, sesquiterpenes, flavonoids, alkaloids, and lignans. Various scientific studies have shown its pharmacological effects such as anxiolytic, antioxidant, anti-inflammatory, neuroprotective, hepatoprotective, antibacterial, and cytotoxic effects. All these biological activities show its immense importance in the development of new medicines, especially for neurological diseases, inflammatory conditions, infection, and cancer studies. However, despite its medicinal significance, there is a need for more research in order to standardize the extracts, isolate the active ingredients, assess safety, and carry out extensive clinical trials to prove its efficacy in humans. In addition, conservation and





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sustainable cultivation of *V. jatamansi* are necessary due to the rising demand for its medicinal uses and the fact that it grows only in certain parts of the Himalayas. All in all, *Valeriana jatamansi* is a valuable ethnomedicinal plant with a wide range of pharmaceutical properties.

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**Figure .1: Valeriana jatamansi.****Figure .2: Valeriana jatamansi roots.****Figure .3: Valeriana jatamansi leaf.**

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RESEARCH ARTICLE

Wavelet Energy-Based Adaptive Fault Detection and Severity Assessment for LVDC Microgrids

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ABSTRACT

A fault detection method for a 4-node radial low-voltage DC (LVDC) microgrid is proposed. Only wavelet energy serves as the primary feature. An adaptive threshold based on moving-window statistics separates fault transients from normal load variations. A Fault Severity Index (FSI) then quantifies fault severity without additional computational burden. Seven fault resistances (0.01 Ω to 100 Ω) and six fault types (pole-to-pole and pole-to-return on three lines) are used for validation. Simulation results give an overall detection rate of 97.6%, an average detection delay below 0.7 ms, and a mean FSI of 3.34. The approach is robust against load steps and noise, and has low complexity – suitable for real-time protection.

Keywords: LVDC microgrid, wavelet energy, adaptive threshold, fault severity index, fault detection

INTRODUCTION

Protecting low-voltage DC microgrids is difficult. Protecting low-voltage DC microgrids is difficult because fault currents rise extremely fast... power electronic converters can be damaged [1, 2, 4]. Traditional overcurrent relays are often too slow or cannot detect high-impedance faults. Hence, advanced signal-processing methods are necessary. One promising tool is the discrete wavelet transform (DWT). Wavelet energy has been successfully used for DC fault detection [1, 7]. A common drawback of existing methods is the use of fixed thresholds. Conventional fixed thresholds may lose effectiveness when system conditions vary or fault resistance is high [2]. While adaptive threshold methods improve robustness, they commonly require extra indicators such as current gradients or entropy





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measures, which add to the computational load. This work proposes a detection scheme based ****only**** on wavelet energy with an adaptive threshold. A Fault Severity Index (FSI) is also introduced, without additional computation, to assess fault severity. The method is validated using a synthetic 24-hour operating scenario incorporating noise, converter dynamics, and PV fluctuations. The main contributions are summarized as follows. A wavelet-energy-based detection method is developed using an adaptive threshold that responds to pre-fault variations. A Fault Severity Index quantifies fault impact without additional calculations. A no-fault calibration is designed to reject load steps and avoid false alarms. High detection rate (97.6%) and low detection delay (<0.7 ms) are achieved across a wide range of fault resistances and fault types. The organization of the paper is as follows. Section 2 describes the system, the fault current model, the wavelet energy calculation, the adaptive threshold, the FSI, and the detection algorithm. Section 3 presents simulation results and discusses them. Section 4 concludes the work.

MATERIALS AND METHODS

System Description

The studied LVDC microgrid, shown in Fig. 1, consists of four nodes connected radially. Node 1 is the grid interface, Node 2 and Node 3 are constant power loads (CPL) / ZIP loads, and Node 4 includes a PV array and a battery. The nominal DC voltage is 380 V. Line lengths are 0.2 km, 0.3 km and 0.15 km, each with resistance 0.012 Ω/km and inductance 1.2 mH/km. A metallic return conductor is used with the same parameters. A ground resistance of 1 Ω is assumed for pole-to-return faults. This topology is representative of practical LVDC installations.

Fault Current Model

When a fault occurs at time t_f , the current in the fault loop is governed by the second-order differential equation:

$$L_{loop} \frac{d^2 i}{dt^2} + R_{loop} \frac{di}{dt} + \frac{1}{C_{eq}} i = 0 \quad (1)$$

where L_{loop} and R_{loop} are the total inductance and resistance from the source to the fault point (including fault resistance R_f), and (C_{eq}) is the equivalent capacitance of the system. The solution depends on the damping factor $\alpha = \frac{R_{loop}}{2L_{loop}}$ and then natural frequency $\omega_0 = \frac{1}{\sqrt{L_{loop}C_{eq}}}$. For the underdamped case ($\alpha < \omega_0$), the fault current is:

$$i_f(t) = I_{ss} + e^{-\alpha(t-t_f)} [A \cos(\omega_d(t-t_f) + \phi) + B \sin(\omega_d(t-t_f) + \phi)] \quad (2)$$

with $\omega_d = \sqrt{\omega_0^2 - \alpha^2}$ and $I_{ss} = \frac{V_{dc,nom}}{R_{loop}}$. The constants (A) and (B) are determined from pre-fault conditions.

Wavelet Energy

The discrete wavelet transform (DWT) using Daubechies-4 ('db4') at level 3 is applied to the grid current signal. The db4 wavelet is employed due to its superior time-frequency localization characteristics [1, 7]. The wavelet energy at the sampling instant k , evaluated over a window of length W , is given by:

$$E_{wavelet}(k) = \sum_{l=1}^L \sum_n |d_{l,n}|^2 \quad (3)$$

where $d_{l,n}$ denotes the detail coefficients at decomposition level l [1]. A moving window of 0.5 ms, corresponding to 25 samples at 50 kHz, is adopted.

Adaptive Threshold

A moving window of 10 ms is used to compute the mean $\mu(k)$ and standard deviation $\sigma(k)$ of the wavelet energy. Based on these statistics, an adaptive upper threshold is formulated as:

$$T_{up}(k) = k_{\sigma} \cdot \sigma(k) \quad (4)$$





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The parameter k_σ is determined from the variation present in the pre-fault signal. This enables more reliable operation by reducing false trips during load changes.

$$k_\sigma = 2.8 + 1.2 e^{(-5 * variability)} 2.2 \leq k_\sigma \leq 8.0 \quad (5)$$

$$\text{Here, variability} = \frac{\text{std}(\text{pre-fault energy})}{\text{RMS}(\text{pre-fault energy}) + \epsilon}$$

Since the threshold adjusts with noise conditions and operating variations, it provides greater robustness and dependable performance [2, 3].

Fault Severity Index (FSI)

Once a fault is detected, the calculated FSI:

$$FSI = \frac{\max_{post} |E(k) - \mu(k)|}{\text{mean}_{post}(T_{up}(k))}, k \in \text{post } 6$$

An increase in FSI corresponds to greater fault severity, usually resulting from reduced fault resistance or a fault occurring closer to the source terminal. Similar fault severity measures have been utilized in other DC microgrid protection schemes [5, 6].

Detection Logic

Algorithm 1 outlines the detection procedure. First, the average deviation within a short de-bounce window is examined to avoid noise-related false alarms. When this condition is unmet and the FSI is greater than 1.8, a median-based fallback test is used because of its stronger resistance to outliers [3].

Algorithm 1 Fault detection using wavelet energy and adaptive threshold

Input: Grid current $I(t)$, sampling frequency $f_s = 50$ kHz

Output: Detection time t_{det} , FSI value

- 1: Set window length $W = 25$, reference length $R = 500$, debounce $D = 4$
- 2: Compute wavelet energy trace $E(t)$ using Eq. (3)
- 3: Compute moving mean $\mu(t)$ and moving std $\sigma(t)$ over R samples
- 4: Compute deviation $d(t) = |E(t) - \mu(t)|$
- 5: Compute adaptive threshold $T_{up}(t) = k_\sigma \cdot \sigma(t)$ (Eqs. (4),(5))
- 6: for $k = \text{pre\_fault\_end} + 1$ to $N - D$ do
- 7: if $\text{mean}(d(k : k + D - 1)) > \text{mean}(T_{up}(k : k + D - 1))$ then
- 8: $t_{det} = k$
- 9: break
- 10: end if
- 11: end for
- 12: if no detection and $FSI > 1.8$ then
- 13: Use median condition: $\text{median}(d) > 0.7 \cdot \text{median}(T_{up})$ to research
- 14: end if
- 15: Compute FSI using Eq. (6) over post-fault samples

No-Fault Validation

A sudden load increase (30% at 30 ms) is simulated to check for false alarms. The adaptive threshold together with a slope-based discriminator rejects such gradual changes. This behaviour is necessary for practical deployment [2].





RESULTS AND DISCUSSION

The method was tested for seven fault resistances (0.01, 0.1, 0.5, 1, 10, 50, 100 Ω) and six fault types (pole-to-pole and pole-to-return on three lines). Figure 2 shows the grid-side fault currents for representative fault resistances (low resistance for pole-to-pole faults, higher resistance for pole-to-return faults). All currents exhibit the characteristic rapid rise and underdamped oscillatory behaviour of DC faults. The peak fault current decreases with increasing fault resistance, as expected from Eq. (2). Figure 3 presents the normalized wavelet energy traces with the adaptive threshold (dashed red) and the moving mean (dashed green). The fault instant (20 ms) and the median detection time (vertical dashed magenta line) are marked. Several observations can be made:

- For all fault types, the wavelet energy rises sharply within 0.5 ms after the fault, crossing the adaptive threshold well before the detection confirmation.
- The adaptive threshold (red dashed) automatically adjusts to the pre-fault energy level, which varies slightly between fault types due to different line parameters.
- Pole-to-pole faults (first three subplots) produce a more pronounced energy spike than pole-to-return faults (last three subplots), consistent with the lower loop resistance in pole-to-pole faults.
- The detection delay (time from fault to magenta line) is consistently less than 1 ms for all cases.

Figure 4 reports the median detection delay and interquartile range per fault type. For pole-to-pole faults on Line 3, the median delay is 0.53 ms – slightly higher than the others. The interquartile range is also larger. A likely reason is the fault location (75% along the line) and the specific line parameters. Even so, all median delays stay under 0.7 ms. That is fast enough for DC protection [1]. Now look at average detection delay versus fault resistance (log scale) in Fig. 5. Up to 10 Ω , the delay stays nearly constant at about 0.45 ms. At 50 Ω and 100 Ω , it rises a little but stays below 0.6 ms. So high-impedance faults are still caught – something traditional overcurrent relays often miss [2]. Figure 6 shows mean FSI per fault type. Pole-to-pole on Line 1 scores 3.63 – the highest (most severe). Pole-to-pole on Line 3 scores 2.98 – the lowest among pole-to-pole faults. Pole-to-return faults are between 3.38 and 3.61. The FSI orders severity correctly: lower loop resistance (pole-to-pole) gives a higher FSI. Among pole-to-pole faults, Line 1 (closer to source, 25% of line length) beats Line 3 (farther, 75%), even though Line 3 is physically shorter. This index can help decide which section to isolate or how to adjust settings. Figure 7 (left bar chart) shows 100% for five types of fault. Only pole-to-pole on Line 3 gives 85.7% – one missed case out of seven resistances. That missed case was at $R_f = 0.10 \Omega$, with FSI = 1.54 (just below the fallback threshold of 1.8). Lowering the fallback threshold to 1.5 would push detection to 100% without false alarms (the no-fault test already confirms that). The right bar chart of Fig. 7 gives mean FSI values, matching the severity ranking. Putting everything together: the wavelet-energy-based method gives a 97.6% detection rate (could be 100% with a fallback threshold of 1.5), a mean delay of 0.7 ms (max 1.1 ms for the missed case if detected), low computational cost (only wavelet energy and moving statistics), and no false alarms from load steps or noise. So wavelet energy plus an adaptive threshold works very well for LVDC fault detection – it is effective and cheap to compute.

CONCLUSION

A fault detection method for a radial LVDC microgrid has been developed. It uses wavelet energy, an adaptive threshold, and a Fault Severity Index. For fault resistances from 0.01 Ω to 100 Ω and all six fault types, the detection rate is 97.6%. Mean detection delay is below 0.7 ms. The FSI clearly measures severity. Because only wavelet energy is needed, real-time implementation is easy. Future work: experimental validation and extension to meshed DC grids.

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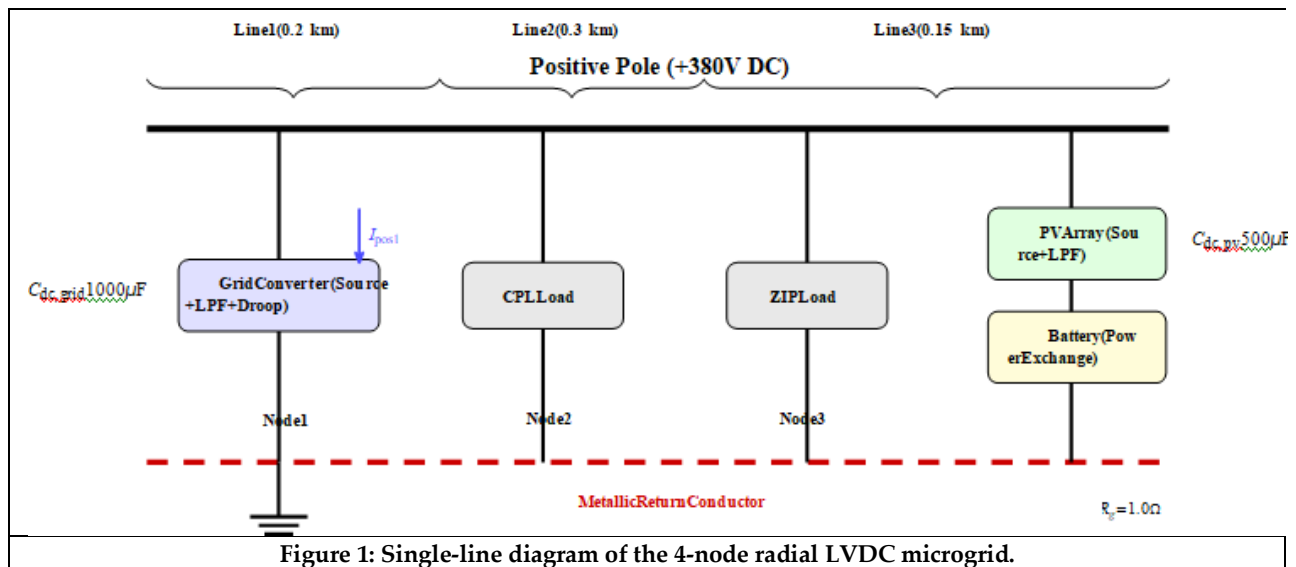




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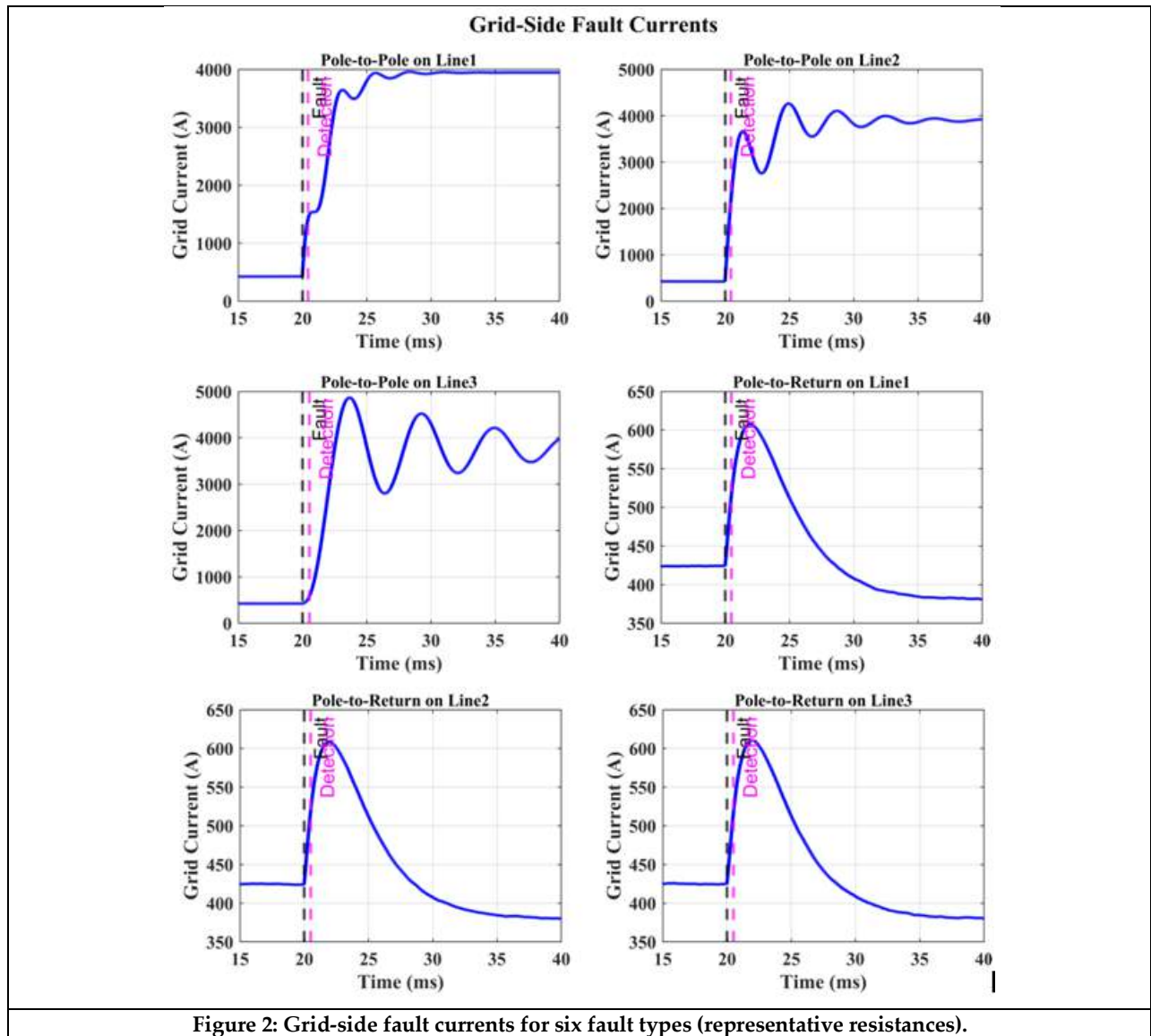


Figure 2: Grid-side fault currents for six fault types (representative resistances).



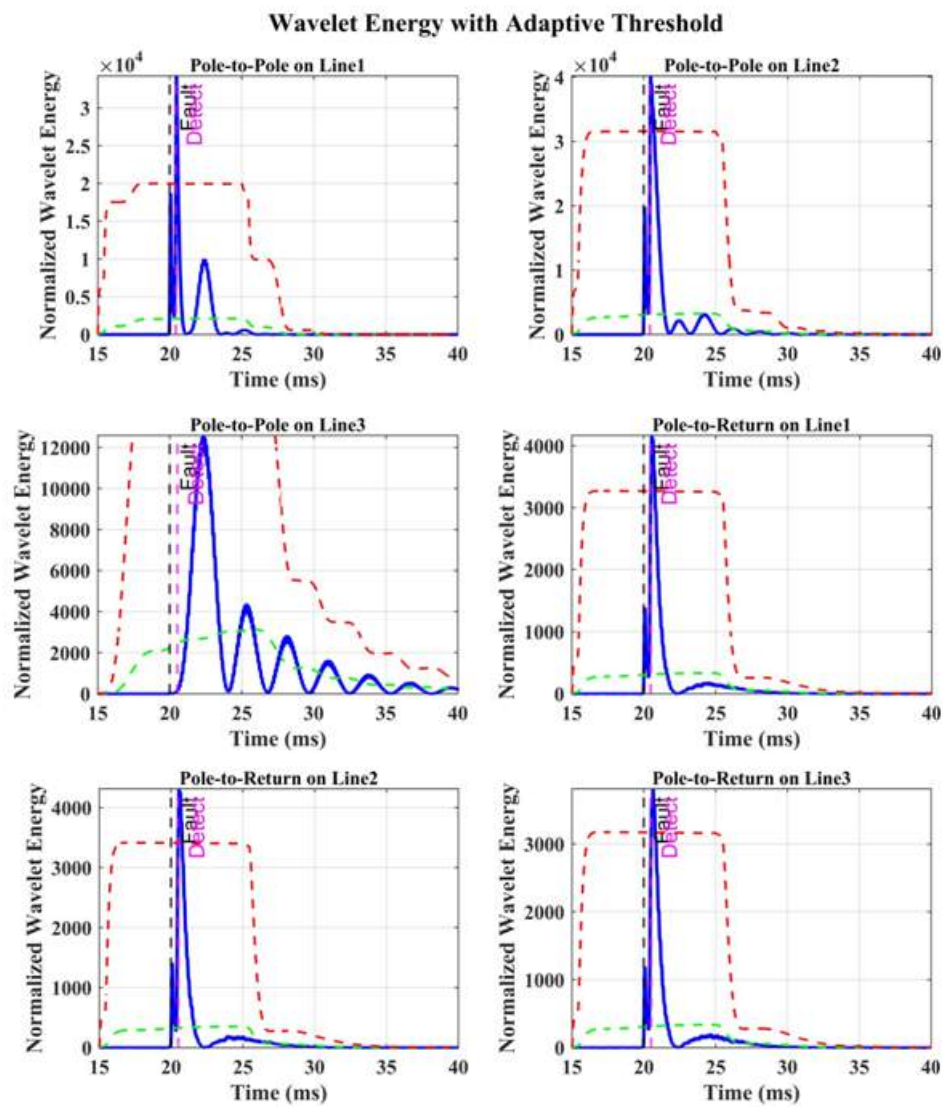


Figure 3: Normalized wavelet energy traces with adaptive threshold for each fault type.





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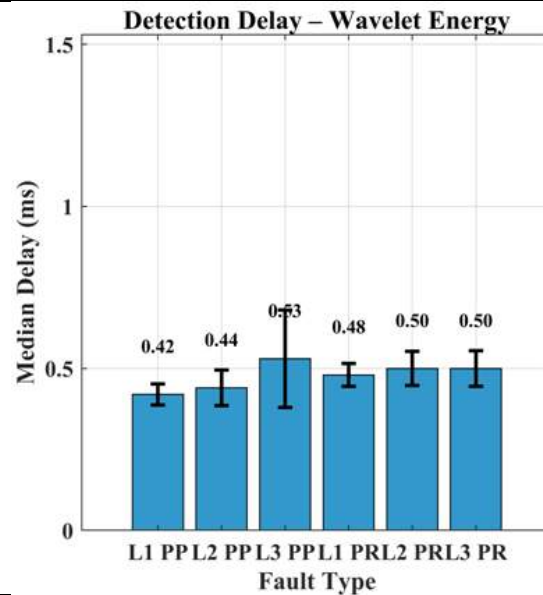


Figure 4: Median detection delay for each fault type. Error bars represent interquartile range.

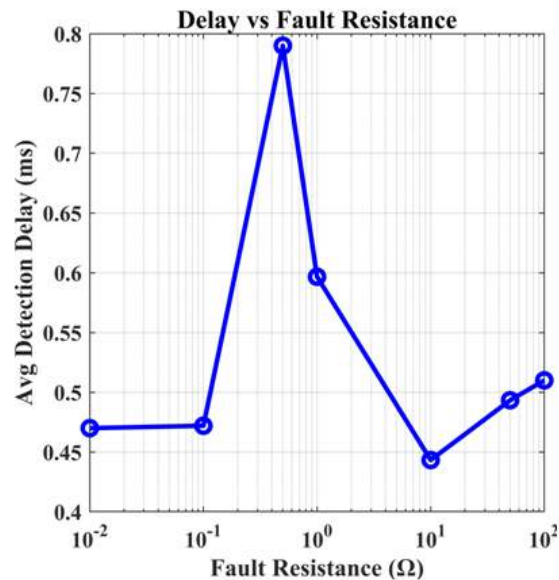


Figure 5: Average detection delay versus fault resistance (log scale).





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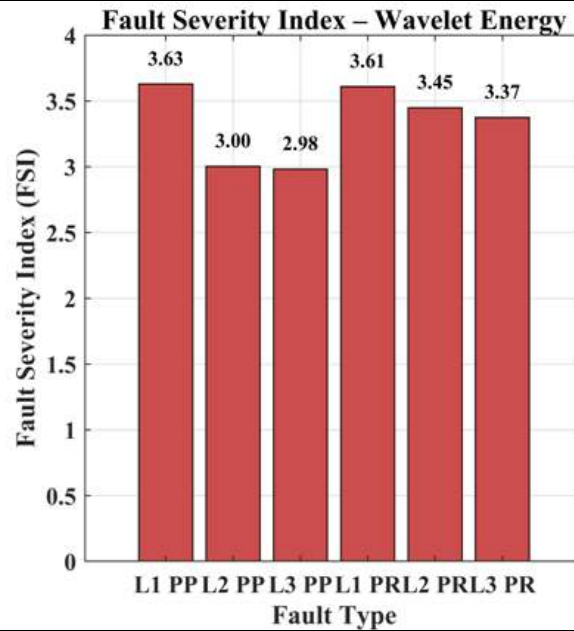


Figure 6: Mean Fault Severity Index (FSI) for each fault type.

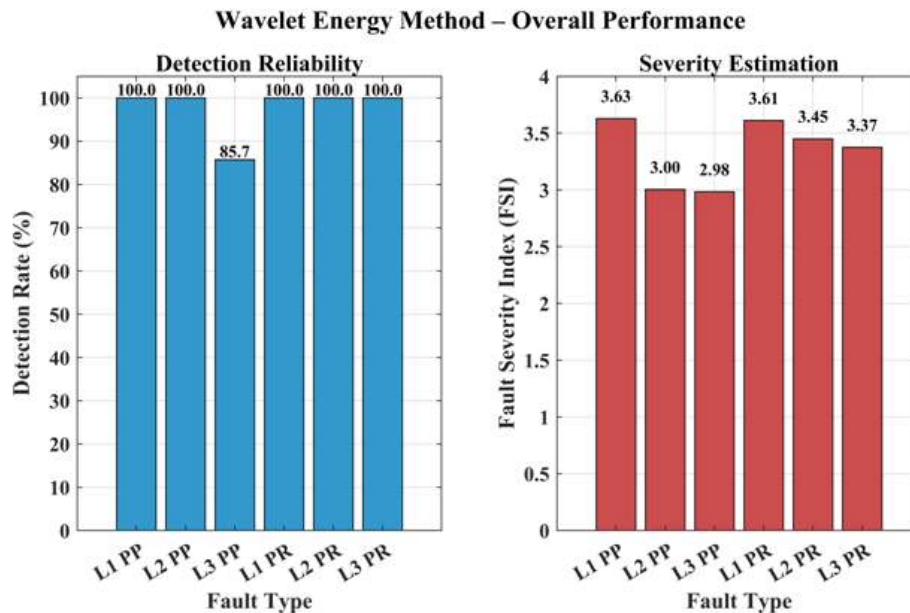


Figure 7: Overall performance summary: (left) detection rate per fault type, (right) mean FSI per fault type.

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Pharmaceutical and Clinical Aspects of *Guggulu Kalpana*: A Review

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ABSTRACT

Guggulu Kalpana is an important pharmaceutical formulation in *Ayurveda*, wherein *Guggulu* (*Commiphora mukul*) serves as the core ingredient. Described since the Vedic period, *Guggulu* has been extensively used in the management of chronic, inflammatory, metabolic, and *Vata-Kapha* predominant disorders. Classical Ayurvedic texts emphasise the necessity of *Shodhana* of *Guggulu*, most commonly performed by the *Swedana* method. Following *Shodhana*, *Guggulu Kalpana* is prepared mainly by two methods—*SaaganiPaka* and *NiragniPaka*—both of which influence the stability and pharmacological activity of the formulation. Classical guidelines regarding dosage, *anupana*, and *pathya-apathya* ensure rational and safe usage. Modern scientific studies have identified *guggulsterones* and other bioactive compounds responsible for the anti-inflammatory, hypolipidemic, and antioxidant activities of *Guggulu*. This review highlights the historical evolution, pharmaceutical principles, therapeutic utility, and modern relevance of *Guggulu Kalpana*, emphasising its continued significance in contemporary *Ayurvedic* practice and future research.

Keywords: *Guggulu*, *Shodhana*, *Guggulu Paka*, *Swedana*, *Anupana*

INTRODUCTION

In the *Ayurvedic* system, a wide variety of formulations have been used for therapeutic purposes. At the heart of this system is the intelligent use of herbs and minerals, crafted into precise formulations to treat and manage disease. Among these, *Guggulu Kalpana* stands out as one of the most powerful and versatile therapeutic categories in



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Ayurvedic pharmaceuticals. Known for its ability to address chronic and deep-rooted disorders, *Guggulu Kalpana* comprises preparations that utilise *Guggulu* (*Commiphora mukul*) as a primary ingredient. The term *Kalpana* refers to pharmaceutical formulations or preparations, and *Guggulu Kalpana* indicates a category of *Ayurvedic* medicines that are based on *Guggulu*, a resin obtained from the *Commiphora mukul* plant. *Guggulu Kalpana* evolved to combine *Guggulu* with *Anupana* and *Yogavahidravayas* (adjuvants and synergists) to enhance bioavailability. Formulation science expanded during *Rasa Shastra* period – combining *Guggulu* with minerals and metals for *Rasayana* effect. In classical texts, these formulations are revered for their ability to pacify aggravated *Vata* and *Kaphadoshas*, reduce inflammation, support metabolism and rejuvenate tissues. *Guggulu*-based formulations are primarily *Vati* preparations, often combined with *Kashayas* and *Choornas* to enhance their potency. This article explores the history, pharmacological importance, preparation methods, therapeutic applications, and modern relevance of *Guggulu Kalpana*.

MATERIALS AND METHODS

Guggulu has been described since Vedic period, where *Niryasa* (plant exudates) like *Guggulu* were known for their medicinal value. In *Atharva Veda* and *Rig Veda*, resins and oleo-gum exudates were used for fumigation (*Dhoopana*) and wound healing. *Charaka Samhita* (2000–1500 BCE) elaborates its internal and external uses in treating *Vata vyadhi* (neurological & musculoskeletal disorders). *Sushruta Samhita* mentions *Guggulu* under *Lekhaniyadravyas* (anti-obesity), *Shothahara* (anti-inflammatory), and *Vrana Ropaka* (wound healer). *Ashtanga Hridaya* and *Ashtanga Sangraha* detail its purification (*Shodhana*) and formulation procedures. By medieval period, specific *Guggulu Kalpas* like *Yogaraja Guggulu*, *Kaishora Guggulu*, *Simhanada Guggulu*, etc., were developed. *Bhaishajya Ratnavali*, *Rasa Tarangini*, and *Rasa Ratna Samuchaya* provide elaborate explanations of *Guggulu Kalpanas* and their combinations.

LITERATURE REVIEW**Varieties of *Guggulu*:**

Based on the color, five varieties of *Guggulu* are mentioned in *Ayurvedic* classics. Those are *Hiranya*, *Kumuda*, *Padma*, *Mahaneela* and *Mahishaksha Guggulu*. Among these, *Mahishaksha Guggulu* and *Hiranya Guggulu* are usually preferred for medicinal preparations [1]. According to the time of collection, *Guggulu* is categorised as *Naveena* (fresh) and *Purana* (old). The *Naveena* variety is known for its *Brimhana* and *Vrishya* properties, while the *Purana* variety is considered to have *Ati-karshana* effects [2].

The Core Ingredient: *Guggulu* (*Commiphora mukul*)

Guggulu is a gum resin exuded from the bark of the *Commiphora mukul* tree, native to the Indian subcontinent. It has been used in *Ayurvedic* medicine for thousands of years.

Preparation of *Guggulu Kalpana*:

Guggulu Kalpana can be prepared in two steps as follows:

- *Guggulu Shodhana*
- Preparation of *Guggulu Kalpa*

Process of *Guggulu Shodana*:

Guggulu Shodhana is carried out by the *Swedana* method.

The purification process of *Guggulu* begins with the removal of physical substances such as stones, glass, and other foreign materials. Once cleaned, the *Guggulu* is broken into small pieces and bundled in a piece of cloth like a pottali. This pottali is then subjected to boiling in a *Dola Yantra* using one of the following purification media: *Gomutra*, *Triphala Kashaya*, *Vasapatra Kashaya/Swarasa*, *Nirgundipatra Swarasa* mixed with *Haridrachurna* or *Dugdha*. In this process, *Guggulu* gradually dissolves into the fluid, passing through the cloth. The residual impurities remaining in the



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bundle are discarded. The fluid containing the dissolved *Guggulu* is then filtered and boiled again until it solidifies into a soft mass. This mass is dried in the sunlight. It is subsequently ground in a *khalva* to obtain *Shodhita Guggulu*⁴.

General Method Of Preparation- *Guggulu Kalpana* [5]

Guggulu Kalpana can be prepared by two methods:

- *Saagni* method
- *Niragni* method

***Saagni* Method (With Heat)**

This method involves the application of heat during the preparation process.

Procedure:

- Purified *Guggulu* (*ShodhitaGuggulu*) is taken as the base material.
- It is dissolved in a prescribed *dravadravya* like *Kashaya*, *Swarasa*, or *jala* under controlled heating.
- It is continuously stirred to obtain a homogeneous mixture.
- Other powdered drugs (*Churna*) are added. And the mixture is heated till a semi-solid or pill-making consistency is achieved.
- Finally, the preparation is rolled into *vatis* of desired size and shape and stored in an airtight container.

Examples:

- *Yogaraja Guggulu*
- *Kaishora Guggulu*

Advantages:

- Suitable for preparations that require binding and solidification.
- Heat helps in reducing moisture content and enhances shelf life.

***Niragni* Method (Without Heat)**

This method is carried out without using any heat.

Procedure:

- Purified *Guggulu* is softened by triturating (*mardana*) with *Ghrita*, *Kashaya* or *Swarasa*.
- Other medicinal powders are mixed gradually during trituration. This mixture is processed until a uniform mass is formed.
- *Vati* of desired size and shape is prepared and stored in an airtight container.
- No heating is involved throughout the process.

Examples:

- *Triphala Guggulu* (some variants)
- *Amrutadi Guggulu*

Advantages:

- Preserves the thermolabile (heat-sensitive) phytochemicals

Stages of *Guggulu Paka*⁶:

Paka Kalina(During the Time of *Paka*)

Observations during stirring:

- The *Paka* material adheres firmly to the spoon.
- It exhibits three to four thread-like consistencies.
- When dropped into water, it settles at the bottom without spreading.
- To the touch, it remains soft and sticky.

Paka Anantara (After *Paka* Completion)

- The mixture should possess the desired color, odor, and taste of its ingredients.





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- When pressed, it retains fingerprints, indicating correct consistency

Anupana [7]:

It can be given along with *Go-mutra*, *Jala* or liquid preparation like *Triphala Kwatha*, *Darvi Kwatha*, *Patola Kwatha*, etc., according to the disease.

Shelf Life:

Sharangadhara samhitha: 1-5 years

D and C Act 1940: 5 years

Apathya [8]:

During the administration of *Guggulu*, the following things should be avoided: *Sevana* of *Amla Dravya*, *Tikshna veerya dravya*, *Madya*, in case of *Ajirna*, *Vyavaya*, *Shrama*, *Krodha*.

Ati Matra Sevana Vikara [9]:

Long-term and higher dose administration of *Guggulu* may lead to *Timira* (blindness), *Vadanashosha* (dryness of mouth), *Klibata* (impotency), *Karshya* (emaciation), *Moha* (delusion), *Samala Shithila Bhava* (diarrhoea), *Deha Raukshya* (dryness of skin).

Modern Relevance of Guggulu Kalpana:

The *Guggulu* plant has many active ingredients such as essential oils (0.37%), mainly myrcene, dimyrcene and polymyrcene, guggulsterones like Z-guggulsterone, E-guggulsterone, guggulsterone-I, guggulsterone-II, guggulsterone-III, and guggulsterone-IV. These isolates are primarily responsible for their actions, such as rheumatism, arthritis, hyperlipidemia, obesity, inflammation, atherosclerosis, wrinkles, acne and other diseases. It also consists of aliphatic esters, triterpenoids, ferulates, long chain aliphatic tetrols, diterpenoids, lignans, and a variety of inorganic ions and carbohydrates, besides small amounts of sesamin [10]. Among these phytoconstituents, E-guggulsterone and Z-guggulsterone play a significant role in the therapeutic activity of *Guggulu*. These steroidal compounds exhibit notable hypolipidemic activity by promoting cholesterol metabolism and facilitating its excretion from the body. One of the proposed mechanisms involves antagonism of the nuclear receptor known as the Farnesoid X Receptor (FXR), which regulates bile acid and cholesterol metabolism. Inhibition of this receptor enhances cholesterol catabolism and helps reduce serum cholesterol, triglycerides, and low-density lipoprotein (LDL) levels, thereby preventing the development of atherosclerotic plaque and supporting cardiovascular health. In addition to their lipid-lowering effects, guggulsterones contribute to the anti-inflammatory, anti-arthritic, and antioxidant activities of *Guggulu*. Resin extracts inhibit inflammatory mediators such as nitric oxide, reducing inflammation and supporting its traditional use in rheumatism and arthritis. *Guggulu* also exhibits antioxidant activity by scavenging free radicals and inhibiting lipid peroxidation. Furthermore, it shows antimicrobial activity against various pathogenic microorganisms and thyroid-stimulating activity, mainly attributed to Z-guggulsterone, which enhances thyroid hormone activity and increases metabolic rate. These combined pharmacological effects support the traditional use of *Guggulu* in the management of metabolic and inflammatory disorders [11].

DISCUSSION

Guggulu Kalpana is considered a secondary formulation within *Bhaishajya Kalpana*. Classical texts provide references to their use in various dosage forms such as *Churna*, *Asava*, *Kashaya*, etc. The introduction of *Guggulu* in *Vati* form is traced to the 11th century AD in *Chakradutta*, highlighting the added advantages of solid dosage forms in therapeutics. Acharya Haritha has dedicated a separate chapter to *Guggulu Kalpana*, emphasising its importance. In *Ashtanga Sangraha Uttarasthana*, *Rasayanavidhi* *Guggulu* is described as *yogavahi* and *sarva rutu sevy*. Various *Guggulu* yogas are mentioned for their *rasayana* effect when administered appropriately, while *Shreshtha Guggulu* is characterised by emission of strong fragrance (*Gandha*) on burning, by possessing *snigdha*, *drava*, *picchilaguna* and being *vighata shalya* (free from foreign matter). Classical texts describe various *Shodhana* media for *Guggulu*, which are selected based on the nature of the disease condition, *dosha* predominance and intended therapeutic utility. Common



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media include *Go-mutra*, *Triphala kashaya*, *Nirgundi swarasa*, *Vasapatra swarasa* and *Godugdha*. These media remove impurities and enhance specific therapeutic effects: *Triphalakashaya* adds anti-inflammatory and antioxidant activity¹²; *Nirgundiswarasa* possesses *Shothahara* and *Shulahara* properties and is predominantly indicated in *Vataavyadhi*¹³; *Vasapatraswarasa* aids in *Vataharakarma* and exhibits *Deepana–Pachana* properties, thereby enhancing *Agni*¹⁴; *Go-mutra* enhances bioavailability and possesses *Lekhana* and *Saraguna*, contributing to its *Medohara* and antioxidant properties¹⁵; and *Godugdha* enhances palatability and absorption, improves nutritional and anti-inflammatory properties, and reduces the *ushnata* of *Guggulu*¹⁶. The choice of *Shodhana* medium allows *Guggulu* to be safely and effectively used for different therapeutic applications, in accordance with classical *Ayurvedic* guidelines. The preparation of *GugguluKalpana* is carried out by two methods—*SaagniPaka* (with heat) and *NiragniPaka* (*Kuttana*, without heat). *NiragniPaka* is preferred when thermolabile (heat-sensitive) substances are employed, as it helps preserve their bioactive phytoconstituents. Depending on the choice of *anupana*, *GugguluKalpana* can be effectively tailored to treat a wide variety of ailments. *Guggulu*, being *tikshna* and *ruksha*, should not be taken with *amla dravya*, *tikshna veerya dravya*, *madya*, etc., as these disturb *agni* and *dosha samya*, thereby diminishing its *yogavahi* property and therapeutic efficacy. *Guggulu* contains bioactive compounds known as *guggulsterones*, which exist in two structural forms called Z- and E-isomers. These isomers, along with related *guggulsterols*, are responsible for many of the pharmacological properties of *Guggulu*, such as its anti-inflammatory, hypolipidemic, and antioxidant effects.

CONCLUSION

Guggulu Kalpana is a versatile *Ayurvedic* formulation, where proper *Shodhana* with an appropriate purification medium ensures safety, bioavailability, and effectiveness. The preparation method, *Saagni Paka* or *Niragni Paka*, influences stability and pharmacological activity, and following classical guidelines on dosage, *anupana*, and *pathya-apathya* supports its rational use. The presence of bioactive compounds like *guggulsterones* explains its wide therapeutic potential, bridging traditional knowledge with modern understanding. Hence, *Guggulu Kalpana* has versatile usage in many ailments and remains highly relevant in *Ayurvedic* practice, with scope for further standardisation and research.

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Table no.01: Rasapanchaka of Guggulu³

Rasa	Katu, Tikta
Guna	Laghu, Ruksha
Virya	Ushna
Vipaka	Katu
Doshagnatha	Pacifies Vata and Kapha
Karma	Lekhana, shothahara, medohara, Deepana-pachana, Rasayana

Table no: 02 -Dose

REFERENCE	DOSE
Astanga Sangraha, Uttartantra 49/261 (Rasayana vidhi)	Up to 1 Tula (100 Pala) must not take more than 1 Pala in a single dose.
Harita Samhita, Kalpa Sthana 5/19	1 Karsha (12g) to 1 Pala (48g)

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REVIEW ARTICLE

Effectiveness of Russian Current in Enhancing Strengthening for Quadriceps Muscle Isokinetic Contraction in Physiotherapeutic Rehabilitation : A Systematic Review and Meta –Analysis

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ABSTRACT

The application of Russian current has been investigated as a way of improving muscle strength particularly where voluntary muscle contraction may be restricted or contraindicated. The goal of this systematic review was to assess the effect of using Russian current on quadriceps muscle strength in healthy individuals, clinical patients, and athletes. To systematically assess the efficacy of Russian current to increase quadriceps muscle strength in healthy individuals, clinical populations and athletes and quantitatively combine strength outcomes when appropriate. Searches of PubMed, Cochrane Library, and PEDro databases were performed from the inception of the databases to 16 August 2025. Randomized controlled trials investigating Russian current either alone or combined with exercise were included. Valid assessment tools were used to extract quantitative strength outcomes and analyzed.

The five studies reviewed present data on the county-level. Participants included healthy young adults, older adults who were at risk for falls, athletes, patients with polyneuropathy, and patients with osteoarthritis. The majority of studies showed an increase in isometric or isokinetic quadriceps strength but results have been inconsistent between studies. Meta analysis showed that there was no overall significant effects, and there was a high degree of heterogeneous effect across the included trials. Russian current may be a potential adjunctive therapy for enhancing the strength of the quadriceps muscle, specifically in those who have a decreased voluntary activation. Some methodological variation and

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heterogeneity across studies does necessitate some degree of caution, however, and there is a need for additional high-quality randomized controlled trials.

Keywords: Muscle Weakness, Muscle Strength, Osteoarthritis, Electrical Stimulation

INTRODUCTION

Russian current stimulation is a medium-frequency alternating current, originally developed by Dr. Yakov Kots in the 1970s for enhancing strength in Soviet Olympic athletes, and is continued as a widely used electrotherapeutic management in the enhancement of sport performance and to facilitate rehabilitation. It is delivered at a carrier frequency of ~2500 Hz with a burst modulation of 50 Hz and a 50% duty cycle, and allows deep muscle activation with reduced superficial discomfort compared to low-frequency stimulation [1]. Its key advantage lies in its ability to override the natural size principle of motor unit recruitment, thereby activating fast-twitch fibres earlier and potentially increasing force production beyond voluntary contraction alone. Physiologically, voluntary contractions follow Henneman's size principle, recruiting small, fatigue-resistant motor units first before engaging larger, fast-twitch units as force demand increases [2]. In contrast, Russian current tends to produce a non-selective, spatially fixed, and temporally synchronous motor unit activation pattern, potentially recruiting larger (type II) fibres earlier than usual, leading to greater torque output but also quicker fatigue [3].

Russian current is superimposed on voluntary contraction; the combination may recruit additional motor units that would otherwise remain inactive, maximizing force generation, especially during early rehabilitation when heavy load training is contraindicated [4]. Russian current is commonly applied in Post-operative rehabilitation, e.g., after anterior cruciate ligament (ACL) reconstruction, to restore quadriceps strength when pain or swelling limits voluntary activation and in knee osteoarthritis (KOA), to supplement exercise and improve muscle strength and functional outcomes [5]. It is also used in neurological and musculoskeletal injuries, where its ability to activate impaired muscles non-volitionally can promote neural recovery [6]. It augments strength rehabilitation in older adults or populations at risk of falls, where high-load resistance training is not feasible or safe but effective strength gains are beneficial [7].

The quadriceps femoris is a knee extensor, formed by four muscles: vastus medialis, vastus lateralis, vastus intermedius, and rectus femoris [8]. Weakness of this group of muscles impairs mobility and increases the risk of falls, and is often followed significantly post-knee surgery or prolonged immobility [7]. Effective stimulation of the quadriceps using Russian current relies heavily on appropriate electrode placement. Research suggests that placing electrodes over the motor points of the vastus medialis and vastus lateralis muscles, typically along the distal and proximal anterior aspect of the thigh, maximizes activation across the muscle belly [9]. A longitudinal positioning (proximal-distal) across the muscle has been shown to produce better torque production than transverse placements [10]. Although Russian current is widely used in physiotherapy and sports rehabilitation, certain contraindications must be carefully considered to ensure patient safety. Absolute contraindications include the presence of electronic implants such as pacemakers or defibrillators, as the electrical impulses may interfere with device function, leading to life-threatening arrhythmias, in case of, pregnant women, especially during the first trimester, should avoid Russian current on abdominal or pelvic regions due to unknown risks to foetal development [11].

A dynamometer is an outcome measure used to measure the strength of muscles; quantification of quadriceps strength is pivotal for evaluating the effectiveness of the Russian current [12]. Two primary methods are mainly used for quantification of strength: a Hand-Held Dynamometer (HHD) and an Isokinetic Dynamometer (ID). HHD is a portable, cost-effective, and practical device which is significant for clinical use. It is a valid and reliable tool for the measurement of isometric quadriceps strength when properly stabilized, especially with a belt or external anchor to



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minimize examiner strength dependency[5].Belt-stabilized setups correlate well with isokinetic gold standards ($r \approx 0.86-0.93$, $ICC \approx 0.88-0.94$), though they may underestimate true torque by $\sim 20-25\%$ [13].ID is considered to be the reference standard for measuring concentric, eccentric, and isometric torques at controlled speeds.Provides objective metrics such as peak torque, torque-time curves, and rate of torque development (RTD) and has shown to have a high reliability and precision with $ICC > 0.99$, and coefficient of variation $\sim 1\%$ [14]. This review aims to evaluate the effectiveness of RC stimulation in strengthening the quadriceps muscle, particularly in rehabilitation and clinical populations, using objective outcome measures such as dynamometers. The main objective of the review is to systematically evaluate whether RC stimulation produces measurable improvements in quadriceps muscle strength, assessed via dynamometry, in clinical and rehabilitation populations compared to standard care or control interventions.

METHODOLOGY

A systematic review was done in 2025, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standard guidelines. Articles were selected based on their publication year and only from the past five years. The systematic review and meta-analysis have been registered on PROSPERO. The PROSPERO Registration number is CRD420251132416.

Search Strategy

An elaborate search was conducted up to August 16th, 2025.Articles were procured from three main databases:PubMed, Cochrane Library, andPEDro. The search was conducted using the following keywords: “Russian current”, “physiotherapy”, “strengthening”, “Quadriceps Muscle”, and/or “Electrotherapy”, along with Boolean operators like “AND”, “OR”. The search strategy used to retrieve articles from various databases is presented in Table1.A total of 465 articles were analysed based on their title and abstract. These were screened, and irrelevant studies were eliminated based on the inclusion criteria. If there was any uncertainty regarding the eligibility of the study from the title and abstract, the full text was retrieved and assessed for eligibility. After an initial review, articles that were considered potentially relevant underwent an exhaustive reading of their full text was carried out, paying special attention to the intervention (type of treatment), relief of symptoms, number of sessions, and duration of treatment.

Eligibility Criteria**Inclusion Criteria**

The selection of articles was based on the PICOS framework (participants, intervention, comparator, outcomes, study design). After properly filtering the articles, they were further screened on the basis of the following eligibility criteria:

- Participants included the healthy, diseased population, and athletic population (soccer players and volleyball players).
- Intervention: The main intervention included Russian current, along with other physiotherapy-based techniques.
- Comparator: Participants were allocated to two groups: one received exercise therapy alone, and the other performed exercise therapy supplemented with Russian current
- The outcome measure was strength, measured using a valid tool, such as a dynamometer.
- All the chosen studies are randomized controlled trials (RCTs).

Exclusion Criteria

The articles that were not available as free full-text articles or were not available in the English language were excluded from the study. The exclusion criteria were further expanded to protocols, pilot studies, and non-RCTs.



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Quality and Risk of Bias Assessment

PEDro scores from the Physiotherapy Evidence Database Scale (PEDro) were used to assess the quality of studies. The PEDro scale contains 11 items, and during the calculation, the first item is omitted; each satisfied item contributes one point to the total score (range 0–10). This tool was used for quality assessment of all the included RCTs. Risk of Bias was assessed using the COCHRANE RISK OF BIAS ASSESSMENT TOOL RoB-2 (robvis) tool. The tool evaluates a study on five major domains and appraises it on four factors, like high risk, low risk, some concern, and no information.

Statistical Analysis

A meta-analysis was performed on MetaAnalysisOnline.com, an online website prominently used for performing meta-analyses. A forest plot meta-analysis was conducted for four studies. Changes in strength were measured using ID, which was used to measure the changes in muscle strength. The analysis was performed using the random-effect statistical model, and the significance level was set at $p < 0.05$ and forest plots were generated for the results.

RESULTS

Selection of Studies

After a comprehensive search of all three databases, we found 24383 articles. After using filters, we were left with 23916 articles. These articles were then uploaded to the RAYYAN website, and duplicates were removed, leaving 465 studies. After applying filters and exhaustive analysis, we selected 5 articles for inclusion in this study. The complete flowchart of this selection methodology is presented in Figure 1.

The evidence synthesized from the seven studies includes 207 participants. Participants included healthy young adults, athletes, individuals with musculoskeletal conditions such as knee osteoarthritis and post-total knee arthroplasty, and patients with neurological impairments such as demyelinating polyneuropathy, despite variations in intervention protocols, electrode placements, and outcome measures

Quality And Risk of Bias Assessment

PEDro scoring was used for assessing the methodological quality of all the studies. Higher scores indicate better quality, and all five studies have above-average quality, i.e., they score more than five on the PEDro scale. Out of the 5 articles included in this review, only four of them obtained a score greater than or equal to 7 on the PEDro scale. These are the ones with the highest methodological quality. These articles did not meet many of the items on the scale. An average score of 7.6 was calculated across all five RCTs. (Table 2). The Cochrane Risk of Bias was assessed using the RoB-2 tool. All five studies were shown to have a high risk. There was bias due to missing outcome data in all five studies, which resulted in a high risk for all the studies. Individually, the study conducted by Suhara S. et al. (2025) also faced bias due to deviations from the intended intervention and bias in the measurement of the outcome. Akinoğlu B. et al. (2020) had bias due to deviations from the intended intervention. (Figure 2) The study has an overall high risk of bias. (Figure 3).

Statistical Analysis

Meta-analysis of the four trials with a total of 136 participants shows no significant overall effect of the intervention compared with control ($Z = 1.00$, $p = 0.3156$), indicating that the combined evidence does not consistently favour either group. Individual study findings varied widely. One study (Ansam Hasan, 2024) demonstrated a large and statistically significant positive effect, while the other three studies (Suhara, 2025; AZIZ, 2021; Bihter Akinoğlu, 2020) showed little to no meaningful difference. This inconsistency is reflected in the very high heterogeneity ($I^2 = 91.7\%$, $p < 0.0001$), suggesting that differences in protocols, sample characteristics, or measurement methods may account for the variation. The wide prediction interval further indicates that future studies could report effects ranging from negative to strongly positive. Overall, current evidence remains inconclusive, and further well-designed, standardized trials are needed to clarify the true impact of the intervention.



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DISCUSSION

This systematic review and meta-analysis synthesized evidence from seven studies assessing the effectiveness of RC stimulation for quadriceps strengthening across diverse populations, including healthy individuals, athletes, patients with musculoskeletal disorders such as knee osteoarthritis, those undergoing postoperative rehabilitation following anterior cruciate ligament (ACL) reconstruction, and individuals with neurological impairments such as chronic inflammatory demyelinating polyneuropathy (CIDP)[16]. The review aimed to determine whether RC could provide consistent and clinically meaningful improvements in quadriceps strength and function compared to exercise alone or alternative stimulation methods[17]. The findings suggest that Russian current is a promising adjunct to exercise-based rehabilitation and athletic training[18]. Several included studies reported significant improvements in quadriceps strength when RC was applied alongside voluntary contraction or structured exercise. For example, ACL reconstruction patients who received combined exercise and RC achieved greater improvements in isometric quadriceps and hamstring strength, as well as functional scores, compared to those who performed exercise alone[19]. Similarly, in neurological populations such as CIDP patients, the integration of RC with exercise resulted in superior outcomes in both quadriceps torque and functional independence measures, demonstrating its role in enhancing neuromuscular activation where voluntary recruitment may be limited[20].

These findings align with the proposed mechanism of RC, which bypasses the natural size principle of motor unit recruitment and preferentially activates type II fibres earlier, resulting in greater torque production and improved force output[21]. In elderly individuals at risk of falls, the addition of RC to isometric training improved not only quadriceps and tibialis anterior strength but also balance and mobility scores[22]. RC may serve as a safe and effective tool for addressing sarcopenia-related weakness, especially when high-load resistance training is contraindicated[23]. A study on university students found that RC delivered via expert stimulation modes (ON2 and Rest) significantly enhanced quadriceps isokinetic torque. Athletes, including volleyball and soccer players, showed gains in quadriceps endurance and torque when RC was compared with other forms of neuromuscular electrical stimulation, such as high-voltage pulsed current[24]. Both RC combined with exercise and exercise alone improved quadriceps strength, pain, and function, but the incremental benefit of RC was not statistically significant. This suggests that in conditions where exercise is already highly effective, the additive effect of RC may be limited. Nonetheless, it remains possible that RC provides subtle neuromuscular adaptations not fully captured by conventional outcome measures, or that its benefits emerge more strongly in subgroups with severe weakness or poor exercise tolerance[25].

Methodological quality of the included studies, as assessed by the PEDro scale, ranged from moderate to high. Four studies scored ≥ 7 , indicating strong design elements, while one scored lower, reflecting issues such as lack of blinding or inadequate reporting. Risk of bias analysis revealed that missing outcome data and deviations from intended interventions were common, raising concerns about internal validity. These limitations reduce confidence in the overall strength of the evidence and suggest that future trials should incorporate rigorous randomization, blinding of outcome assessors, intention-to-treat analyses, and transparent reporting of attrition. Nevertheless, caution is warranted in interpreting the current evidence base. The small sample sizes, variable protocols, and short-term follow-up in many included studies limit the generalizability of findings. Long-term outcomes such as sustained strength gains, functional independence, and quality of life remain underexplored. Furthermore, while handheld and isokinetic dynamometers provided objective outcome measures, additional parameters such as electromyographic activity, muscle architecture, and fatigue indices could enrich the understanding of RC's physiological impact.

Future research should prioritize large-scale, multi-centre randomized controlled trials with standardized stimulation protocols and longer follow-up periods. Comparative studies against other neuromuscular electrical stimulation modalities could clarify whether RC provides unique advantages. Additionally, individualized parameter adjustments, such as tailoring frequency and duty cycle to patient tolerance and rehabilitation goals, may optimize outcomes. This review supports the role of Russian current as an effective and versatile adjunct in muscle



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strengthening. It demonstrates clear utility in postoperative and neurological populations, potential benefits in elderly fall-prevention, and positive results in athletes and healthy adults. However, methodological limitations and inconsistent findings necessitate further investigation. Until more robust evidence emerges, clinicians should consider RC as a complementary tool to exercise therapy, particularly where voluntary activation is impaired, while remaining mindful of its limitations.

CONCLUSION

Russian current stimulation, whether applied alone in healthy adults or combined with exercise in clinical populations, consistently enhances muscle strength and functional outcomes. By modulating stimulation parameters, we can individualize treatment, using higher frequencies for rapid strength gains or lower frequencies to minimize fatigue. Evidence supports RC as an effective adjunct in postoperative rehabilitation and neuromuscular disorders; however, variability in methodology highlights the need for standardized protocols and long-term follow-up. Future research should refine optimal parameters and evaluate combined training approaches to ensure sustained improvements in muscle performance and functional independence.

What is known about the subject

Muscle weakness is commonly managed using neuromuscular electrical stimulation when voluntary contraction is limited. Russian current has been shown to improve muscle strength in healthy individuals and selected clinical and athletic populations, but evidence remains inconsistent and fragmented.

What this study adds to existing knowledge

This review synthesizes randomized controlled trials demonstrating that Russian current can effectively improve muscle strength across healthy, athletic, and clinical populations. It supports the Russian current as a promising adjunct to strengthening interventions, particularly when voluntary activation is compromised.

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Author contribution:

All authors contributed to the study conception and design. The first author contributed by performing the investigation, initial data curation, doing formal analysis, writing the methodology, and writing the original draft. The second author contributed by doing project administration, supervision, validation, and reviewing and editing the draft.

The third author contributed by performing initial data curation, methodology, reviewing, and editing the draft.





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Ethical Approval:

The study did not require any ethical approval as it did not include any human or animal participation. Although PROSPERO registration was done for this study.

Consent to participate: Not required

Consent to publish: Not required

Data Availability: There is no data to be reported in this study.

Table 1: Search Strategies in different data base

Keyword	DATABASE		
	PUBMED	PEDro	Cochrane Library
"Russian current" AND "physiotherapy" OR "quadriceps"	24208	0	13
"Russian Current" OR "quadriceps" AND "Electrotherapy"	17	0	99
"Russian Current" AND "strengthening"	7	2	17
"Russian Current" AND "quadriceps"	6	1	13
Total	24238	3	142

Table 2: Summary of the quality of the RCTs included in this review on the basis of PEDro scale

Author, Year	1	2	3	4	5	6	7	8	9	10	11	Total
Akinoğlu B, et al. (2020)	✓	✓	✗	✓	✗	✗	✓	✓	✗	✓	✓	7/10
Sandra M. Ahmed (2021)	✓	✓	✓	✓	✗	✗	✓	✓	✗	✓	✓	8/10
Suhara S., Lakshmipriya V., Jeyanthi S. (2025)	✓	✓	✗	✓	✗	✗	✗	✓	✗	✓	✓	6/10
Ibrahim Moustafa, and Tamer Shousha	✓	✓	✓	✓	✓	✗	✗	✓	✓	✗	✓	8/10
Arrais Guida Modesto 2020	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	9/10
Total Average												7.6

Table3: Search Strategies in different data base

No	Author, Year	Population & Sample Size	Type of Study	Objective	Intervention	Outcome Measures	Results
1.	Akinoğlu & Kocahan, 2020	Volleyball athletes	RCT	To evaluate the impact of Russian current (RC) and high voltage pulsed current (HVPC) on the quadriceps muscle strength and endurance.	2 (RC vs. HVPC, split limbs)	Isokinetic Dynamometer, Endurance Ratio	Both improved; no significant difference
2.	Modesto et al., 2020	Soccer player	RCT	We studied the effects of different neuromuscular electrical stimulation currents, RC, and PC on neuromuscular	3 Group 1. control group 2. Russian current (2500 Hz, burst 100Hz phase duration 200 micro sec)	Muscle endurance (FI), Dynamometer Torque (Nm)	No significant difference; both effective




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				system after a week training period			
3.	Abdel Aziz et al., 2021	CIDP patients	Single-blinded RCT	To evaluate the difference between effect of Russian current and combined exercise and only exercise therapy on muscle strength and function in chronic inflammatory demyelinating neuropathy	2 (Exercise only vs. Exercise + RC)	Dynamometer Quadriceps strength, Barthel Index	RC group showed significantly better outcomes
4.	Hasan et al., 2024	Healthy adults	Single-blind RCT	This study evaluate the direct effect of Russian current (expert modes) on knee extensors muscle strength in healthy adults.	2 (RUSSIAN CURRENT ON2 vs. RUSSIAN CURRENT Rest Mode)	Quadriceps Isokinetic Torque (Dynamometer)	Significant improvement in both groups
5.	Suhara et al., 2025	ACL reconstruction patients (sports injuries)	Experimental study	To evaluate the combined effect of Russian current and structured exercise in improving knee function following ACL reconstruction.	2 (Russian current and structured exercise vs. exercise only)	ROM (goniometer), Isometric Strength (dynamometer), Lysholm Score	RC group showed greater improvement (p < 0.001)





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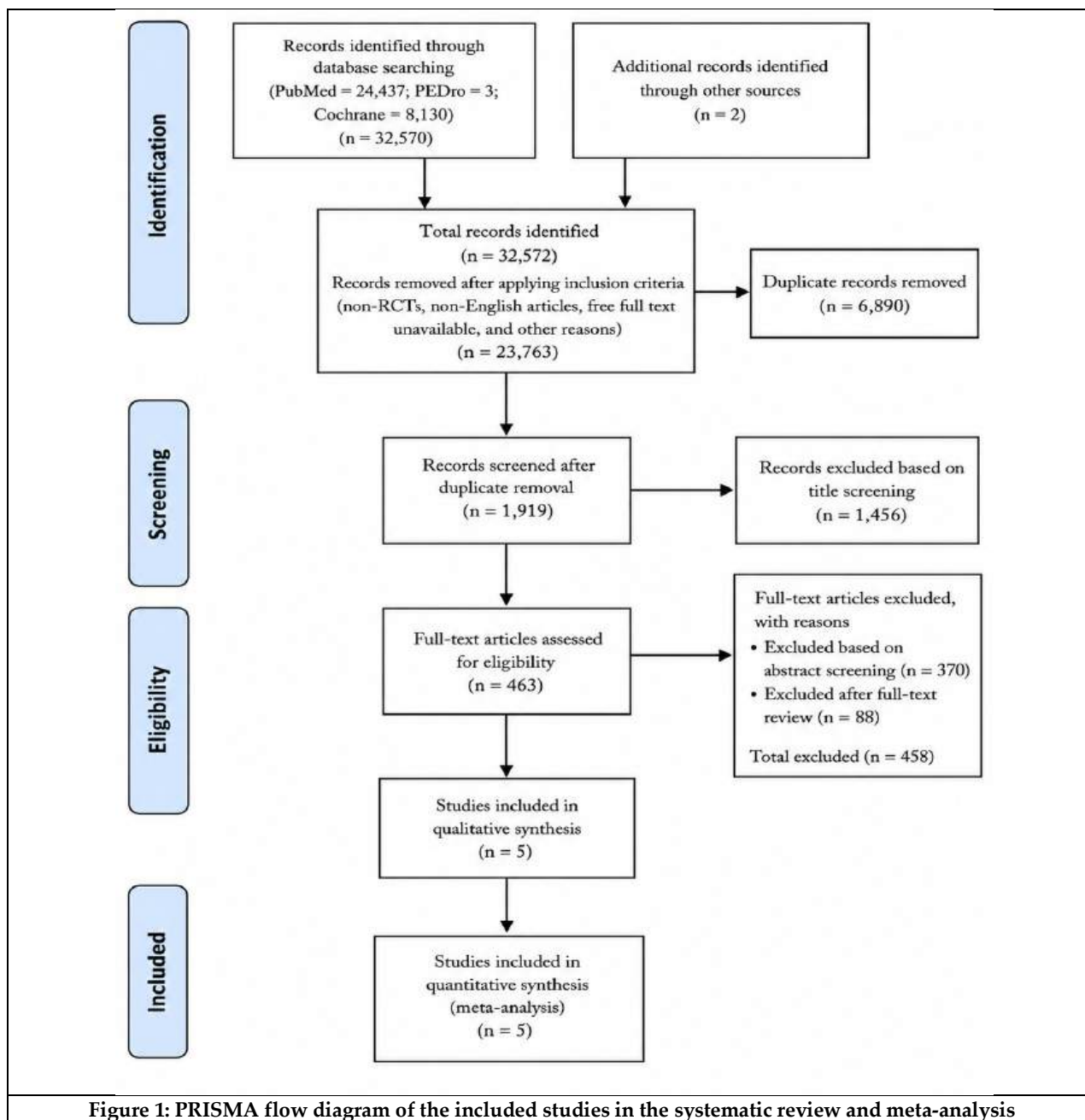


Figure 1: PRISMA flow diagram of the included studies in the systematic review and meta-analysis





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RESEARCH ARTICLE

Study on the Breeding Performance and Developmental Stages of *Anabas testudineus* (Bloch, 1972) Induced with Synthetic Hormone

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ABSTRACT

Anabas testudineus (climbing perch) is an economically significant native fish species of north-eastern India. In view of irregular natural breeding and scarcity of seed, the current work was carried out to assess induced breeding and embryonic development of *Anabas testudineus* under controlled aquarium circumstances. Healthy brooders were chosen in the ratio of 2:1 (female:male) and were injected with synthetic hormone S-GnRHa (Ovasis) at 0.3 ml/kg and 0.1ml/kg body weight for male and female respectively. Spawning occurred within 7-10 h after injection and hatching was seen within 16-18 h at 26-28°C. The reported rates of fertilization, hatching and survival were 80%, 60% and 30% respectively. The morula, blastula, and gastrula stages were completed at around 3-4 hours, 7 hours, and 8-9 hours post fertilization. The research shows that induced breeding using synthetic hormone is beneficial for the captive breeding and seed production of *Anabas testudineus*.

Keywords: fertilization, *Anabas testudineus*, nutrition and revenue production

INTRODUCTION

Fish culture has become an essential aspect of aquaculture since it helps considerably to food supply, nutrition and revenue production in underdeveloped nations [1]. Induced breeding methods are frequently used for several economically significant fish species which don't breed successfully in the confined circumstances for enhancement



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of fish seed output. This approach is based on the use of hormonal stimulation to induced the release of egg and sperm from adult brood fish under regulated environmental circumstances. Induced breeding increases breeding success, hatchability and seed supply and decrease reliance on natural sources [2]. The Climbing Perch (*Anabas testudineus*) is a freshwater air-breathing fish of the family Anabantidae Commonly known as Koi or Kawoi. The species is widespread in various tropical and subtropical Asian nations and is prevalent in ponds, marshes, swamps, rice fields, canals and slow-moving freshwater bodies[3]. The fish has a particular respiratory organ, which allows it to tolerate little oxygen and stay alive for a while without water [4]. *Anabas testudineus* is regarded as one of the important indigenous fish species in North Eastern India due to its excellent nutritional quality, customer preference and market worth. The flavor of this species is popular and has *Anabas testudineus* is regarded as one of the important indigenous fish species in North Eastern India due to its excellent nutritional quality, customer preference and market worth also having necessary fatty acids required for human health [5].

It is increasing demand in local markets has generated more interest in its culture and seed production [6]. The natural reproduction of climbing perch mostly happens in the rainy season and is highly dependent on the environmental variables such as rainfall, water level and temperature. These environmental requirements mean natural seed supply is frequently insufficient for large-scale agriculture [7]. Hence techniques of induced breeding are essential for continued seed production under captive settings. In earlier investigations, several hormones and breeding strategies have been effectively employed for induced breeding of this species[8]. Though many works have focused on mating and rearing procedures of the climbing perch, although thorough information on embryonic development under controlled settings is still scarce. Therefore, the current work was carried out to examine the induced breeding performance using synthetic hormone and to investigate the embryonic developmental phases of *Anabas testudineus* under aquarium settings.

MATERIALS AND METHODS

The current study was carried out between February-April 2026 at the laboratory of Pandu College (affiliated college of Gauhati University) located in Guwahati, Assam, India.

Tank Preparation

A medium sized aquarium (45×35×60 cm) is used for broodstock management is thoroughly washed, then cleaned and subsequently rinsed with water to eliminate any germs or bacteria that could infect the brooders.

Collection of brooders and stock management

Brooders are being collected from Deepor Beel, Guwahati, Assam. Aeration was provided which gives an oxygen-rich environment in the aquarium, promoting a healthy habitat for fish. Broods were acclimatized for 10-15 days. Throughout the experimental period, various physicochemical parameters (water temperature, pH, dissolved oxygen) of the brood stock tank were measured following standard methods [9]. Water quality is a critical factor in fish breeding, making it an essential parameter for the success of the process.

Feeding methods

The brood fishes were fed twice a day once in the morning and in the afternoon. The feeds used are white portion of boiled eggs, larvae of insects and commercial feed. Measurement of the fish weight was attained 30-40 grams for both males and females, and the length was measured with a scale of approximately 9-14 cm.

Injection of brooders

Brooders were injected in the intra-muscular part which is generally given in the muscle below the tip of the pectoral fin, at a 45° angle. The brooders were injected in the noon (11:30am) with a dosage of 0.3 ml for females and 0.1 ml for males at the ratio of 2:1 (female: male).



**Harshita Kashyap et al.,****Study of Embryonic development**

Fertilized eggs are being taken in a petri dish for further study of embryonic development. Then they were taken in a slide with the help of a dropper and observed under a stereo zoom microscope and photographed. Fertilization rate was also calculated using the following formula: Fertilization Rate (%) = Number of fertilized egg/Total number of eggs×100, Survival rate was calculated using the following formula: Survival Rate (%) = Number of surviving fry/Total number of hatched larvae× 100

RESULTS**Water Parameters**

During the present investigation, the water quality parameters maintained in the breeding aquarium were found to be suitable for the induced breeding and embryonic development of *Anabas testudineus* (Table 1).

Induced Breeding

The fertilized eggs appeared spherical, transparent, non-adhesive, and buoyant, floating near the surface of the water. In contrast, unfertilized eggs appeared opaque and either remained suspended in the water column or settled at the bottom of the aquarium. After spawning, the brood fishes were removed carefully from the tank to prevent predation and disturbance to the developing eggs. Hatching was observed between 32–34 h after fertilization. Newly hatched larvae were free swimming and were initially fed with small zooplankton and phytoplankton collected from nearby pond water.

Fertilization Rate

A satisfactory fertilization rate and hatching rate (Table 2) was recorded in ovasis induced breeding.

Embryonic Development of *Anabas testudineus*

The embryonic development of *A. testudineus* was observed continuously from fertilization until larval hatching. The fertilized eggs were golden brown in colour, spherical in shape, transparent, and free floating in nature. The first cleavage was observed shortly after fertilization, resulting in the formation of the 2-cell stage. Subsequent cell divisions produced the 4-cell, 8-cell, 16-cell, and multi cellular stages. Cleavage divisions occurred rapidly and uniformly during the early developmental period. Further embryonic development led to the formation of morula and blastula stages, characterized by the accumulation and arrangement of blastomeres. Gastrulation was marked by differentiation and migration of embryonic cells, followed by the initiation of organogenesis. During segmentation, the embryonic body became clearly distinguishable with the development of head and tail regions. Newly hatched larvae possessed a yolk sac attached to the ventral region of the body and showed limited swimming movements immediately after hatching (Figure.10). Different time of stages of embryonic development was also recorded accordingly (Table 3). The first cleavage was seen within 20 minutes after fertilization followed by 4-cell, 8-cell, 16-cell and 32-cell phases at around 1 hour 5 minutes, 1 hour 25 minutes, 1 hour 55 minutes and 2 hours 15 minutes correspondingly. The hatching occurred after 32-34 hours.

DISCUSSION

The current work showed effective induced breeding and embryonic development of *Anabas testudineus* under controlled aquarium condition using synthetic hormone S-GnRHa (ovasis). The recorded water temperature throughout the experiment, pH and DO were found appropriate for effective breeding and larval development. Proper water quality maintenance and constant aeration may have played a crucial role in effective spawning and hatching[10]. Fertilized eggs were clear, spherical and floating, unfertilized eggs were opaque and sank at the bottom. Similar findings were observed in prior investigations of induced breeding of climbing perch[11]. During the



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experiment, the observed low survival rates (30%) may be due to climatic variations, broodstock condition, handling stress and larval nutrition management[12]. Differences in breeding success reported across studies may also be attributable to hormone dose, water quality, climatic circumstances and hatchery techniques[13]. The embryonic developmental phases of *A. testudineus* were closely followed in the research and similarities can be observed in the developmental time of *A. testudineus* while compared with previous research[6,10]. The current research shown that induced breeding using synthetic hormone is a successful strategy for captive breeding and seed production of *Anabas testudineus*. The research also gives helpful information on embryonic development that might be used to improve hatchery management and larval rearing procedures for this commercially important significant indigenous fish species.

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Table 1. Water quality parameters maintained during induced breeding of *A. testudineus*

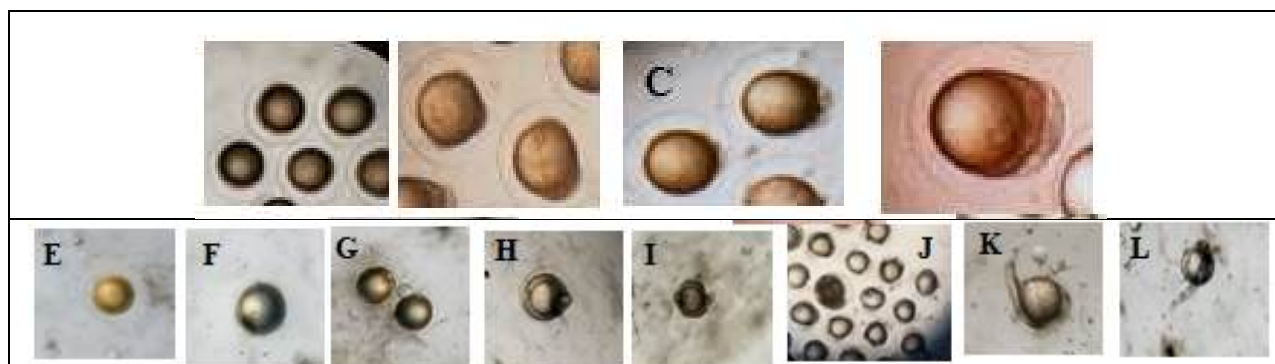
Water parameters	Values
Temperature	27±2.1°C
pH	6.7±1.1
DO	7.8±1.6ppm

Table 2: Fertilization rate and survival rate from the experiment

Species	Fertilization rate (%)	Hatching rate (%)	Survival rate (%)
<i>Anabas testudineus</i>	80%	60%	30%

Table 3: Time of different embryonic stages after fertilization in *A. testudineus*

Stages of Development	Time after Fertilization
Start of cleavage	20min
2-cell stage	35min
4-cell stage	1 hour and 5 min
8-cell stage	1 hour and 25 min
16-cell stage	1 hour and 55 min
32-cell stage	2 hour and 5 min
Morula	2 hours – 4 hours
Blastula	6 hours – 7 hours 30 min
Gastrula	8 hours – 9 hours 20 min
Neurula	9 hours 30 min – 11 hours
Segmentation	15 hours – 24 hours
Newly hatch larvae	32 hours – 34 hours



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Figure 1.The different stages of embryonic development of *A. testudineus*
(A) Fertilized egg, (B–F) Cleavage stages, (G) Blastula stages, (H) Gastrula and organogenesis stages, (I) Neurula, (J) Segmentation stages, (K–L) Newly hatched larvae, and (M–N) Free-swimming larva (O).

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RESEARCH ARTICLE

Strong α - Level Bijective Single Valued Neutrosophic Graphs and its Application in Agricultural Farming

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ABSTRACT

In this paper a new concept of strong α – level sets of bijective single valued neutrosophic sets and its graphs have been defined. Some of their structural characteristics have been established. Further basic set-theoretic operations on Bijective single valued neutrosophic sets, including subset relation, equality, intersection, union, complement and set difference are investigated in neutrosophic environment.

Keywords: Neutrosophic sets, Bijective single valued neutrosophic graph, strong α – level

INTRODUCTION

Graph theory is widely recognized as a branch of applied mathematics. It useful for real-life problems related to optimization and computer science. When uncertainty arises in the set of vertices, edges or both, a graph transforms into a fuzzy graph and intuitionistic fuzzy graphs [1] capturing the essence of ambiguity in its structure. But, when relations between vertices and edges become indeterminate it takes a new structure as neutrosophic graph. A fuzzy set was defined by Zadeh L [2] in 1965. His purpose was to develop a theory for sets which are ambiguous and imprecise. Every element in the universal set is assigned a grade of membership, a value in $[0,1]$. The elements in the universal set along with their grades of membership form a fuzzy set. The concept of neutrosophic sets was first introduced by Smarandache [3,4] as a generalization of intuitionistic fuzzy sets where the degree of membership of each element in X . The neutrosophic set is a powerful mathematical tool for dealing with incomplete, indeterminate and inconsistent information in real world. The neutrosophic sets are characterized by a truth-membership function





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(t), an indeterminacy-membership function (i) and a falsity- membership function (f) independently, which are within the real standard or nonstandard unit interval] $-0, 1 + [$. In order to conveniently use neutrosophic sets in real life applications.

Al-omeri et al. [5, 6, 7] studied about topological and metric spaces. Broumi et al. [8] introduced a neutrosophic graph, which allows the attachment of truth-membership (t), indeterminacy-membership (i) and falsity-membership (f) both to vertices and edges, and some of their properties. Wang et al. [9] introduced the concept of the single valued neutrosophic set (SVNS), as a subclass of the neutrosophic sets. Further [10, 11, 12, 13,14] deals with single valued NS. The single valued neutrosophic graph is a generalization of fuzzy graph and intuitionistic fuzzy graph. Johnson Awolola [15] who initially defined α -level NS, a new notion of α -level NS aimed at enhancing the precision and practicality of outcomes. Within this concept of an α -level NS and a robust variant termed the strong α -level NS. These concepts applied to the domain of neutrosophic graphs, enabling the exploration of diverse properties and their implications. In this paper, a new concept of strong α -level bijective single valued neutrosophic graph has been defined. Basic operations and De Morgan's Laws defined for strong α -level bijective single valued neutrosophic sets. Some of their relation between α -level and strong α -level bijective single valued neutrosophic sets has been studied. It also includes an application of strong α -level bijective single valued neutrosophic graph in agricultural farming.

Basic Operations on Bijective Single Valued Neutrosophic Set

Let X be a crisp set. A Bijective Single Valued Neutrosophic Set (BSVNS) A is characterized by truth membership function $T_V(P)$, an indeterminacy membership function $I_V(P)$ and a falsity membership function $F_V(P)$ for every point $p \in V$; $T_V(p), I_V(p), F_V(p) \in [0,1]$ such that $T_V(P_i)$ and $T_V(P_j)$, $I_V(P_i)$ and $I_V(P_j)$, $F_V(P_i)$ and $F_V(P_j)$ are distinct respectively, for any i and j .

Definition 1.2:[16]

A Bijective Single Valued Neutrosophic Graph (BSVNG) is a triplet $G = (V, \sigma, \mu)$ in which the truth-membership function of vertices and edges are bijective (i.e.) $\sigma_T : V \rightarrow [0,1]$ and $\mu_T : E \subseteq V \times V \rightarrow [0,1]$ are bijective. Similarly, indeterminacy-membership function of vertices and edges are bijective respectively i.e., $\sigma_I : V \rightarrow [0,1]$ and $\mu_I : E \subseteq V \times V \rightarrow [0,1]$ are bijective, and $\sigma_F : V \rightarrow [0,1]$ and $\mu_F : E \subseteq V \times V \rightarrow [0,1]$ are bijective where $\mu_T(V_i, V_j) < \min(\sigma_T(v_i), \sigma_T(v_j))$, $\mu_I(V_i, V_j) > \max(\sigma_I(v_i), \sigma_I(v_j))$, $\mu_F(V_i, V_j) > \max(\sigma_F(v_i), \sigma_F(v_j))$ for and $v_i \in V$ $i,j=1,2,...n$.

The following conditions are trivial in BSVNG as in case of SVNG

- i. $0 \leq \sigma_T(v_i) + \sigma_I(v_i) + \sigma_F(v_i) \leq 3$ for all $v_i \in V$ ($i=1,2,...n$)
- ii. $0 \leq \mu_T(v_i, v_j) + \mu_I(v_i, v_j) + \mu_F(v_i, v_j) \leq 3$ for all $v_i, v_j \in V \times V$ ($i,j=1,2,...n$).

Definition 1.3:

A Bijective Single Valued Neutrosophic Graph $G = (V, E)$ is said to be an Empty Bijective Single Valued Neutrosophic Graph if $V = \Phi$ and $E = \Phi$.



**Definition 1.4:**

Let A be any Bijective Single Valued Neutrosophic set in a non-empty set X . Then for any $\alpha \in [0,1]$ the strong α -level sets of A denoted by $S(V, \alpha)$ and defined as $S(V, \alpha) = \{x \in X : T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha\}$

Definition 1.5:

A Bijective Single Valued Neutrosophic Graph $G=(V, E)$ is called strong α -level (or) $S(G, \alpha)$ - level Bijective Single Valued Neutrosophic Graph if

$$T_V(x) > \alpha, I_V(x) + F_V(x) < 1 - \alpha \text{ for all } x \in V$$

$$T_E(xy) > \alpha, I_E(xy) + F_E(xy) < 1 - \alpha \text{ for all } xy \in E, \alpha \in [0,1]$$

Remark 1.6:

If G is a Bijective Single Valued Neutrosophic Graph and if $\alpha = 1$ then $V=\Phi$ and $E=\Phi$.

Definition 1.7:

If A and B are two Bijective Single Valued Neutrosophic sets in a non-empty set X . Then

1. $A \subseteq B \Leftrightarrow T_A(x) \leq T_B(x), I_A(x) \geq I_B(x), F_A(x) \geq F_B(x) \text{ for all } x \in X$
2. $A = B \Leftrightarrow T_A(x) = T_B(x), I_A(x) = I_B(x), F_A(x) = F_B(x) \text{ for all } x \in X$
3. $A \cap B = \{x, \wedge(T_A(x), T_B(x)), \vee(I_A(x), I_B(x)), \vee(F_A(x), F_B(x)) \mid \text{for all } x \in X\}$
4. $A \cup B = \{x, \vee(T_A(x), T_B(x)), \wedge(I_A(x), I_B(x)), \wedge(F_A(x), F_B(x)) \mid \text{for all } x \in X\}$
5. $A^c = \{x, F_A(x), 1 - I_A(x), T_A(x) \mid \text{for all } x \in X\}$
6. $A \setminus B = \{x, T_A(x) \wedge F_B(x), I_A(x) \vee 1 - I_B(x), F_A(x) \vee T_B(x) \mid \text{for all } x \in X\}$

Theorem 1.8:

If A and B are two Bijective Single Valued Neutrosophic sets in a non-empty X and $\alpha, \beta \in [0,1]$, then $A \subseteq B \Rightarrow S(A, \alpha) \subseteq S(B, \alpha)$.

Proof:

Let $A \subseteq B$. Assume that $x \in S(A, \alpha)$

$$\Rightarrow T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha$$

$$\Rightarrow T_B(x) > \alpha, I_B(x) + F_B(x) < 1 - \alpha$$

$$[\text{Since, } A \subseteq B \Rightarrow T_A(x) \leq T_B(x), I_A(x) \geq I_B(x), F_A(x) \geq F_B(x)]$$

$$\Rightarrow x \in S(B, \alpha)$$

$$\text{Hence } A \subseteq B \Rightarrow S(A, \alpha) \subseteq S(B, \alpha).$$

Theorem 1.9:

Let A and B be Bijective single valued neutrosophic sets of a non empty set X and $\alpha, \beta \in [0,1]$. If $\alpha \geq \beta$, then the strong α level of A is contained in strong β level of B

Proof:

Let $\alpha \geq \beta$. Assume that $x \in S(A, \alpha)$



**Theorem 1.10:**

If A and B are two Bijective Single Valued Neutrosophic sets in a non-empty X and $\alpha, \beta \in [0,1]$, then

- i) $S(A \cup B, \alpha) = S(A, \alpha) \cup S(B, \alpha).$
- ii) $S(A \cap B, \alpha) = S(A, \alpha) \cap S(B, \alpha).$

Proof:

$$\begin{aligned}
 S(A \cup B, \alpha) &= \{x \in X: T_{A \cup B}(x) > \alpha, I_{A \cup B}(x) + F_{A \cup B}(x) < 1 - \alpha\} \\
 &= \{x \in X: \vee \{T_A(x), T_B(x)\} > \alpha, \wedge \{I_A(x), I_B(x)\} + \wedge \{F_A(x), F_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: \{T_A(x) \vee T_B(x)\} > \alpha, \{I_A(x) + F_A(x)\} \wedge \{I_B(x) + F_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: \{T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha\} \cup \{T_B(x) > \alpha, I_B(x) + F_B(x) < 1 - \alpha\} \\
 &\quad \{x \in X: T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha\} \cup \\
 &= \{x \in X: T_B(x) > \alpha, I_B(x) + F_B(x) < 1 - \alpha\} \\
 &= S(A, \alpha) \cup S(B, \alpha)
 \end{aligned}$$

$$\text{Hence } S(A \cup B, \alpha) = S(A, \alpha) \cup S(B, \alpha).$$

$$\begin{aligned}
 S(A \cap B, \alpha) &= \{x \in X: T_{A \cap B}(x) > \alpha, I_{A \cap B}(x) + F_{A \cap B}(x) < 1 - \alpha\} \\
 &= \{x \in X: \wedge \{T_A(x), T_B(x)\} > \alpha, \vee \{I_A(x), I_B(x)\} + \vee \{F_A(x), F_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: T_A(x) \wedge T_B(x) > \alpha, \{I_A(x) + F_A(x)\} \vee \{I_B(x) + F_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: \{T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha\} \cap \{T_B(x) > \alpha, I_B(x) + F_B(x) < 1 - \alpha\}\} \\
 &\quad \{x \in X: T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha\} \cap \\
 &= \{x \in X: T_B(x) > \alpha, I_B(x) + F_B(x) < 1 - \alpha\} \\
 &= S(A, \alpha) \cap S(B, \alpha)
 \end{aligned}$$

$$\text{Hence } S(A \cap B, \alpha) = S(A, \alpha) \cap S(B, \alpha).$$

Theorem 1.11

Two neutrosophic Bijective singled valued sets A and B are equal iff their α level sets are equal for all $\alpha \in [0,1]$

Proof:

Assume that $A=B$

$$\Rightarrow T_A(x) = T_B(x), I_A(x) = I_B(x), F_A(x) = F_B(x), \text{ for all } x \in X.$$

We have, $S(A, \alpha)$

$$\begin{aligned}
 &= \{x \in X: T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha\} \\
 &= \{x \in X: T_B(x) > \alpha, I_B(x) + F_B(x) < 1 - \alpha\} \text{ [Since, } A=B \text{]} \\
 &= S(B, \alpha)
 \end{aligned}$$

$$\text{Hence } A = B \Leftrightarrow (A, \alpha) = (B, \alpha) \text{ for all } \alpha \in [0,1].$$





Conversely, let us consider for $\alpha \in [0,1]$, $S(A, \alpha) = S(B, \alpha)$ but $A \neq B$. Suppose $x \in A$ such that $x \notin B$. So, there exists an $\alpha \in [0,1]$ for each

$x \in S(A, \alpha)$. But, $x \notin B$ implies $x \notin S(B, \alpha)$ for each $\alpha \in [0,1]$. Therefore $S(A, \alpha) \neq S(B, \alpha)$ which is a contradiction to $S(A, \alpha) = S(B, \alpha)$ for all $\alpha \in [0,1]$.

Hence, $A = B \Leftrightarrow S(A, \alpha) = S(B, \alpha)$, for all $\alpha \in [0,1]$.

Theorem 1.12

The strong α level set of the union of a family of sets is equal to the union of their strong α level sets.

Proof:

$$\begin{aligned} & S\left(\bigcup_{i \in J} (A_i, \alpha)\right) \\ &= \{x \in X : T_{\bigcup_{i \in J} A_i}(x) > \alpha, I_{\bigcup_{i \in J} A_i}(x) + F_{\bigcup_{i \in J} A_i}(x) < 1 - \alpha\} \\ &= \{x \in X : \bigvee_{i \in J} T_{A_i}(x) > \alpha, \bigwedge_{i \in J} I_{A_i}(x) + \bigwedge_{i \in J} F_{A_i}(x) < 1 - \alpha\} \\ &= \{x \in X : \bigvee_{i \in J} T_{A_i}(x) > \alpha, \bigwedge_{i \in J} \{I_{A_i}(x) + F_{A_i}(x)\} < 1 - \alpha\} \\ &= \bigcup_{i \in J} \{x \in X : T_{A_i}(x) > \alpha, I_{A_i}(x) + F_{A_i}(x) < 1 - \alpha\} \\ &= \bigcup_{i \in J} S(A_i, \alpha) \end{aligned}$$

$$\text{Hence } S\left(\bigcup_{i \in J} (A_i, \alpha)\right) = \bigcup_{i \in J} S(A_i, \alpha).$$

Theorem 1.13

For any Neutrosophic set A_i ,

$$S\left(\bigcap_{i \in J} A_i, \alpha\right) = \bigcap_{i \in J} S(A_i, \alpha).$$

Proof:

$$\begin{aligned} & S\left(\bigcap_{i \in J} (A_i, \alpha)\right) \\ &= \{x \in X : T_{\bigcap_{i \in J} A_i}(x) > \alpha, I_{\bigcap_{i \in J} A_i}(x) + F_{\bigcap_{i \in J} A_i}(x) < 1 - \alpha\} \\ &= \{x \in X : \bigwedge_{i \in J} T_{A_i}(x) > \alpha, \bigvee_{i \in J} I_{A_i}(x) + \bigvee_{i \in J} F_{A_i}(x) < 1 - \alpha\} \\ &= \{x \in X : \bigwedge_{i \in J} T_{A_i}(x) > \alpha, \bigvee_{i \in J} \{I_{A_i}(x) + F_{A_i}(x)\} < 1 - \alpha\} \\ &= \bigcap_{i \in J} \{x \in X : T_{A_i}(x) > \alpha, I_{A_i}(x) + F_{A_i}(x) < 1 - \alpha\} \\ &= \bigcap_{i \in J} S(A_i, \alpha) \end{aligned}$$

$$\text{Hence } S\left(\bigcap_{i \in J} (A_i, \alpha)\right) = \bigcap_{i \in J} S(A_i, \alpha).$$

Theorem 1.14:

If A is a Bijjective Single-Valued Neutrosophic set then $S(A, \alpha) \subseteq (A, \alpha)$

for all $\alpha \in [0,1]$.



**Proof:**

Let $x \in S(A, \alpha)$

$$\Rightarrow T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha$$

$$\Rightarrow T_A(x) \geq \alpha, I_A(x) + F_A(x) \leq 1 - \alpha$$

$$\Rightarrow x \in (A, \alpha)$$

Hence $S(A, \alpha) \subseteq (A, \alpha)$, for all $\alpha \in [0, 1]$.

Theorem 1.15:

If A is a Bijective Single-Valued Neutrosophic set in a fixed set X . Let $\beta \in [0, 1]$ and $\alpha_i \in [0, \beta)$ for each $i \in J$ where Λ is an indexed set. Then $S(A, \beta) \subseteq \bigcap_{i \in J} S(A, \alpha_i)$.

Proof:

Assume that $x \in S(A, \beta)$

$$\Rightarrow T_A(x) > \beta, I_A(x) + F_A(x) < 1 - \beta, \text{ for all } x \in X$$

$$\Rightarrow T_A(x) > \beta > \alpha_i, I_A(x) + F_A(x) < 1 - \beta < 1 - \alpha_i, \text{ for all } x \in X \text{ and } \alpha_i \in [0, \beta)$$

$$\Rightarrow T_A(x) > \alpha_i, I_A(x) + F_A(x) < 1 - \alpha_i, \text{ for all } x \in X \text{ and } \alpha_i \in [0, \beta)$$

$$\Rightarrow x \in S(A, \alpha_i), \alpha_i \in [0, \beta)$$

Hence $S(A, \beta) \subseteq \bigcap_{i \in J} S(A, \alpha_i)$.

Theorem 1.16:

If A is a Bijective Single Valued Neutrosophic set in a fixed set X . Let $\beta \in [0, 1]$ and $\alpha_i \in (\beta, 1]$ for each $i \in J$ where Λ is an indexed set. Then $\bigcup_{i \in J} S(A, \alpha_i) \subseteq S(A, \beta)$.

Proof:

Let $x \in \bigcup_{i \in J} S(A, \alpha_i)$

Then $x \in S(A, \alpha_i)$ for each $i \in J$

$$\Rightarrow T_A(x) > \alpha_i, I_A(x) + F_A(x) < 1 - \alpha_i$$

$$\Rightarrow T_A(x) > \alpha_i > \beta, I_A(x) + F_A(x) < 1 - \alpha_i < 1 - \beta$$

$$\Rightarrow T_A(x) > \beta, I_A(x) + F_A(x) < 1 - \beta$$

$$\Rightarrow x \in S(A, \beta)$$

Hence $\bigcup_{i \in J} S(A, \alpha_i) \subseteq S(A, \beta)$

De Morgan's Laws in Bijective Single Valued Neutrosophic sets:**Theorem 2.1:**

If A and B are two Bijective Single Valued Neutrosophic sets in a non-empty X . Then the De Morgan's Laws hold:

- $S(A \cup B, \alpha)^c = S(A, \alpha)^c \cap S(B, \alpha)^c$
- $S(A \cap B, \alpha)^c = S(A, \alpha)^c \cup S(B, \alpha)^c$ for all $\alpha \in [0, 1]$.





Proof:

$$\begin{aligned}
 \text{i. } & S(A \cup B, \alpha)^c \\
 &= \{x \in X: T_{(A \cup B)^c}(x) > \alpha, I_{(A \cup B)^c}(x) + F_{(A \cup B)^c}(x) < 1 - \alpha\} \\
 &= \{x \in X: T_{A^c \cap B^c}(x) > \alpha, I_{A^c \cap B^c}(x) + F_{A^c \cap B^c}(x) < 1 - \alpha\} \\
 &= \{x \in X: \wedge \{T_{A^c}(x), T_{B^c}(x)\} > \alpha, \vee \{I_{A^c}(x), I_{B^c}(x)\} + \vee \{F_{A^c}(x), F_{B^c}(x)\} < 1 - \alpha\} \\
 &= \{x \in X: \wedge \{F_A(x), F_B(x)\} > \alpha, \vee \{1 - I_A(x), 1 - I_B(x)\} + \vee \{T_A(x), T_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: \{F_A(x) \wedge F_B(x)\} > \alpha, \{1 - I_A(x) + T_A(x)\} \vee \{1 - I_B(x) + T_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: F_A(x) > \alpha, 1 - I_A(x) + T_A(x) < 1 - \alpha\} \cap \\
 &\quad \{x \in X: F_B(x) > \alpha, 1 - I_B(x) + T_B(x) < 1 - \alpha\} \\
 &= S(A, \alpha)^c \cap S(B, \alpha)^c \\
 \text{Hence } & S(A \cup B, \alpha)^c = S(A, \alpha)^c \cap S(B, \alpha)^c
 \end{aligned}$$

$$\begin{aligned}
 \text{ii. } & S(A \cap B, \alpha)^c \\
 &= \{x \in X: T_{(A \cap B)^c}(x) > \alpha, I_{(A \cap B)^c}(x) + F_{(A \cap B)^c}(x) < 1 - \alpha\} \\
 &= \{x \in X: T_{A^c \cup B^c}(x) > \alpha, I_{A^c \cup B^c}(x) + F_{A^c \cup B^c}(x) < 1 - \alpha\} \\
 &= \{x \in X: \vee \{T_{A^c}(x), T_{B^c}(x)\} > \alpha, \wedge \{I_{A^c}(x), I_{B^c}(x)\} + \wedge \{F_{A^c}(x), F_{B^c}(x)\} < 1 - \alpha\} \\
 &= \{x \in X: \vee \{F_A(x), F_B(x)\} > \alpha, \wedge \{1 - I_A(x), 1 - I_B(x)\} + \wedge \{T_A(x), T_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: \{F_A(x) \vee F_B(x)\} > \alpha, \{1 - I_A(x) + T_A(x)\} \wedge \{1 - I_B(x) + T_B(x)\} < 1 - \alpha\} \\
 &= \{x \in X: F_A(x) > \alpha, 1 - I_A(x) + T_A(x) < 1 - \alpha\} \cup \\
 &\quad \{x \in X: F_B(x) > \alpha, 1 - I_B(x) + T_B(x) < 1 - \alpha\} \\
 &= S(A, \alpha)^c \cup S(B, \alpha)^c \\
 \text{Hence } & S(A \cap B, \alpha)^c = S(A, \alpha)^c \cup S(B, \alpha)^c.
 \end{aligned}$$

Remark 2.2:

If $\{V_i \mid i \in J\}$ be a family of Bijjective Single Valued Neutrosophic sets and $\alpha \in [0, 1]$. Then the De Morgan's Laws hold:

$$\begin{aligned}
 \text{i. } & S\left(\bigcup_{i \in J} V_i, \alpha\right)^c = \bigcap_{i \in J} S(V_i, \alpha)^c. \\
 \text{ii. } & S\left(\bigcap_{i \in J} V_i, \alpha\right)^c = \bigcup_{i \in J} S(V_i, \alpha)^c.
 \end{aligned}$$

Theorem 2.3:

If A and B are two Bijjective Single Valued Neutrosophic sets in a non-empty set X and $\alpha \in [0, 1]$. Then $A \subseteq B \Rightarrow S(B, \alpha)^c \subseteq S(A, \alpha)^c$.

Proof:

Given that $A \subseteq B$





Let $x \in S(B, \alpha)^c$

$$\Rightarrow F_B(x) > \alpha, 1 - I_B(x) + T_B(x) < 1 - \alpha$$

Since $A \subseteq B \Rightarrow T_A(x) \leq T_B(x), I_A(x) \geq I_B(x), F_A(x) \geq F_B(x)$

$$\Rightarrow F_A(x) > \alpha, 1 - I_A(x) + T_A(x) < 1 - \alpha$$

$$\Rightarrow x \in S(A, \alpha)^c$$

Hence $A \subseteq B \Rightarrow S(B, \alpha)^c \subseteq S(A, \alpha)^c$.

Theorem 2.4:

If A and B are two Bijective Single Valued Neutrosophic sets in a non-empty set X and $\alpha \in [0, 1]$. Then $S(A \setminus B, \alpha) = S(A \cap B^c, \alpha)$.

Proof:

$$\begin{aligned} S(A \setminus B, \alpha) &= \{x \in X: T_A(x) \wedge F_B(x) > \alpha, \{I_A(x) \vee 1 - I_B(x)\} + \{F_A(x) \vee T_B(x)\} < 1 - \alpha\} \\ &= \{x \in X: \wedge \{T_A(x), F_B(x)\} > \alpha, \vee \{I_A(x), 1 - I_B(x)\} + \{F_A(x), T_B(x)\} < 1 - \alpha\} \\ &= \{x \in X: T_A(x) > \alpha, I_A(x) + F_A(x) < 1 - \alpha\} \cap \\ &\quad \{F_B(x) > \alpha, 1 - I_B(x) + T_B(x) < 1 - \alpha\} \\ &= S(A \cap B^c, \alpha) \end{aligned}$$

Hence $S(A \setminus B, \alpha) = S(A \cap B^c, \alpha)$

Role of Strong α – Level Bijective Single Valued Neutrosophic Graphs In Agricultural Farming:

Agricultural farming is the science, art and business of cultivating soil, producing crops and raising livestock to provide food, fiber and raw materials. As a foundational human activity, it includes various systems from traditional subsistence farming to modern industrial agriculture, driving economic growth and global food security.

Agricultural land or farm land refers to areas used for producing food, fiber and livestock, including arable land (crops), permanent pastures and orchards. Irrigation is the artificial application of water to soil to assist in crop production, particularly in areas with irregular rainfall, dry seasons or to ensure consistent agricultural yields.

Mathematical Representation

To determine the agricultural land suitable for crop cultivation in the context of BSVNG.

Consider a BSVNG, vertices represented as Agricultural lands and edges represented as irrigation efficiency.

A vertex membership values are represented as

T- nature of water

I - uncertainty rainfall

F – lack of moisture

The edges membership values are represented as

T - Drip Irrigation

I – Sprinkle Irrigation

F – Surface Irrigation

Here the vertex set is $V = (A, B, C, D)$ represents agricultural lands $E = (e_1, e_2, e_3, e_4)$ represents an irrigation efficiency in Fig.1

Barley cultivation





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To find which agricultural land is suitable for 10 % of the barley cultivation

Let $\alpha = 0.1$

Then $1-\alpha = 0.9$

10 % of the barley cultivation is given in Fig.2

Agricultural lands A, B, C and D are suitable for 10% of the Barley cultivation.

(i.e.) the nature of water, uncertainty of rainfall and lack of moisture suitable for 10% barley cultivation in agricultural lands are A, B, C and D.

In 10% barley cultivation, irrigation efficiency is suitable for the lands BD and CD.

But there is no irrigation between the lands AC and AB.

Maize cultivation

To find which agricultural land is suitable for 30 % of the maize cultivation.

Let $\alpha = 0.3$

Then $1-\alpha = 0.7$

Agricultural lands B and D suitable for 30% of the Maize cultivation is represented in Fig.3

That is, nature of water, uncertainty of rainfall and lack of moisture suitable for 30% maize cultivation in agricultural lands are B and D.

In 30% maize cultivation, the irrigation efficiency is suitable for land BD.

But there is no irrigation efficiency between the lands AC, AB and CD.

Similarly, we can find the different level of crops cultivation in BSVNG.

CONCLUSION

Some results of Strong α – Level Bijective Single Valued Neutrosophic Graphs have been found using basic operations. De Morgan's Laws verified for Strong α – Level Bijective Single Valued Neutrosophic sets. Relation between α – Level and Strong α – Level Bijective Single Valued Neutrosophic sets has been found. In future, some more properties of α – level and strong α – level bijective single valued neutrosophic graphs can be explored.

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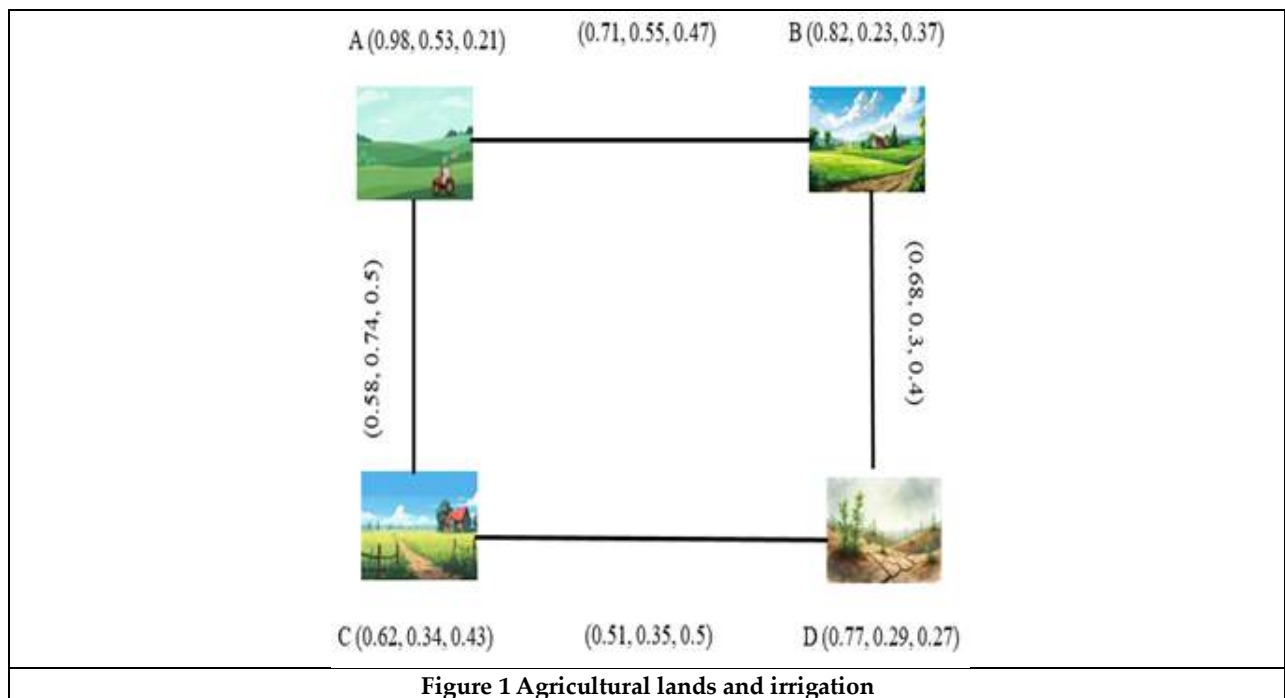
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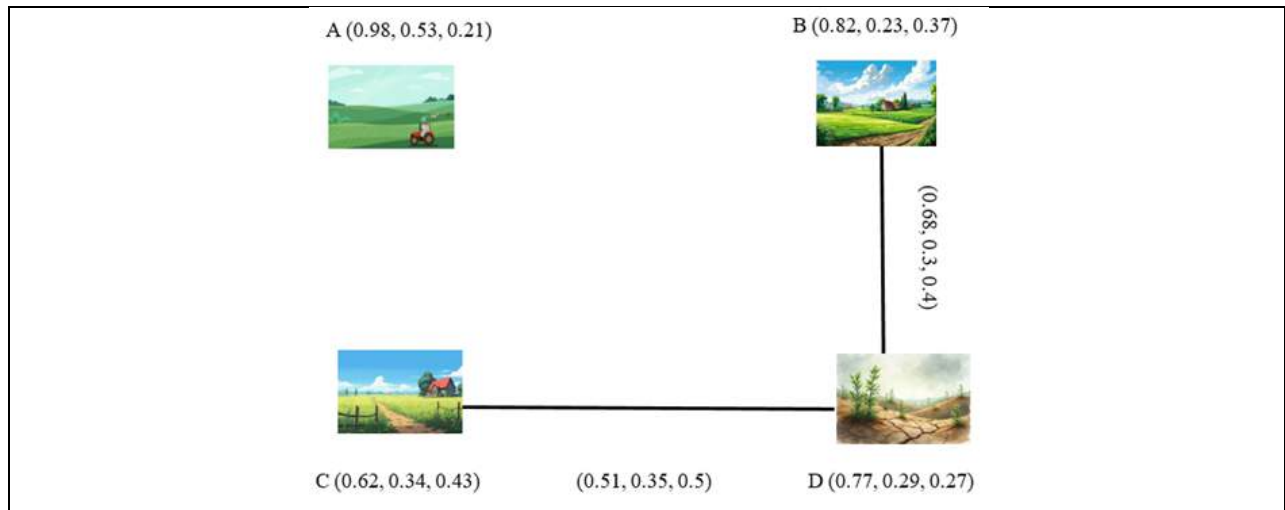


Figure 2: 10 % barley cultivation

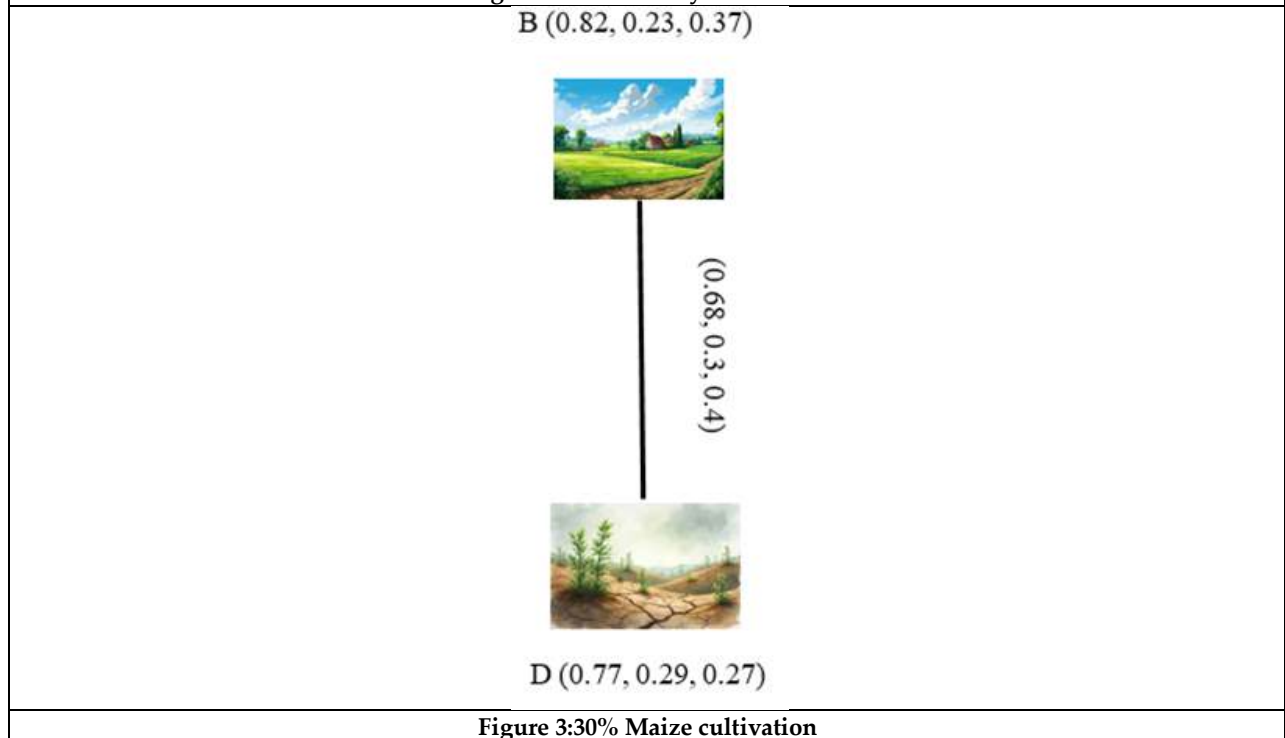


Figure 3:30% Maize cultivation

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RESEARCH ARTICLE

A Design of Two Stage Chain Sampling Plan ChSP-(0,2) using Fuzzy Parameter

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ABSTRACT

This study develops two stages ChSP-(0,2) using fuzzy parameters. FOC Curve is explained through illustrations. FOC Curve values are determined using fuzzy parameter where tables and figures are provided by fixing the sample size (n). The optimum value units required in the sample is obtained such that to satisfy both the condition of risks for the given conditions and also minimizes the sum of the risks.

Keywords: Operating Characteristic (OC) Curve , Acceptance Sampling , Fuzzy number, Trapezoidal Fuzzy Number

INTRODUCTION

Acceptance sampling is used to obtain higher quality at a reduced cost and enhance productivity. [15] It is used in industries to reduce product damage during inspection. Occasionally, results acquired in fractional values for proportion defective, acceptance number and sample size are impossible to be displayed as crisp numbers in a few industries. [19] To alleviate this discomfort in acceptance sampling , a fuzzy set is used. In designing medication, meteorology , assembling etc, where fuzzy is applied for numerous spaces of daily life [24]. Montgomery [15] introduced statistical quality control. Schilling [19] acceptance sampling quality control. Dodge [2] provided OC curve and properties of chain sampling plan. Clark [1] studied oc curves for ChSP-1. Frishman and Fred [4] prolonged chain sampling plan. Raju [17] studied contributions of chain sampling plans. Stephens [20] evaluated cumulative results of sampling plans. Stephens and Dodge presented a generalised family of two-stage chain sampling plans that





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are expansions of ChSP-1 plans [21, 22, 23]. Narasimha murthy [16] studied special purpose plans. Raju and Narasimha murthy [18] proposed two stage ChSP-(0,2) and ChSP-(1,2) as part- I. Jothikumar and Raju [6] developed constructions for two stage ChSP-(0,2) and ChSP-(1,2) as part- II.

Kahraman and Kaya [7] proposed fuzzy acceptance sampling plans for single and double sampling plan. The outcome shows that fuzzy boundary gives greater adaptability and convenience. Jamkhaneh and Sadeghpour Gildeh [5] discussed about ChSP-1 using fuzzy probability theory. Kahraman, Kaya and Turanoglu [8] derived acceptance probability using fuzzy parameters and its OC curves. Kavi priya and Sudamani Ramaswamy [9,10,11] designed MChSP-1, TSMCChSP-1, TSCCChSP-1 plans using fuzzy parameters. Kavi priya and Sudamani Ramaswamy [12,13,14] used fuzzy parameters for various plans like DSP(0,1), RGS and ChSP-(0,1). Basic definitions of fuzzy sets are provided in this work, followed by operating procedures for ChSP-(0,2), FOC curves for two stage ChSP-(0,2) and tables with examples. Binomial distribution is used to obtain the parameters. FPA values are calculated for the given $\bar{AQL}$ and $\bar{LQL}$ which are presented in tables, which can be used for the selection of the plan.

Definitions

Fuzzy Number (Zadeh [24] and Dubis & Prade [3]): "Fuzzy set that are characterized on the arrangement of real numbers having the structure $\tilde{E}: R$ tends to $[0,1]$ are known as fuzzy number. A fuzzy number $\tilde{E}$ will be a fuzzy set in the real line that fulfills the state of both normal and convexity".

Trapezoidal fuzzy number (Zadeh [24] and Dubis & Prade [3]): "If trapezoidal fuzzy numbers (TrFNs) are $\tilde{E} = (e_1, e_2, e_3, e_4)$ and its membership function as"

$$\text{TrFN} = \begin{cases} 0 & , \text{ otherwise} \\ \frac{y-e_1}{e_2-e_1} & , e_1 \leq y \leq e_2 \\ 1 & , e_2 \leq y \leq e_3 \\ \frac{e_4-y}{e_4-e_3} & , e_3 \leq y \leq e_4 \\ 0 & , \text{ otherwise} \end{cases} \quad (1)$$

"The interval of confidence of trapezoidal fuzzy number defined by γ cuts can be written as follows"

$$\tilde{E}[\gamma] = [e_1 + (e_2 - e_1)\gamma, e_4 - (e_4 - e_3)\gamma] \quad (2)$$

Operating Procedure for ChSP- (0,2)

"According to Narasimha Murthy [16], Raju and Narasimha Murthy [18] and Jothikumar and Raju [6]

Step 1: Select a sample of size n from the first lot and each subsequent lot at the outset.

Step 2: Count the number of defective units (d) in each sample and add the total number of defective units (D) in all samples from the first to the last.

Step 3: During the cumulation, accept the lot linked with each current sample as long as $D_i < c_1$; $1 < i \leq k_1$

Step 4: Once all k_1 consecutive samples have been accepted, add the defective units, D , in the samples plus any extra samples up to and including k_2 sample.

Step 5: During the cumulation, accept the lot linked with each new sample as long as c_2 , $k_1 < i \leq k_2$

Step 6: Start cumulating defective units as a moving total over k_2 samples by adding the current sample result while dropping the sample result of the k_2 th preceding sample from the sum once the second stage of the restart period has been successfully completed. Continue this method as long as $D_i < c_2$ allows, accepting in each case.

Step 7: If $D_i > c$, reject the lot, then go back to Step 1 and restart the process again."

Fuzzy Probability of Acceptance (FPA) and Fuzzy Proportion of Defective (FPrD)

Consider $\check{p}_s = (s, e_2 + s, e_3 + s, e_4 + s)$ Where $e_i = b_i - b_1$, $i = 2,3,4$ and $s \in [0,1 - e_4]$ γ cuts of trapezoidal fuzzy number to find fuzzy operating characteristic curve where $\gamma = 0$ and $\gamma = 1$. FPA is calculated using binomial distribution. γ cut of trapezoidal fuzzy number is used to solve ChSP-(0,2) such that $\tilde{E}[\gamma] = [e_1 + (e_2 - e_1)\gamma, e_4 -$





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$(e_4 - e_3)\gamma$ and taking $\gamma=0,1$ then we get FPrD value as $\check{p}_s[\gamma] = [\check{p}_s^{lb}, \check{p}_s^{ub}]$ and FPA value using $\check{P}_{as}[\gamma] = [\check{P}_{as}^{lb}, \check{P}_{as}^{ub}]$.

The probability of acceptance for ChSP-(0, 2) is given by

$$P_a = \left\{ p_0 + (p_1 + p_2)p_0^{k_1} \left[\frac{(1-p_0^{k_2-k_1})}{(1-p_0)} \right] + p_1^2 p_0^{k_1} \left[\frac{(1-p_0^{k_2-k_1})}{(1-p_0)^2} - \frac{(k_2-k_1)p_0^{k_2-k_1-1}}{(1-p_0)} \right] \right\} \div \left\{ 1 + (p_1 + p_2)p_0^{k_1} \left[\frac{(1-p_0^{k_2-k_1-1})}{(1-p_0)} \right] + p_1^2 p_0^{k_1} \left[\frac{(1-p_0^{k_2-k_1-1})}{(1-p_0)^2} - \frac{(k_2-k_1-1)p_0^{k_2-k_1-2}}{(1-p_0)} \right] \right\}, k_2 > k_1 \quad \dots\dots\dots (1)$$

FPA for ChSP-(0, 2) is given by

$$\begin{aligned} \check{P}_{as} &= \left\{ (1-\check{p}_s)^n + \left(n\check{p}_s(1-\check{p}_s)^{n-1} + \frac{(n\check{p}_s)^2}{2} (1-\check{p}_s)^{n-2} \right) (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1)})}{1-(1-\check{p}_s)^n} \right] \right. \\ &+ \left. (n\check{p}_s(1-\check{p}_s)^{n-1})^2 (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1)})}{(1-(1-\check{p}_s)^n)^2} - \frac{(k_2-k_1)(1-\check{p}_s)^{n(k_2-k_1-1)}}{(1-(1-\check{p}_s)^n)} \right] \right\} \\ &\div \left\{ 1 + \left(n\check{p}_s(1-\check{p}_s)^{n-1} + \frac{(n\check{p}_s)^2}{2} (1-\check{p}_s)^{n-2} \right) (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1-1)})}{1-(1-\check{p}_s)^n} \right] \right. \\ &+ \left. (n\check{p}_s(1-\check{p}_s)^{n-1})^2 (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1-1)})}{(1-(1-\check{p}_s)^n)^2} - \frac{(k_2-k_1-1)(1-\check{p}_s)^{n(k_2-k_1-2)}}{(1-(1-\check{p}_s)^n)} \right] \right\} \\ \check{P}_{as}^{lb}[\gamma] &= \min \left[\left\{ (1-\check{p}_s)^n + \left(n\check{p}_s(1-\check{p}_s)^{n-1} + \frac{(n\check{p}_s)^2}{2} (1-\check{p}_s)^{n-2} \right) (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1)})}{1-(1-\check{p}_s)^n} \right] \right. \right. \right. \\ &+ \left. \left. (n\check{p}_s(1-\check{p}_s)^{n-1})^2 (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1)})}{(1-(1-\check{p}_s)^n)^2} - \frac{(k_2-k_1)(1-\check{p}_s)^{n(k_2-k_1-1)}}{(1-(1-\check{p}_s)^n)} \right] \right\} \right. \\ &\div \left. \left\{ 1 + \left(n\check{p}_s(1-\check{p}_s)^{n-1} + \frac{(n\check{p}_s)^2}{2} (1-\check{p}_s)^{n-2} \right) (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1-1)})}{1-(1-\check{p}_s)^n} \right] \right. \right. \\ &+ \left. \left. (n\check{p}_s(1-\check{p}_s)^{n-1})^2 (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1-1)})}{(1-(1-\check{p}_s)^n)^2} - \frac{(k_2-k_1-1)(1-\check{p}_s)^{n(k_2-k_1-2)}}{(1-(1-\check{p}_s)^n)} \right] \right\} \right] \\ \check{P}_{as}^{ub}[\gamma] &= \max \left[\left\{ (1-\check{p}_s)^n + \left(n\check{p}_s(1-\check{p}_s)^{n-1} + \frac{(n\check{p}_s)^2}{2} (1-\check{p}_s)^{n-2} \right) (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1)})}{1-(1-\check{p}_s)^n} \right] \right. \right. \right. \\ &+ \left. \left. (n\check{p}_s(1-\check{p}_s)^{n-1})^2 (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1)})}{(1-(1-\check{p}_s)^n)^2} - \frac{(k_2-k_1)(1-\check{p}_s)^{n(k_2-k_1-1)}}{(1-(1-\check{p}_s)^n)} \right] \right\} \right. \\ &\div \left. \left\{ 1 + \left(n\check{p}_s(1-\check{p}_s)^{n-1} + \frac{(n\check{p}_s)^2}{2} (1-\check{p}_s)^{n-2} \right) (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1-1)})}{1-(1-\check{p}_s)^n} \right] \right. \right. \\ &+ \left. \left. (n\check{p}_s(1-\check{p}_s)^{n-1})^2 (1-\check{p}_s)^{n k_1} \left[\frac{(1-(1-\check{p}_s)^{n(k_2-k_1-1)})}{(1-(1-\check{p}_s)^n)^2} - \frac{(k_2-k_1-1)(1-\check{p}_s)^{n(k_2-k_1-2)}}{(1-(1-\check{p}_s)^n)} \right] \right\} \right] \\ \check{P}_{as}[\gamma] &= [\check{P}_{as}^{lb}, \check{P}_{as}^{ub}] \end{aligned}$$

Using these above formulae the values are calculated and presented in Table 1.

Table 1 shows that when n value is fixed as 10, $k_1=1$ and $k_2=3$, the fuzzy proportion defective value is computed for both gamma equal zero and one, respectively using γ cut of trapezoidal fuzzy number.

Fuzzy Operating Characteristic (FOC) Curve

OC curve has contains an upper and lower bounds, it is referred to as the FOC Curve. When γ values increases from 0 to 1, FOC Curve value becomes closer.





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Real Life Application

When the optical manufacturing company produces large number of optical. Before taking optical to showroom for sales, the quality of optical is checked by person working in optical showroom. She used two stage of ChSP-(0,2) to inspect the optical. (whether the frame is in correct size or lens are fixed correctly etc).

Assume that $\check{p}_s = (0.002, 0.003, 0.004, 0.005)$, $n=10$, $k_1=1$ and $k_2=3$. Then γ cut of trapezoidal fuzzy number is used to get fuzzy proportion defective value for $\gamma=0$ and $\gamma=1$ we get FPA as $\check{P}_{as}(0) = [0.9298 \quad 0.8136]$ and $\check{P}_{as}(1) = [0.8523 \quad 0.8319]$.

Example 1

Assuming $\check{p}_s = (0.001, 0.002, 0.003, 0.004)$ and a sample size n is 10, γ cut of trapezoidal fuzzy number is used to compute the interval of FPrD $\check{p}_s[0] = [0.001 \quad 0.005]$, $\check{p}_s[1] = [0.003 \quad 0.004]$ and FPA values as given in Table 2. When comparing the value of $\check{P}_{as}[\gamma = 0]$ to the value of $\check{P}_{as}[\gamma = 1]$, the table 1 shows that the value of $\gamma = 0$ gives a superior outcome. Table 2 shows how the fuzzy parameter is determined using ChSP-(0, 2) for various values of k_1 and k_2 where k_1 is lower than k_2 values.

Example 2

If $\check{p}_s = (0.001, 0.002, 0.003, 0.004)$ and the sample size is changed, the fuzzy proportion defective $\check{p}_s[0] = [0.001 \quad 0.005]$, $\check{p}_s[1] = [0.003 \quad 0.004]$ and FPA values are calculated using γ cut of trapezoidal fuzzy number as indicated in the table below. Table 3 shows that if $k_1=1$ and $k_2=3$ are fixed in ChSP-(0, 2) then sample size values are adjusted using the fuzzy parameter

Determination of Sample size

The risk of producer is denoted by $\widetilde{\alpha}_f$ and the risk of consumer is denoted by $\widetilde{\beta}_f$. Accepting quality level ($\widetilde{AQL}$) is denoted as $\check{p}_{1f}$ and Limiting quality level ($\widetilde{LQL}$) is denoted as $\check{p}_{2f}$. Here two stage of ChSP-(0,2) plan is designed using the fuzzy parameter. The sample size n is calculated in order to satisfy both the inequalities for $\check{P}_{1fa}$ and $\check{P}_{2fa}$ simultaneously for the given values of $\widetilde{\alpha}_f$ and $\widetilde{\beta}_f$. $\check{P}_{1fa} \geq 1 - \widetilde{\alpha}_f$ and $\check{P}_{2fa} \leq \widetilde{\beta}_f$ where $\widetilde{\alpha}_f = 0.05$ and $\widetilde{\beta}_f = 0.10$ is fixed so that the interval of FPA is satisfied the conditions $\check{P}_{1fa} \geq 0.95$ and $\check{P}_{2fa} \leq 0.10$ for different sample sizes.

$$\begin{aligned} \overline{P}_{1fa} = & \left\{ (1 - \widetilde{p}_{1f})^n + \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} + \frac{(n\widetilde{p}_{1f})^2}{2} (1 - \widetilde{p}_{1f})^{n-2} \right) (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1)})}{1 - (1 - \widetilde{p}_{1f})^n} \right] \right. \\ & + \left. \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} \right)^2 (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1)})}{(1 - (1 - \widetilde{p}_{1f})^n)^2} - \frac{(k_2 - k_1)(1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 1)}}{(1 - (1 - \widetilde{p}_{1f})^n)} \right] \right\} \\ & \div \left\{ 1 + \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} + \frac{(n\widetilde{p}_{1f})^2}{2} (1 - \widetilde{p}_{1f})^{n-2} \right) (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 1)})}{1 - (1 - \widetilde{p}_{1f})^n} \right] \right. \\ & + \left. \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} \right)^2 (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 1)})}{(1 - (1 - \widetilde{p}_{1f})^n)^2} - \frac{(k_2 - k_1 - 1)(1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 2)}}{(1 - (1 - \widetilde{p}_{1f})^n)} \right] \right\} \geq 0.95 \end{aligned}$$

$$\begin{aligned} \overline{P}_{1fa} = & \left\{ (1 - \widetilde{p}_{1f})^n + \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} + \frac{(n\widetilde{p}_{1f})^2}{2} (1 - \widetilde{p}_{1f})^{n-2} \right) (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1)})}{1 - (1 - \widetilde{p}_{1f})^n} \right] \right. \\ & + \left. \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} \right)^2 (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1)})}{(1 - (1 - \widetilde{p}_{1f})^n)^2} - \frac{(k_2 - k_1)(1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 1)}}{(1 - (1 - \widetilde{p}_{1f})^n)} \right] \right\} \\ & \div \left\{ 1 + \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} + \frac{(n\widetilde{p}_{1f})^2}{2} (1 - \widetilde{p}_{1f})^{n-2} \right) (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 1)})}{1 - (1 - \widetilde{p}_{1f})^n} \right] \right. \\ & + \left. \left(n\widetilde{p}_{1f}(1 - \widetilde{p}_{1f})^{n-1} \right)^2 (1 - \widetilde{p}_{1f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 1)})}{(1 - (1 - \widetilde{p}_{1f})^n)^2} - \frac{(k_2 - k_1 - 1)(1 - \widetilde{p}_{1f})^{n(k_2 - k_1 - 2)}}{(1 - (1 - \widetilde{p}_{1f})^n)} \right] \right\} \geq 0.95 \end{aligned}$$

$$\overline{P}_{2fa} = \left\{ (1 - \widetilde{p}_{2f})^n + \left(n\widetilde{p}_{2f}(1 - \widetilde{p}_{2f})^{n-1} + \frac{(n\widetilde{p}_{2f})^2}{2} (1 - \widetilde{p}_{2f})^{n-2} \right) (1 - \widetilde{p}_{2f})^{n k_1} \left[\frac{(1 - (1 - \widetilde{p}_{2f})^{n(k_2 - k_1)})}{1 - (1 - \widetilde{p}_{2f})^n} \right] \right\}$$





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$$\begin{aligned}
 & + \left(n\widetilde{p}_{2f}(1-\widetilde{p}_{2f})^{n-1} \right)^2 (1-\widetilde{p}_{2f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{2f})^{n(k_2-k_1)})}{(1-(1-\widetilde{p}_{2f})^n)^2} - \frac{(k_2-k_1)(1-\widetilde{p}_{2f})^{n(k_2-k_1-1)}}{(1-(1-\widetilde{p}_{2f})^n)} \right] \\
 & \div \left\{ 1 + \left(n\widetilde{p}_{2f}(1-\widetilde{p}_{2f})^{n-1} + \frac{(n\widetilde{p}_{2f})^2}{2} (1-\widetilde{p}_{2f})^{n-2} \right) (1-\widetilde{p}_{2f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{2f})^{n(k_2-k_1-1)})}{1-(1-\widetilde{p}_{2f})^n} \right] \right. \\
 & \left. + \left(n\widetilde{p}_{2f}(1-\widetilde{p}_{2f})^{n-1} \right)^2 (1-\widetilde{p}_{2f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{2f})^{n(k_2-k_1-1)})}{(1-(1-\widetilde{p}_{2f})^n)^2} - \frac{(k_2-k_1-1)(1-\widetilde{p}_{2f})^{n(k_2-k_1-2)}}{(1-(1-\widetilde{p}_{2f})^n)} \right] \right\} \leq 0.10
 \end{aligned}$$

Minimizing the sum of risks

The sample size is calculated so as to minimize the sum of the risks and it is presented in Table 5 & 6. Where $\widetilde{AQL}$ is denoted as $\widetilde{p}_{1f}$ and $\widetilde{LQL}$ is denoted as $\widetilde{p}_{2f}$ and the corresponding the probability of acceptance values are $\widetilde{P}_{1fa}$ and $\widetilde{P}_{2fa}$. The mathematical expression to minimize the sum of risk is

$$\begin{aligned}
 \widetilde{\alpha}_f + \widetilde{\beta}_f &= 1 - \widetilde{P}_{1fa} + \widetilde{P}_{2fa} \\
 &= 1 - \left[\left\{ (1-\widetilde{p}_{1f})^n + \left(n\widetilde{p}_{1f}(1-\widetilde{p}_{1f})^{n-1} + \frac{(n\widetilde{p}_{1f})^2}{2} (1-\widetilde{p}_{1f})^{n-2} \right) (1-\widetilde{p}_{1f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{1f})^{n(k_2-k_1)})}{1-(1-\widetilde{p}_{1f})^n} \right] \right. \right. \\
 &+ \left. \left(n\widetilde{p}_{1f}(1-\widetilde{p}_{1f})^{n-1} \right)^2 (1-\widetilde{p}_{1f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{1f})^{n(k_2-k_1)})}{(1-(1-\widetilde{p}_{1f})^n)^2} - \frac{(k_2-k_1)(1-\widetilde{p}_{1f})^{n(k_2-k_1-1)}}{(1-(1-\widetilde{p}_{1f})^n)} \right] \right\} \\
 &\div \left\{ 1 + \left(n\widetilde{p}_{1f}(1-\widetilde{p}_{1f})^{n-1} + \frac{(n\widetilde{p}_{1f})^2}{2} (1-\widetilde{p}_{1f})^{n-2} \right) (1-\widetilde{p}_{1f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{1f})^{n(k_2-k_1-1)})}{1-(1-\widetilde{p}_{1f})^n} \right] \right. \\
 &+ \left. \left(n\widetilde{p}_{1f}(1-\widetilde{p}_{1f})^{n-1} \right)^2 (1-\widetilde{p}_{1f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{1f})^{n(k_2-k_1-1)})}{(1-(1-\widetilde{p}_{1f})^n)^2} - \frac{(k_2-k_1-1)(1-\widetilde{p}_{1f})^{n(k_2-k_1-2)}}{(1-(1-\widetilde{p}_{1f})^n)} \right] \right\} \right] + \\
 &\left\{ (1-\widetilde{p}_{2f})^n + \left(n\widetilde{p}_{2f}(1-\widetilde{p}_{2f})^{n-1} + \frac{(n\widetilde{p}_{2f})^2}{2} (1-\widetilde{p}_{2f})^{n-2} \right) (1-\widetilde{p}_{2f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{2f})^{n(k_2-k_1)})}{1-(1-\widetilde{p}_{2f})^n} \right] \right. \\
 &+ \left. \left(n\widetilde{p}_{2f}(1-\widetilde{p}_{2f})^{n-1} \right)^2 (1-\widetilde{p}_{2f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{2f})^{n(k_2-k_1)})}{(1-(1-\widetilde{p}_{2f})^n)^2} - \frac{(k_2-k_1)(1-\widetilde{p}_{2f})^{n(k_2-k_1-1)}}{(1-(1-\widetilde{p}_{2f})^n)} \right] \right\} \\
 &\left\{ 1 + \left(n\widetilde{p}_{2f}(1-\widetilde{p}_{2f})^{n-1} + \frac{(n\widetilde{p}_{2f})^2}{2} (1-\widetilde{p}_{2f})^{n-2} \right) (1-\widetilde{p}_{2f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{2f})^{n(k_2-k_1-1)})}{1-(1-\widetilde{p}_{2f})^n} \right] \right. \\
 &+ \left. \left(n\widetilde{p}_{2f}(1-\widetilde{p}_{2f})^{n-1} \right)^2 (1-\widetilde{p}_{2f})^{n k_1} \left[\frac{(1-(1-\widetilde{p}_{2f})^{n(k_2-k_1-1)})}{(1-(1-\widetilde{p}_{2f})^n)^2} - \frac{(k_2-k_1-1)(1-\widetilde{p}_{2f})^{n(k_2-k_1-2)}}{(1-(1-\widetilde{p}_{2f})^n)} \right] \right\}
 \end{aligned}$$

The sum of risks is obtained as interval of fuzzy.

CONCLUSION

In this study a procedure of designing two stage of ChSP-(0, 2) using trapezoidal fuzzy number is presented. Binomial distribution is used to calculate FPA value. FOC Curve values are calculated for the fixed sample size. One can note that fuzzy probability of acceptance is more for $\gamma=0$ than $\gamma=1$ and FOC Curve is closer when $\gamma=1$. For $\gamma=0$, the sample size value is calculated such that it satisfied both the condition of the risks. The optimum value units required in the sample is obtained such that to satisfy both the condition of risks for the given conditions and also minimizes the sum of risks.





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Table 1: Fuzzy probability of acceptance $n=10$, $k_1=1$ and $k_2=3$

$\check{p}_s = (s, e_2 + s, e_3 + s, e_4 + s)$	$\check{p}_s[\gamma = 0]$	$\check{P}_{as}[\gamma = 0]$	$\check{p}_s[\gamma = 1]$	$\check{P}_{as}[\gamma = 1]$
(0.000,0.001,0.002, 0.003)	[0 .000 0.003]	[NaN 0.9008]	[0.001 0.002]	[0.9626 0.9298]
(0.001,0.002,0.003, 0.004)	[0.001 0.005]	[0.9626 0.8523]	[0.003 0.004]	[0.9008 0.8752]
(0.002,0.003,0.004, 0.005)	[0.002 0.007]	[0.9298 0.8136]	[0.005 0.006]	[0.8523 0.8319]
(0.003,0.004,0.005, 0.006)	[0.003 0.009]	[0.9008 0.7822]	[0.007 0.008]	[0.8136 0.7971]
(0.004,0.005,0.006, 0.007)	[0.004 0.011]	[0.8752 0.7564]	[0.009 0.010]	[0.7822 0.7687]
(0.005,0.006,0.007, 0.008)	[0.005 0.013]	[0.8523 0.7349]	[0.011 0.012]	[0.7564 0.7452]
(0.006,0.007,0.008, 0.009)	[0.006 0.015]	[0.8319 0.7167]	[0.013 0.014]	[0.7349 0.7254]
(0.007, 0.008, 0.009, 0.01)	[0.007 0.017]	[0.8136 0.7012]	[0.015 0.016]	[0.7167 0.7087]
(0.008, 0.009, 0.01, 0.011)	[0.008 0.019]	[0.7971 0.6877]	[0.017 0.018]	[0.7012 0.6942]
(0.009,0.010,0.011, 0.012)	[0.009 0.021]	[0.7822 0.6758]	[0.019 0.020]	[0.6877 0.6816]
(0.010,0.011,0.012, 0.013)	[0.010 0.023]	[0.7687 0.6652]	[0.021 0.022]	[0.6758 0.6704]
(0.011,0.012,0.013, 0.014)	[0.011 0.025]	[0.7564 0.6556]	[0.023 0.024]	[0.6652 0.6603]
(0.012,0.013,0.014, 0.015)	[0.012 0.027]	[0.7452 0.6467]	[0.025 0.027]	[0.6556 0.6511]
(0.013,0.014,0.015, 0.016)	[0.013 0.029]	[0.7349 0.6384]	[0.027 0.028]	[0.6467 0.6425]
(0.014,0.015,0.016, 0.017)	[0.014 0.031]	[0.7254 0.6305]	[0.029 0.030]	[0.6384 0.6344]
(0.015,0.016,0.017, 0.018)	[0.015 0.033]	[0.7167 0.6229]	[0.031 0.032]	[0.6305 0.6267]
(0.016,0.017,0.018, 0.019)	[0.016 0.035]	[0.7087 0.6155]	[0.033 0.034]	[0.6229 0.6192]
(0.017,0.018, 0.019, 0.02)	[0.017 0.037]	[0.7012 0.6082]	[0.035 0.036]	[0.6155 0.6119]
(0.018, 0.019, 0.02, 0.021)	[0.018 0.039]	[0.6942 0.6010]	[0.037 0.038]	[0.6082 0.6046]
(0.019, 0.02, 0.021, 0.022)	[0.019 0.041]	[0.6877 0.5938]	[0.039 0.040]	[0.6010 0.5974]

Table 2: Fuzzy probability of acceptance when k_1 and k_2 values varies

k_1	k_2	$\check{P}_{as}[\gamma = 0]$	$\check{P}_{as}[\gamma = 1]$
1	3	[0.9626 0.8523]	[0.9008 0.8752]
1	4	[0.9540 0.8277]	[0.8814 0.8526]
1	5	[0.9456 0.8060]	[0.8635 0.8323]
2	4	[0.9543 0.8318]	[0.8835 0.8557]
2	5	[0.9460 0.8105]	[0.8659 0.8358]
2	6	[0.9380 0.7916]	[0.8496 0.8177]
3	5	[0.9464 0.8147]	[0.8682 0.8390]
3	7	[0.9306 0.7794]	[0.8372 0.8051]
4	6	[0.9389 0.8002]	[0.8545 0.8246]
4	8	[0.9236 0.7690]	[0.8261 0.7970]
4	9	[0.9163 0.7559]	[0.8134 0.7808]
5	7	[0.9316 0.7878]	[0.8422 0.8119]
5	8	[0.9242 0.7731]	[0.8287 0.7975]
5	10	[0.9099 0.7482]	[0.8044 0.7723]
6	8	[0.9247 0.7771]	[0.8312 0.8008]





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6	9	[0.9175 0.7639]	[0.8187 0.7877]
6	10	[0.9105 0.7521]	[0.8070 0.7757]
7	9	[0.9181 0.7677]	[0.8212 0.7909]
7	10	[0.9111 0.7559]	[0.8096 0.7789]
8	10	[0.9118 0.7595]	[0.8121 0.7821]
9	11	[0.9057 0.7522]	[0.8038 0.7742]
10	12	[0.8998 0.7457]	[0.7962 0.7670]

Table 3 Fuzzy probability of acceptance when k_1 and k_2 value is fixed

n	$\check{P}_{as}[\gamma = 0]$	$\check{P}_{as}[\gamma = 1]$
50	[0.8530 0.6602]	[0.7196 0.6854]
45	[0.8640 0.6719]	[0.7326 0.6976]
40	[0.8756 0.6852]	[0.7473 0.7116]
35	[0.8880 0.7007]	[0.7641 0.7278]
30	[0.9011 0.7191]	[0.7836 0.7471]
25	[0.9150 0.7417]	[0.8061 0.7701]
20	[0.9299 0.7698]	[0.8325 0.7980]
15	[0.9457 0.8057]	[0.8637 0.8323]
10	[0.9626 0.8523]	[0.9008 0.8752]
5	[0.9807 0.9146]	[0.9455 0.9296]

Table 4 Optimum value of the parameter n, when $\check{P}_{1fa} \geq 0.95$ and $\check{P}_{2fa} \leq 0.10$

$(A\bar{Q}L)$	$(L\bar{Q}L)$	n
(0.001,0.0011,0.0012,0.0013)	(0.320, 0.321, 0.322, 0.323)	10
	(0.340, 0.341, 0.342, 0.343)	10
	(0.340, 0.341, 0.342, 0.343)	8
	(0.340, 0.341, 0.342, 0.343)	5
	(0.280, 0.281, 0.282, 0.283)	10
	(0.290, 0.291, 0.292, 0.293)	10
	(0.290, 0.291, 0.292, 0.293)	9
	(0.300, 0.301, 0.302, 0.303)	8
	(0.310, 0.311, 0.312, 0.313)	7
	(0.320, 0.321, 0.322, 0.323)	6
	(0.330,0.331, 0.322, 0.323)	6
(0.002,0.0021,0.0022,0.0023)	(0.350, 0.351, 0.352, 0.353)	5
	(0.360, 0.361, 0.362, 0.363)	5
	(0.370, 0.371, 0.372, 0.373)	5
	(0.380, 0.381, 0.382, 0.383)	5
	(0.400, 0.401, 0.402, 0.403)	5
	(0.380, 0.381, 0.382, 0.383)	4
	(0.400, 0.401, 0.402, 0.403)	4
	(0.430, 0.431, 0.432, 0.433)	4
(0.003,0.0031,0.0032,0.0033)	(0.370, 0.371, 0.372, 0.373)	4
	(0.380, 0.381, 0.382, 0.383)	4
	(0.390, 0.391, 0.392, 0.393)	4
	(0.400, 0.401, 0.402, 0.403)	4





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	(0.410, 0.411, 0.412, 0.413)	4
	(0.420, 0.421, 0.422, 0.423)	4
	(0.430, 0.431, 0.432, 0.433)	4

Table 5 Optimum value of the parameter n which minimizes sum of risks for $k_1=1$ and $k_2=3$ When $\tilde{\alpha}_f \cong 0.05$ and $\tilde{\beta}_f \cong 0.10$

n	$\tilde{p}_{1f} [Y = 0]$	$\tilde{P}_{1fa}[Y = 0]$	$\tilde{p}_{2f} [Y = 0]$	$\tilde{P}_{2fa}[Y = 0]$	$\tilde{\alpha}_f + \tilde{\beta}_f$
10	[0.001 0.0013]	[0.9626 0.9523]	[0.320 0.323]	[0.0256 0.0246]	[0.0630 0.0723]
10	[0.001 0.0013]	[0.9626 0.9523]	[0.340 0.343]	[0.0195 0.0187]	[0.0569 0.0664]
8	[0.001 0.0013]	[0.9697 0.9612]	[0.340 0.343]	[0.0406 0.0392]	[0.0709 0.0780]
5	[0.001 0.0013]	[0.9807 0.9751]	[0.340 0.343]	[0.1046 0.1016]	[0.1239 0.1265]
10	[0.001 0.0013]	[0.9626 0.9523]	[0.280 0.283]	[0.0432 0.0416]	[0.0806 0.0893]
10	[0.001 0.0013]	[0.9626 0.9523]	[0.290 0.293]	[0.0380 0.0366]	[0.0754 0.0843]
9	[0.001 0.0013]	[0.9661 0.9567]	[0.290 0.293]	[0.0516 0.0499]	[0.0855 0.0932]
8	[0.001 0.0013]	[0.9697 0.9612]	[0.300 0.303]	[0.0625 0.0605]	[0.0928 0.0993]
7	[0.001 0.0013]	[0.9733 0.9657]	[0.310 0.313]	[0.0763 0.0741]	[0.1030 0.1084]
6	[0.001 0.0013]	[0.9769 0.9704]	[0.320 0.323]	[0.0935 0.0910]	[0.1136 0.1206]
6	[0.001 0.0013]	[0.9769 0.9704]	[0.330 0.323]	[0.0853 0.0830]	[0.1084 0.1126]
5	[0.002 0.0023]	[0.9625 0.9573]	[0.350 0.353]	[0.0941 0.0921]	[0.1316 0.1348]
5	[0.002 0.0023]	[0.9625 0.9573]	[0.360 0.363]	[0.0857 0.0831]	[0.1232 0.1258]
5	[0.002 0.0023]	[0.9625 0.9573]	[0.370 0.373]	[0.0771 0.0746]	[0.1146 0.1173]
5	[0.002 0.0023]	[0.9625 0.9573]	[0.380 0.383]	[0.0689 0.0665]	[0.1064 0.1092]
5	[0.002 0.0023]	[0.9625 0.9573]	[0.400 0.403]	[0.0534 0.0511]	[0.0909 0.0938]
4	[0.002 0.0023]	[0.9696 0.9653]	[0.380 0.383]	[0.0886 0.0846]	[0.1190 0.1193]
4	[0.002 0.0023]	[0.9696 0.9653]	[0.400 0.403]	[0.0619 0.0579]	[0.0923 0.0926]
4	[0.002 0.0023]	[0.9696 0.9653]	[0.430 0.433]	[0.0184 0.0133]	[0.0488 0.0480]
4	[0.003 0.0033]	[0.9556 0.9515]	[0.370 0.373]	[0.1020 0.0979]	[0.1464 0.1464]
4	[0.003 0.0033]	[0.9556 0.9515]	[0.380 0.383]	[0.0886 0.0846]	[0.1330 0.1331]
4	[0.003 0.0033]	[0.9556 0.9515]	[0.390 0.393]	[0.0753 0.0713]	[0.1197 0.1198]
4	[0.003 0.0033]	[0.9556 0.9515]	[0.400 0.403]	[0.0619 0.0579]	[0.1063 0.1064]
4	[0.003 0.0033]	[0.9556 0.9515]	[0.410 0.413]	[0.0482 0.0440]	[0.0926 0.0925]
4	[0.003 0.0033]	[0.9556 0.9515]	[0.420 0.423]	[0.0339 0.0294]	[0.0783 0.0779]
4	[0.003 0.0033]	[0.9556 0.9515]	[0.430 0.433]	[0.0184 0.0133]	[0.0628 0.0618]



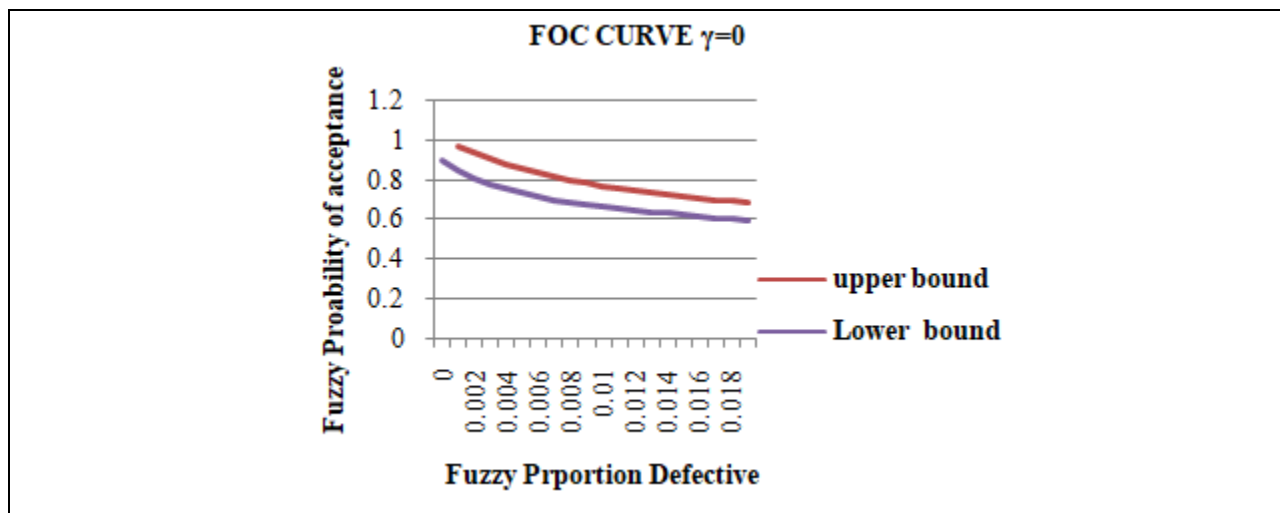
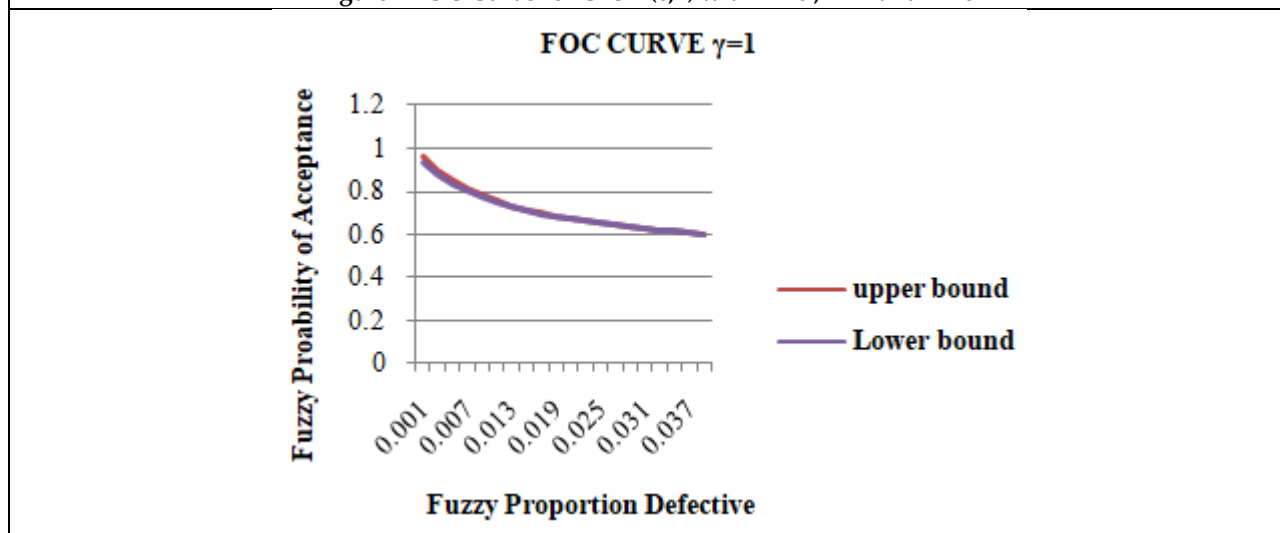


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Table 6 Optimum value of the parameter n which minimizes sum of risks for $k_1=1$ and $k_2=3$ When $\widetilde{\alpha}_f \cong 0.05$ and $\widetilde{\beta}_f \cong 0.10$

n	$\check{p}_{1f}[Y=1]$	$\check{P}_{1fa}[Y=1]$	$\check{p}_{2f}[Y=1]$	$\check{P}_{2fa}[Y=1]$	$\widetilde{\alpha}_f + \widetilde{\beta}_f$
12	[0.0011 0.0012]	[0.9642 0.9613]	[0.171 0.172]	[0.1054 0.1038]	[0.1412 0.1425]
12	[0.0011 0.0012]	[0.9642 0.9613]	[0.181 0.182]	[0.0911 0.0898]	[0.1269 0.1285]
11	[0.0011 0.0012]	[0.9669 0.9642]	[0.201 0.202]	[0.0847 0.0836]	[0.1178 0.1194]
11	[0.0011 0.0012]	[0.9669 0.9642]	[0.211 0.212]	[0.0738 0.0727]	[0.1069 0.1085]
10	[0.0011 0.0012]	[0.9697 0.9672]	[0.221 0.222]	[0.0823 0.0812]	[0.1126 0.1140]
10	[0.0011 0.0012]	[0.9697 0.9672]	[0.231 0.232]	[0.0723 0.0714]	[0.1026 0.1042]
9	[0.0011 0.0012]	[0.9725 0.9702]	[0.241 0.242]	[0.0836 0.0826]	[0.1111 0.1124]
9	[0.0011 0.0012]	[0.9725 0.9702]	[0.251 0.252]	[0.0742 0.0733]	[0.1017 0.1031]
8	[0.0011 0.0012]	[0.9753 0.9733]	[0.261 0.262]	[0.0890 0.0880]	[0.1137 0.1147]
8	[0.0011 0.0012]	[0.9753 0.9733]	[0.271 0.272]	[0.0798 0.0789]	[0.1045 0.1056]
7	[0.0011 0.0012]	[0.9782 0.9764]	[0.281 0.282]	[0.0993 0.0984]	[0.1211 0.1220]
7	[0.0011 0.0012]	[0.9782 0.9764]	[0.291 0.292]	[0.0901 0.0892]	[0.1119 0.1128]
8	[0.0021 0.0022]	[0.9556 0.9538]	[0.301 0.302]	[0.0570 0.0563]	[0.1014 0.1025]
8	[0.0021 0.0022]	[0.9556 0.9538]	[0.311 0.312]	[0.0508 0.0502]	[0.0952 0.0964]
7	[0.0021 0.0022]	[0.9606 0.9589]	[0.321 0.322]	[0.0665 0.0659]	[0.1059 0.1070]
7	[0.0021 0.0022]	[0.9606 0.9589]	[0.331 0.332]	[0.0600 0.0594]	[0.0994 0.1005]
6	[0.0021 0.0022]	[0.9657 0.09642]	[0.341 0.342]	[0.0819 0.0812]	[0.1162 0.1170]
6	[0.0021 0.0022]	[0.9657 0.09642]	[0.351 0.352]	[0.0747 0.0740]	[0.1090 0.1098]
5	[0.0021 0.0022]	[0.9709 0.9697]	[0.361 0.362]	[0.1065 0.1057]	[0.1356 0.1360]
5	[0.0021 0.0022]	[0.9709 0.9697]	[0.371 0.372]	[0.0985 0.0977]	[0.1276 0.1280]
5	[0.0031 0.0032]	[0.9586 0.9575]	[0.381 0.382]	[0.0909 0.0901]	[0.1323 0.1326]
5	[0.0031 0.0032]	[0.9586 0.9575]	[0.391 0.392]	[0.0838 0.0831]	[0.1252 0.1256]
5	[0.0031 0.0032]	[0.9586 0.9575]	[0.401 0.402]	[0.0771 0.0765]	[0.1185 0.1190]
4	[0.0031 0.0032]	[0.9661 0.9652]	[0.431 0.432]	[0.1048 0.1041]	[0.1387 0.1389]
4	[0.0031 0.0032]	[0.9661 0.9652]	[0.441 0.442]	[0.0976 0.0969]	[0.1315 0.1317]
4	[0.0031 0.0032]	[0.9661 0.9652]	[0.451 0.452]	[0.0908 0.0902]	[0.1247 0.1250]
4	[0.0041 0.0042]	[0.9565 0.9556]	[0.441 0.442]	[0.0976 0.0969]	[0.1408 0.1413]
4	[0.0041 0.0042]	[0.9565 0.9556]	[0.451 0.452]	[0.0908 0.0902]	[0.1343 0.1346]
3	[0.0051 0.0052]	[0.9591 0.9584]	[0.531 0.532]	[0.1032 0.1025]	[0.1441 0.1441]
3	[0.0051 0.0052]	[0.9591 0.9584]	[0.541 0.542]	[0.0967 0.0961]	[0.1376 0.1377]
3	[0.0051 0.0052]	[0.9591 0.9584]	[0.551 0.552]	[0.0905 0.0899]	[0.1314 0.1315]



Figure 1 FOC Curve for ChSP-(0,2) with $n=10$, $k_1=1$ and $k_2=3$ Figure 2 FOC Curve for ChSP-(0,2) with $n=10$, $k_1=1$ and $k_2=3$

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RESEARCH ARTICLE

Autoimmune Hypothyroidism Treated with Individualised Homoeopathic Medicines: A Case Series

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ABSTRACT

Autoimmune thyroid disease is rapidly on the rise and is one of the most frequent causes of Hypothyroidism in adults. It is characterised by the formation of antibodies that attack the Thyroid gland resulting in hypothyroidism. Several studies have established that the presence of Anti-thyroid peroxidase (ATPO) and Anti-thyroglobulin (ATG) antibodies are not just associated with thyroid gland damage, but also possibly have a role in systemic inflammation causing extra thyroidal effects including cancer.¹⁾ As thyroid hormones have a key role in the metabolic processes of almost all the tissues in the body, therefore, autoimmune hypothyroidism causes multitude and ambiguous signs and symptoms involving multiple organ systems including a risk of malignancy, and therefore, there is a need to develop effective solutions to treat them. Keeping this in view, a case series of diagnosed autoimmune hypothyroidism treated with individualised Homoeopathic medicines is being reported here. Case summary - 7 diagnosed cases of Autoimmune hypothyroidism were treated with individualised Homoeopathic medicines prescribed after a detailed case taking based on a structured case record proforma. The treatment outcome was assessed based on the ATPO/ ATG titres tested before and after



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intervention. The prescribed individualised Homoeopathic medicines were found to have a curative effect in the given cases of Autoimmune hypothyroidism as is evidenced in the reduction in ATPO and ATG titres to normal range, thereby suggesting a good scope of Homoeopathic intervention in the treatment of this condition. Furthermore, large scale clinical trials are necessary to generate more conclusive evidence.

Key words: Case series, Homoeopathy, Autoimmune hypothyroidism, ATPO, Individualised homoeopathic medicines

INTRODUCTION

Autoimmune hypothyroidism falls under the category of primary hypothyroidism and is an organ specific autoimmune disorder which is characterised by infiltration of the thyroid gland by inflammatory cells resulting in the development of auto antibodies to thyroid specific antigens. The two primary thyroid specific antigens are Thyroglobulin and Thyro-peroxidase. The clinical diagnosis of autoimmune hypothyroidism is based on both physical and biochemical abnormalities as well as serological demonstration of autoantibodies to these major Thyroid specific antigens. Autoimmune hypothyroidism has been found to be associated with an exaggerated iodine intake. Radiation exposure, certain viruses such as hepatitis C virus chronic infection, selenium and vitamin D deficiency are some of the environmental risk factors associated with autoimmune hypothyroidism. Stress (both emotional and psychological) has also been identified to be a risk factor for autoimmune hypothyroidism [2]. As per studies, it was found that women are at a higher risk of developing autoimmune hypothyroidism than men. The prevalence of autoimmune hypothyroidism varies from region to region across the globe and was found to be 5.8% in Asia as per a study [3]. As per a cross-sectional, multi-centre, epidemiological study conducted across 8 major cities of India to study the prevalence of hypothyroidism among adult population, it was found that ATPO positivity was very high, with a prevalence of more than 20% in five cities [4].

There is a rise in the prevalence of autoimmune hypothyroidism cases across all age groups, races, genders and regions worldwide. Given the central role of thyroid hormones in systemic metabolism, hypothyroidism is characterized by a wide spectrum of non-specific manifestations affecting multiple organ systems, with potential long-term risks including malignancy. This emphasizes the need to develop effective solutions to treat them. Homoeopathic system is based on a holistic approach and offers a good scope in the treatment of autoimmune hypothyroidism. An exploratory, randomised, placebo controlled, single blind was conducted at Dr. B.R Sur Homoeopathic Medical College, Hospital and Research centre and Institute of Nuclear medicine and Allied sciences, under Defense Research Development Organisation, Ministry of Defense, Timarpur, Delhi on 194 subjects suffering from subclinical hypothyroidism (SCH) with or without autoimmune thyroiditis (AIT). The subjects were divided into 3 major groups – Group A: SCH + AIT (n=38; high TSH with anti TPO ab+), Group B: AIT (n=47; normal TSH with anti TPO ab+), and Group C: SCH (n= 109; only high TSH). These groups were further randomised to two subgroups – verum and control.

Individualised homoeopathic medicine or identical placebo was administered to respective subgroups. Assessment of follow up was done based on changes in serum TSH, serum anti TPO antibody levels and serum FT 4 levels. Homoeopathic remedies were found to have not only brought about a statistically significant decrease in serum TSH and serum anti TPO antibody titres, but also demonstrated a potential to prevent progression to overt hypothyroidism. ($p < 0.006$ and $p < 0.05$) [5]. An open-label, prospective, single-arm trial was conducted on 40 patients suffering from hypothyroidism at the outpatient department of D. N. De Homeopathic Medical College and Hospital, West Bengal, India. The subjects were treated with individualised homoeopathic remedies. Serum TSH and FT 4 were considered as the primary outcomes and Zuleswki's clinical scoring (ZCS) and thyroid symptom



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questionnaire (TSQ) as the secondary outcomes, measured at baseline and after 3 months of treatment. Intention-to-treat sample was analysed in the end by paired t-tests. Individualised homoeopathic remedies were found to have promising effects in the treatment of hypothyroidism with a significant reduction in serum TSH and FT 4 levels ($p < 0.001$) [6].

A prospective single-arm clinical study without a control group was conducted in out-patient department (OPD), inpatient department (IPD), thyroid specialty clinic and peripheral health center of Sarada Krishna Homoeopathic medical college (SKHMC) from January 2021 to January 2022, on 30 subjects with elevated thyroid stimulating hormone, anti- microsomal antibody/ anti-thyroid peroxidase antibody, and anti-thyroglobulin antibody. The subjects were administered individualised homoeopathic medicines and followed up every month for a period of 12 months. Treatment outcomes were assessed based on anti-thyroglobulin antibody levels, TSH levels, zulewski's clinical score values of before and after 12 months of treatment. Homoeopathic medicines were found to be effective in the reduction of anti-thyroglobulin-antibody levels. ($p = 0.05$) [7]. This case series of patients diagnosed with autoimmune hypothyroidism and treated with individualised homoeopathic medicines is presented here in accordance with PITCH guidelines, with the aim of further exploring the potential role of homoeopathic intervention in the management of this condition.

MATERIALS AND METHODS

Seven patients diagnosed with Autoimmune hypothyroidism were treated with individualised Homoeopathic medicines. The prime objective of this retrospective case series is to substantiate that Homoeopathy has a curative effect in the treatment of Autoimmune hypothyroidism. All the cases presented here were treated at the out-patient department of Nishika Homoeo Clinic, Bangalore. The cases were diagnosed on the basis of serum ATPO and ATG titres evaluated before treatment. The patients included in this study were those who were not under any other medication at the time of homoeopathic intervention. A detailed history of all the patients was taken as per a structured case record proforma. The cases were analysed according to the principles of Homoeopathy. The individualised homoeopathic medicine was selected based on repertorisation using RADAR 10.0 software and finalised in consultation with the Homoeopathic Materia medica. The medicines were administered in centesimal potency and repeated according to the improvement of the patient. The cases were followed up every month from baseline to 6 months and improvement was assessed based on ATPO and ATG Titres. The individual case profiles are as described below:

Case 1

A 47 year old female, housewife, diagnosed with Autoimmune Hypothyroidism with raised ATG levels, presented with elevated TSH levels since 6 months and increased menstrual cramps before menses since 4 months, with menstrual bleeding characterised by large clots. In the past, she had suffered from COVID in 2020, and was operated for fissure-in-ano. Patient was thermally hot and thirsty and couldn't tolerate hunger. She was short tempered and often quarrelled with family members. She was very picky and choosy by nature, always wanted to be prioritised first and given importance and preferred to buy expensive and branded things. She couldn't bear to be dictated by anyone and often argued with her husband for the same. She would become emotional on seeing or hearing others' sad stories, and was easily moved by sad scenes played on Television too. Respect was of utmost importance to her and she wouldn't take it if anyone spoke rudely to her. She was haughty and would cut off from relationships wherever she felt hurt. Her baseline antibody values were - ATG - 111.2 IU/mL. (Fig 8)

Intervention:

The totality of symptoms was listed and repertorised (Fig 1) using the synthesis repertory from RADAR 10.0 software. The following rubrics were considered for repertorisation-

- MIND - Horrible things, sad stories, affect her profoundly



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- MIND - Exclusive, too
- MIND - Casting off people against her will
- GENERALITIES - Hunger, agg

The remedy that came up in the repertorisation was Platina, and upon consulting the Homoeopathic Materia medica, Platina was found to match the patient's disposition. A single dose of Platina 200C was prescribed (4 globules of 30 size pills) to be taken on an empty stomach in the morning followed by placebo twice daily for a period of one month.

Follow up- The case was followed up every month for a period of 6 months. There was a gradual reduction in her ATG levels along with a corresponding reduction in the intensity of her pre-menstrual cramps and clot size. The post-intervention antibody levels were - ATG - 3.6 IU/ ml. (Fig 9) The detailed follow-up is shown in Table 1.

Case 2

A 50 year old female, housekeeper by profession, diagnosed with Autoimmune Hypothyroidism with raised ATPO levels, presented with elevated TSH levels since one year and hair fall and weight gain since two years. Patient also reported that she was experiencing a change of voice in the last 6 months. In the past, she had suffered from recurrent renal calculi. She was married to her maternal uncle until his death 13 years ago, and had 3 children. She had attained menopause one year ago. Patient was thermally chilly and thirsty. She could not tolerate injustice and would confront even higher ups at work. She was a hard worker who did her work sincerely. Patient felt extremely guilty about having gotten her daughter married early as she was being subjected to a lot of harassment by her husband and in-laws. She constantly blamed herself for the same and was deeply saddened by it. Patient was constantly worried as to who will take care of her children, if something were to happen to her. Patient preferred to have piping hot food and drinks, and was highly anxious by nature. Her baseline antibody values were found to be - ATPO - 36.4 IU/mL. (Fig 10)

Intervention:

The totality of symptoms was listed and repertorised (Fig 2) using the synthesis repertory from RADAR 10.0 software. The following rubrics were considered for repertorisation-

- MIND - Reproaching oneself
- MIND – Injustice, cannot support
- MIND - Industrious
- MIND - Anxiety, children about, his
- GENERALITIES - Food and drinks - warm food, desire

Upon consulting the Homoeopathic Materia medica, Arsenicum Album was found to match the patient's disposition. A single dose of Arsenicum album 10M was prescribed (4 globules of 30 size pills) to be taken on an empty stomach in the morning followed by placebo twice daily for a period of one month.

Follow up- The case was followed up every month for a period of 6 months. Her ATPO levels were found to gradually reduce to normal range with a corresponding significant reduction in hairfall. She regained her normal voice. The post-intervention antibody levels were - ATPO - 7.1 IU/mL. (Fig 11) The detailed follow-up is shown in Table 1.

Case 3

A 45 year old male, anaesthesiologist by profession, diagnosed with Autoimmune Hypothyroidism with raised ATPO levels, presented with hypothyroidism since 2 years. Patient also had depigmented patches on both elbows, and left ankle since 1 year. In the past, patient had suffered from allergic rhino-bronchitis. Patient was thermally chilly and very thirsty. Patient was extremely fastidious, fault finding and short tempered when others would not listen to him. He was very anxious about his health. Patient had a tendency to hit himself when angry. Patient had a



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lot of earning, but was very frugal in his spendings. His baseline antibody values were found to be - ATPO - 51.06 IU/mL. (Fig 12)

Intervention:

The totality of symptoms was listed and repertorised (Fig 3) using the synthesis repertory from RADAR 10.0 software. The following rubrics were considered for repertorisation-

- MIND - Striking himself
- MIND - Fastidious
- MIND - Censorious, critical
- MIND - Avarice
- GENERALITIES - Food and drinks - warm food, desire
- SKIN - Discoloration, white

Upon consulting the Homoeopathic Materia medica, Arsenicum Album was found to match the patient's disposition. A single dose of Arsenicum album 10M was prescribed (4 globules of 30 size pills) to be taken on an empty stomach in the morning followed by placebo twice daily for a period of one month.

Follow up - The case was followed up every month for a period of 6 months. The patient's ATPO and ATG levels showed a gradual decline toward normal limits, accompanied by repigmentation of the previously depigmented patches over the elbows and ankle, which was interpreted as being consistent with Hering's law of cure. The post-intervention antibody levels were - ATPO - 27.06 IU/mL. (Fig 13) The detailed follow-up is shown in Table 1.

Case 4

A 42 year old male, software professional, presented with hypothyroidism since a week detected on routine annual health check-up. On further investigations, he was diagnosed to have Autoimmune Hypothyroidism with raised ATPO and ATG levels. In the past, patient had suffered from Typhoid. Patient was thermally hot and thirsty and had hunger intolerance since childhood. Patient was an extrovert who could make connections very quickly. He was lazy at home, but driven at work. He was very intelligent, curious and had an affinity towards learning new things. He was extremely disorganised and least bothered about his personal appearance and was dressed shabbily. He yearned to be recognised as a great achiever. On observation, he was found to be extremely talkative with an element of boasting about himself and making theories about everything. His baseline antibody values were found to be - ATPO > 1300 U/mL, ATG - 500 U/mL. (Fig 14)

Intervention:

The totality of symptoms was listed and repertorised (Fig 4) using the synthesis repertory from RADAR 10.0 software. The following rubrics were considered for repertorisation-

- MIND - Curious
- MIND - Boaster, braggart
- MIND - Indifference apathy, appearance, about personal
- MIND - Theorising
- GENERALITIES - Hunger, agg.

Upon consulting the Homoeopathic Materia medica, Sulphur was found to match the patient's disposition. A single dose of Sulphur 200 c was prescribed (4 globules of 30 size pills) to be taken on an empty stomach in the morning followed by placebo twice daily for a period of one month.

Follow up - The case was followed up every month for a period of 6 months. A progressive reduction in the ATPO, and ATG levels towards normal limits was observed.

The post-intervention antibody levels were - ATPO - 26.5 IU/mL, ATG - 106 IU/mL. (Fig 15, 16) The detailed follow-up is shown in Table 1.



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A 26year old female, software professional, presented with profound depression with intense suicidal thoughts after the break-up of a relationship which occurred a few months ago. She was diagnosed with autoimmune hypothyroidism and reported that she felt numb completely and just wanted to die. She had considered her partner the most important person in her life and described him as a very lively and enthusiastic person. Patient blamed herself for the break-up constantly as she felt that she didn't match up to her partner's personality. It was observed that throughout the history taking, she kept sighing involuntarily as she narrated her symptoms. Patient was thermally chilly and thirstless. She was a highly emotional person, easily moved to tears and didn't like to be consoled. Her baseline investigation values were found to be - ATPO - 21.5 IU/mL. (Fig 17)

Intervention:

The totality of symptoms was listed and repertorised (Fig 5) using the synthesis repertory from RADAR 10.0 software. The following rubrics were considered for repertorisation-

- MIND - Reproaching oneself
- MIND - Suicidal disposition, thoughts
- MIND - Sighing - involuntarily
- MIND - Consolation, agg.
- MIND - Sadness, love; from disappointed

Upon consulting the Homoeopathic Materia medica, Ignatia was found to match the patient's disposition. A single dose of Ignatia 10M was prescribed (4 globules of 30 size pills) to be taken on an empty stomach in the morning followed by placebo twice daily for a period of one month.

Follow up - The case was followed up every month for a period of 6 months. A progressive reduction in ATPO levels toward the normal range was observed, alongside significant improvement in the patient's mental health, with complete resolution of suicidal ideation. The post-intervention investigation levels were - ATPO - 6.9 IU/mL. (Fig 18) The detailed follow-up is shown in Table 1.

Case 6

A 74 year old female, homemaker, a known case of hypothyroidism, presented with constantly fluctuating thyroid hormone levels in spite of conventional medication. Her physician had to frequently change the dose of eltroxin administered to her. The patient presented with weight loss, reduced interest in occupational activities, and frequent crying spells. The patient reported frequent criticism from her husband despite her efforts to care for him. The patient attributed her husband's behaviour to her infertility, accompanied by persistent self-blame. She described feelings of inadequacy as a wife and perceived her husband's actions as justified. Patient was thermally chilly. She was a duty-oriented person and performed her duties irrespective of the state of her health. She was very fastidious by nature. Physically, emaciation was markedly noticeable. Her baseline investigation values were found to be - ATPO - 295 U/mL. (Fig 19)

Intervention:

The totality of symptoms was listed and repertorised (Fig 6) using the synthesis repertory from RADAR 10.0 software. The following rubrics were considered for repertorisation-

- MIND - Delusion - reproach; he has neglected his duty and deserves
- MIND - Duty too much sense of duty
- GENERALITIES - Emaciation

Upon consulting the Homoeopathic Materia medica, Aurum arsenicum was found to match the patient's disposition. A single dose of Aurum arsenicum 10M was prescribed (4 globules of 30 size pills) to be taken on an empty stomach in the morning followed by placebo twice daily for a period of one month. Aurum arsenicum 10M was repeated once more after 3 months when the improvement came to a standstill.





Follow up - The case was followed up every month for a period of 6 months. A progressive normalization of ATPO levels was observed, along with improvement in body weight and restoration of interest in work.

The post-intervention investigation levels were - ATPO - 30.9 IU/mL. (Fig 20) The detailed follow-up is shown in Table 1.

Case 7

A 63 year old female, homemaker, diagnosed with autoimmune hypothyroidism, presented with swelling on the anterior neck and weight loss since few months. Patient was thermally hot and thirsty. She could not tolerate hunger since childhood. The patient reported that her only daughter had been married to a man settled in the USA; however, she later became aware of abusive behaviour by the son-in-law, with her daughter experiencing considerable distress. The patient expressed marked guilt and self-blame, with recurrent thoughts that the marital alliance had not been adequately evaluated by her. By nature, patient was extremely industrious and very fast in all her activities.

Neck ultrasonography demonstrated thyroiditis with bilateral thyroid nodules. Her baseline antibody values were found to be - ATPO - 306.69 U/mL. (Fig 21)

Intervention:

The totality of symptoms was listed and repertorised (Fig 7) using the synthesis repertory from RADAR 10.0 software. The following rubrics were considered for repertorisation-

- MIND - Reproaching oneself
- MIND - Industrious
- GENERALITIES - Hunger agg
- GENERALITIES - Emaciation

Upon consulting the Homoeopathic Materia medica, Aurum iodatum was found to match the patient's disposition. A single dose of Aurum iodatum 200 was prescribed (4 globules of 30 size pills) to be taken on an empty stomach in the morning followed by placebo twice daily for a period of one month.

Follow up - The case was followed up every month for a period of 6 months. A progressive reduction in anti-thyroid peroxidase (ATPO) levels toward the normal range was observed, along with an improvement in her body weight and resolution of thyroiditis on neck ultrasonography. The post-intervention antibody levels were - ATPO - 3.50 IU/mL. (Fig 22) The detailed follow-up is shown in Table 1.

RESULTS

Out of the 7 cases chosen for the case series, 5 were females and 2 were males. (Fig 23). A majority of 4 of the subjects were found to be in the 40-50 years age group, 2 subjects were found to be in the 60-70 years age group and only 1 subject was found to be in the 20-30 years age group. (Fig 24). A majority of 3 of the subjects were homemakers, 2 were software professionals, while the others were a housekeeper, and an anaesthesiologist, respectively. (Fig 25). A majority of 5 of the subjects were found to have raised ATPO titres only, whereas 1 subject had both ATPO and ATG titres raised, and 1 subject had only raised ATG titres. A maximum number of 2 cases were prescribed Arsenicum album, and the remaining 5 were prescribed Platina, Sulphur, Ignatia, Aurum arsenicum and Aurum iodatum each respectively. (Fig 26). Maximum number of the 4 cases were prescribed the indicated homoeopathic medicine in 10M potency and the remaining 3 cases were prescribed the medicine in 200C potency. (Fig 27). All of the subjects responded well to the indicated homoeopathic medicines as reflected in a complete reversal of their thyroid antibodies to within normal limits with a corresponding improvement in their presenting complaints.





DISCUSSION

This study has shown that autoimmune hypothyroidism is more prevalent in those between the ages 40 to 50 years. Most of the subjects considered for the study were found to be females which is concurrent with the findings of other studies. Most of the subjects were from the working professional group followed by housewives. Arsenicum album was the remedy which was most indicated, having been prescribed to about 2 subjects. Aurum arsenicum, Aurum iodatum, Ignatia, Sulphur and Platina were prescribed to each of the remaining subjects, respectively. These remedies have demonstrated a good scope in the treatment of autoimmune hypothyroidism as they were found to have brought complete reduction in the ATPO and ATG titres to the normal range. Although formal follow-up was conducted for 6 months, additional follow-up suggested sustained normalization of thyroid function tests and antibody titres, with patients reporting resolution of their presenting complaints. These findings suggest that individualised homeopathic medicines, prescribed on the basis of homeopathic principles, have a positive role in the treatment of Autoimmune hypothyroidism. However, owing to the small number of cases taken up for the study, the results of this study can be considered as exploratory and may serve as the basis of future research studies.

CONCLUSION

This study concludes that homeopathic individualised medicine is effective in reducing the levels of ATPO and ATG in autoimmune hypothyroidism. Further studies on larger populations can be helpful in substantiating the effectiveness of Homoeopathy in treatment of Autoimmune hypothyroidism.

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Conflict of Interest:

No conflict of interest.

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7. Vishnu Priya S, Sathish Kumar V, Aarathy V, Pillai AS. INDIVIDUALIZED HOMOEOPATHIC MEDICINE IN ANTI-THYROGLOBULIN ANTIBODY TITER IN HASHIMOTO THYROIDITIS-A CLINICAL STUDY.

The repertorisation charts with the totality considered for the cases are as below

Fig. 1. Case 1- Repertorisation sheet using RADAR 10.0 software

Sum of symptoms (sort:deg) - Sum of symptoms (sort:deg) - Intensity is considered

1	1234	1	MIND - HORRIBLE things, sad stories affect her profoundly	67
2	1234	1	MIND - EXCLUSIVE, too	6
3	1234	1	MIND - CASTING OFF people against her will	1
4	1234	1	GENERALS - HUNGER - agg.	39

	plat.	nat-m.	iod.	calc.	kali-c.	sil.	sulph.	aur.	caust.	phos.
	4/6	3/4	2/6	2/5	2/5	2/5	2/5	2/4	2/4	2/4
1	1	2	3	4	2	2	2	2	2	2
2	1	1	-	1	-	-	-	-	-	-
3	3	-	-	-	-	-	-	-	-	-
4	1	1	3	-	3	3	3	2	2	2

Fig. 2. Case 2- Repertorisation sheet using RADAR 10.0 software

Sum of symptoms (sort:deg) - Sum of symptoms (sort:deg) - Intensity is considered

1	1234	1	MIND - REPROACHING oneself	86
2	1234	1	MIND - INJUSTICE, cannot support	63
3	1234	1	MIND - INDUSTRIOUS	156
4	1234	1	MIND - ANXIETY - children - about his	18
5	1234	1	GENERALS - FOOD and DRINKS - warm food - desire	41

	ars.	cupr.	carc.	ph-ac.	sep.	sulph.	falco-pe.	calc.	med.	aur.
	5/9	5/5	4/7	4/5	4/5	4/5	4/5	4/4	4/4	3/6
1	2	1	2	1	1	1	1	-	1	2
2	1	1	3	1	1	1	2	1	1	1
3	1	1	1	-	2	1	1	1	1	3
4	2	1	1	1	1	2	1	1	-	-
5	3	1	-	2	-	-	-	1	1	-

Fig. 3. Case 3- Repertorisation sheet using RADAR 10.0 software

Sum of symptoms (sort:deg) - Sum of symptoms (sort:deg) - Intensity is considered

1	1234	1	MIND - STRIKING - himself	31
2	1234	1	MIND - FASTIDIOUS	73
3	1234	1	MIND - CENSORIOUS	148
4	1234	1	MIND - AVARICE	45
5	1234	1	GENERALS - FOOD and DRINKS - warm food - desire	41
6	1234	1	SKIN - DISCOLORATION - white	18





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	ars.	sil.	lyc.	phos.	sep.	sulph.	nat-m.	plat.	calc.	con.
	6/17	5/7	4/6	4/6	4/6	4/6	4/5	4/5	4/4	4/4
1	1	-	-	2	1	1	-	1	-	1
2	3	1	1	1	1	1	2	1	-	1
3	3	1	1	2	2	3	1	2	1	1
4	4	3	2	1	2	1	1	1	1	1
5	3	1	2	-	-	-	-	-	1	-
6	3	1	-	-	-	-	1	-	1	-

Fig. 4. Case 4- Repertorisation sheet using RADAR 10.0 software

Sum of symptoms (sort:deg) - Sum of symptoms (sort:deg) - Intensity is considered

1	1234	1	MIND - CURIOUS	39
2	1234	1	MIND - BOASTER	21
3	1234	1	MIND - INDIFFERENCE - appearance; to his personal	18
4	1234	1	MIND - THEORIZING	40
5	1234	1	GENERALS - HUNGER - agg.	39

	sulph.	verat.	lyc.	aur-s.	aur.	lach.	calc.	hydrog.	puls.	positr.
	5/14	4/6	4/5	4/4	3/5	3/4	3/3	3/3	3/3	3/3
1	1	1	1	1	1	1	1	1	1	1
2	3	2	2	1	-	1	1	1	1	-
3	4	-	-	1	-	-	1	-	-	1
4	3	2	1	1	2	2	-	1	1	1
5	3	1	1	-	2	-	-	-	-	-

Fig. 5. Case 5- Repertorisation sheet using RADAR 10.0 software

Sum of symptoms (sort:deg) - Sum of symptoms (sort:deg) - Intensity is considered

1	1234	1	MIND - REPROACHING oneself	86
2	1234	1	MIND - SUICIDAL disposition - thoughts	62
3	1234	1	MIND - SIGHING - involuntary	4
4	1234	1	MIND - CONSOLATION - agg.	55
5	1234	1	MIND - SADNESS - love; from disappointed	13

	ign.	nat-m.	aur-m-n.	aur.	carc.	hell.	aur-s.	calc-p.	acon.	merc.
	5/13	4/10	4/8	4/8	4/6	4/5	3/5	3/5	3/4	3/4
1	2	2	2	2	2	1	1	1	2	1
2	2	1	2	3	1	1	3	-	1	2
3	3	-	-	-	-	1	-	2	-	-
4	3	4	2	1	2	2	-	2	1	1
5	3	3	2	2	1	-	1	-	-	-

Fig. 6. Case 6- Repertorisation sheet using RADAR 10.0 software

Sum of symptoms (sort:deg) - Sum of symptoms (sort:deg) - Intensity is considered

1	1234	1	MIND - DELUSIONS - reproach; he has neglected his duty and deserves	2
2	1234	1	MIND - DUTY - too much sense of duty	38
3	1234	1	GENERALS - EMACIATION	299





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	aur.	calc.	nit-ac.	ars.	kali-c.	lyc.	nat-m.	nat-s.	nux-v.	thuj.
	3/5	2/6	2/6	2/5	2/5	2/4	2/4	2/4	2/4	2/4
1	2	-	-	-	-	-	-	-	-	-
2	1	3	3	2	3	1	1	2	1	2
3	2	3	3	3	2	3	3	2	3	2

Fig. 7. Case 7- Repertorisation sheet using RADAR 10.0 software

Sum of symptoms (sort:deg) - Sum of symptoms (sort:deg) - Intensity is considered

1	1234	1	MIND - REPROACHING oneself	86
2	1234	1	MIND - INDUSTRIOUS	156
3	1234	1	GENERALS - EMACIATION	299
4	1234	1	GENERALS - HUNGER - agg.	39

	aur.	sil.	sulph.	kali-c.	lyc.	nat-m.	merc.	verat.	staph.	iod.
	4/9	4/8	4/8	4/7	4/7	4/7	4/5	4/5	4/4	3/8
1	2	1	1	1	1	2	1	1	1	-
2	3	1	1	1	2	1	1	1	1	2
3	2	3	3	2	3	3	2	2	1	3
4	2	3	3	3	1	1	1	1	1	3

Table 8: Case profiles with Homoeopathic prescription and scoring from baseline to six months of follow- up

Timeline	Case profiles	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Baseline	Symptoms:	Elevated ATG levels. Increased pre-menstrual cramps with discharge of large clots during menses.	Elevated ATPO levels. Hair fall. Weight gain. (86 kgs) Change of voice.	Elevated ATPO levels. Depigmented patches on both elbows and left ankle.	Elevated ATPO and ATG levels. Sulphur 200C – one dose,	Elevated ATPO levels. Profound sadness with suicidal ideation.	Elevated ATPO levels. Weight loss. (45 kgs) Loss of interest in work.	Elevated ATPO levels. Weight loss. (42 kgs) Swelling on anterior Neck
	HI*	Platina 200C – One dose, PL** – twice daily.	Arsenicum album 10M- One dose, PL – twice daily.	Arsenicum album 10M – one dose, PL – twice daily.	PL – twice daily	Ignatia 10M- One dose, PL – twice daily	Aurum arsenic 10M – one dose, PL – twice daily	Aurum iodatum 200C – one dose, twice daily
	ATPO/ ATG level	ATG – 111.2 IU/mL	ATPO – 36.4 IU/mL	ATPO - 51.06 IU/mL	ATPO > 1300 U/mL, ATG - 500 U/mL	ATPO - 21.5 IU/mL	ATPO – 295 U/mL	ATPO – 306.69 U/mL
1 month	Symptoms:	Pre-menstrual cramps	Self - blaming has	Anger has reduced, able to have self-	Generals are good.	Suicidal ideation reduced.	Guilt feeling has come	Self-blaming has





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		better. Size of clots reduced.	reduced. Voice is slightly better. Hair fall is better. Weight has remained same. (86 kgs)	control. No episode of striking himself in anger. Pigmentation is observed in the elbows in the depigmented areas.			down. Interest in work is renewed Weight improved by 2 kgs. (47 kgs)	reduced. Weight improved. Gained 1 kg weight. (43 kgs)
2 months	Symptoms:	Pre-menstrual cramps better. Size of clots reduced.	Self-blaming has reduced. Voice is slightly better. Hair fall is better. Slight loss of weight. (85.5 kgs)	Better self-control when angry. Pigmentation is observed in the elbows in the depigmented areas – better than previous month.	Generally good.	Sadness and crying spells are better. No suicidal thoughts.	Not much of changes. Same as previous. Weight is stable.	Generally happier. Gained weight. Neck swelling has reduced. (43.5 kgs)
	HI	PL – Twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily
3 months	Symptoms:	Bearable pre-menstrual cramps. Clots have reduced.	Much happier state of mind. Voice is much better.	Not much of anger. No episodes of striking himself. Pigmentation has started appearing in the ankle area also.	Generally good.	Much better. Able to accept the break-up. Doesn't blame self for it anymore. No suicidal ideation.	Not much of changes. Same as previous. Weight is stable.	Much better. Gained weight. Swelling is better. (44.5 kgs)
	HI	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	Aurum arsenicum 10M – one dose, PL twice daily	PL – twice daily
4 months	Symptoms:	No pain before menses.	Voice is back to usual.	No anger. Elbows and ankle	Better.	Back to usual cheerful	Feeling much better and	Much better. Gaining





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		Flow is back to usual.		pigmentation is improving.		self. No more thoughts of past.	more interested in work. Gained weight. (49 kgs)	weight steadily. Swelling better. (46 kgs)
	HI	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily
5 months	Symptoms:	No pain and no clots. Generally, feeling better.	Voice is back to normal. Overall, better.	Elbows are completely pigmented to usual complexion.	Better	Doing better.	Better. Weight -50 kgs.	Better. Swelling has subsided. Weight – 48 kgs.
	HI	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily
6 months	Symptoms:	No complaints.	Better	Much better. Pigmentation of ankle is much better.	Better	Better	Weight – 52 kgs.	Better. Weight – 49.5 kgs. Swelling on neck is subsided.
	HI	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily	PL – twice daily
	ATPO/ ATG levels	ATG – 3.6 IU/mL	ATPO - 7.1 IU/mL	ATPO - 27.06 IU/mL	ATPO - 26.5 IU/mL, ATG - 106 IU/mL	ATPO - 6.9 IU/mL	ATPO - 30.9 IU/mL	ATPO- 3.50 IU/mL

*HI – Homoeopathic intervention, ** PL – Placebo



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Medical Laboratory Report			
Reference: DR.AMRUTHA DIAGNOSTIC CENTRE KASTURINAGAR Sample Collected At: Amrutha Diagnostic Center - Kasthuri Nagar, Amrutha Diagnostic Center - Kasthuri Nagar #74, ground Floor, Kasturinagar, Main Road, Bchannasandra, Bangalore 29, -ka 560001 India Processing Location:- Metropolis Healthcare Ltd. #76/10, 15th Floor, Malleshwaram, Bangalore		VID: 230242504175064 Registered On: 03/02/2024 01:12 PM Collected On: 03/02/2024 1:10 PM Reported On: 03/02/2024 04:49 PM	
PID NO: P22723518063962 Age: 46 Year(s) Sex: Female			
Investigation	Observed Value	Unit	Biological Reference Interval
Thyroid Antibodies-TPO and ATG, Serum (Serum, Chemiluminescence)			
Microsomal (TPO) Antibody Titre, Serum	<9.00	IU/mL	< 34.0
Interpretation- 1. Anti-thyroid peroxidase (anti-TPO) antibodies are specific against TPO, which catalyses iodine oxidation & iodination reactions in the thyroid gland. 2. 10-15% of normal individuals & during pregnancy can have raised anti-TPO antibody titres. Anti-TPO antibodies are the most common anti-thyroid autoantibody, present in approximately 90% of Hashimoto's thyroiditis, 75% of Graves' disease and 10-20% of nodular goitre or thyroid carcinoma. Relatives of patients with an autoimmune thyroid disorder (40%-50%) may have elevated serum TPOAb levels. High serum antibodies are found in active phase chronic autoimmune thyroiditis & antibody titer can be used to assess disease activity. Other autoimmune disorders often associated with elevated TPOAb include: Sjogren's syndrome, lupus, rheumatoid arthritis, diabetes mellitus (type1) and pernicious anemia.			
Thyroglobulin Antibody (ATG), Serum	111.20	IU/mL	< 4.11
-- End of Report --			

Figure 1: Case 1 – Baseline thyroid antibody titres

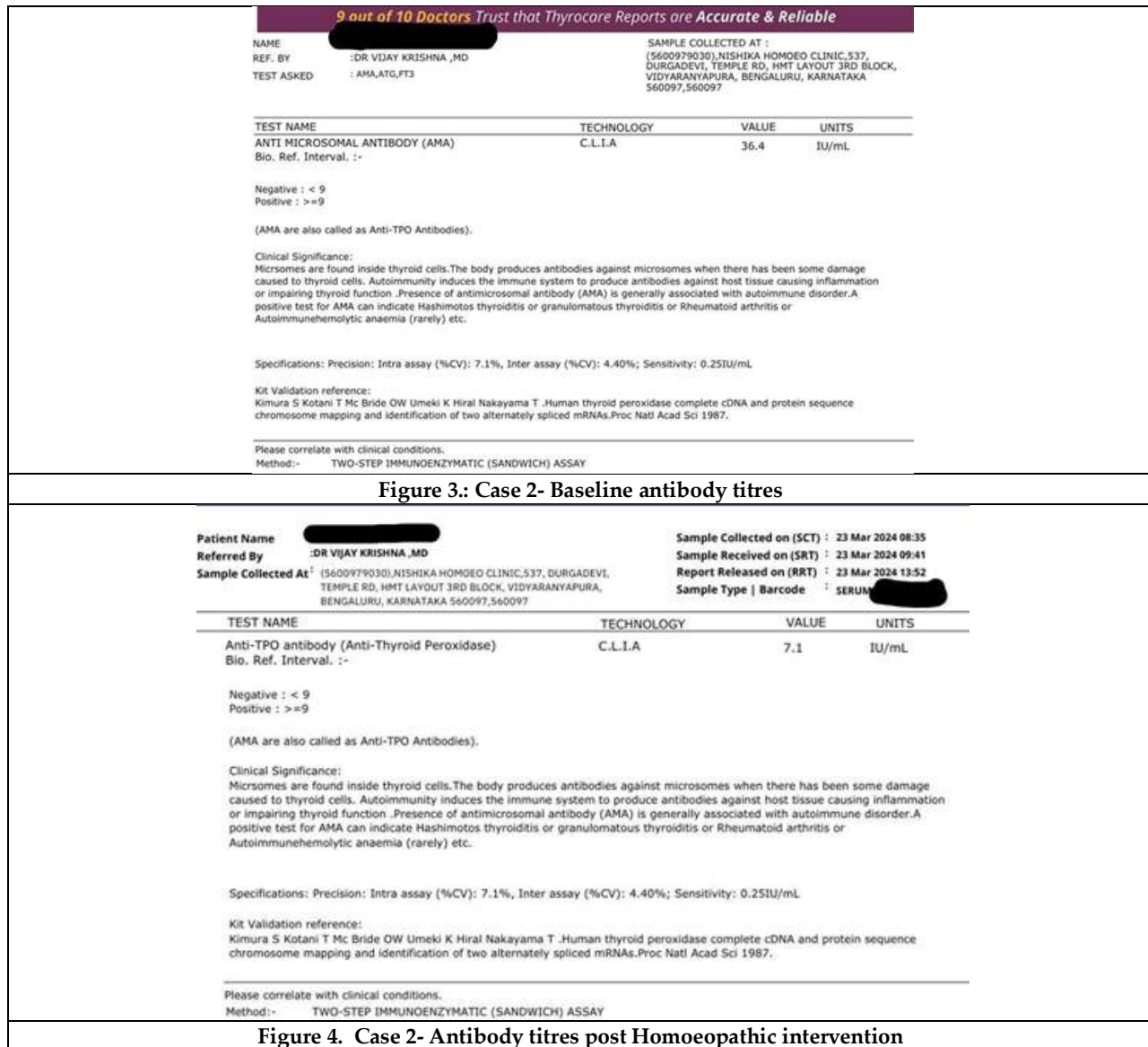
SRI MARUTHI DIAGNOSTIC		Center For Hi-tech Diagnostic Service	
		97439 66134 / 90368 66134. srimaruthidiagnostic134@gmail.com	
NAME : [REDACTED] AGE/SEX : 46 Yrs / Female REFERRED BY : REF CENTER : SRI MARUTHI DIAGNOSTIC CENTRE		REG LAB NO. : 24061328 / 176476 DATE OF RECEIVED : 19-06-2024 at 12:03 PM DATE OF REPORT : 19-06-2024 at 02:36 PM	
TEST PARAMETER	RESULT	REFERENCE RANGE	
HORMONE ASSAYS			
ANTI THYROGLOBULIN ANTIBODY (ANTI Tg)			
ANTI THYROGLOBULIN ANTIBODY (ANTI Tg) CMIA/CLIA	3.60 IU/mL	< 4.11 IU/mL	
CLINICAL NOTE: Anti Tg autoantibody measurements are recommended if Anti TPO autoantibody is negative, but clinical suspicion of Autoimmune thyroid disease is high. Detection of these antibodies in cases of Neonatal hypothyroidism suggests transplacental antibody transfer particularly if there is a maternal history of autoimmune thyroiditis.			

Figure 2. Case 1- Antibody titres post Homoeopathic intervention





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TEST REPORT				
Lab. Id	[REDACTED]	UHID	Reg. Date	14-March-2023 / 13:18 PM
Name	[REDACTED]		Collection	14-March-2023 / 13:14 PM
Age/Gender	47Y / Male		Received	14-March-2023 / 13:59 PM
Collected At			Report	14-March-2023 / 15:39 PM
Referral Dr		Report Status :Final	Print	14-March-2023 / 15:39 PM
Bed	:			

Biochemistry				
Investigation	Observed Values	Units	Biological Ref Ranges	Specimen
ANTI-THYROID PEROXIDASE 51.06 ANTIBODY (aTPO) Method: ECLIA		IU/mL	Newborn : <117 I 6days-3 months : <47 I 4months-12 months : <32 I 1-6 years : <13 I 7-11 years : <18 I 12-20 years : <26 I Healthy subjects : <34 I	Serum

Comments:
Thyroid peroxidase (TPO) is a membrane associated protein enzyme involved in thyroid hormone synthesis. Anti-TPO antibodies are autoantibodies, which activate complement and are thought to be involved in thyroid dysfunction and pathogenesis of hypothyroidism. It is also used as a tool to detect which patients of subclinical hypothyroidism may progress to overt hypothyroidism and require treatment to prevent it.
High levels are seen in:
1. Autoimmune Thyroiditis/Hashimoto thyroiditis
2. Graves disease
3. Non thyroid autoimmune diseases like pernicious anaemia
4. Thyroid cancers

Figure 5.: Case 3- Baseline antibody titres

TEST REPORT				
Lab. Id	[REDACTED]	UHID	Reg. Date	20-June-2023 / 09:18 AM
Name	[REDACTED]		Collection	20-June-2023 / 10:14 AM
Age/Gender	47Y / Male		Received	20-June-2023 / 11:59 AM
Collected At			Report	20-June-2023 / 15:39 PM
Referral Dr		Report Status :Final	Print	20-June-2023 / 15:39 PM
Bed	:			

Biochemistry				
Investigation	Observed Values	Units	Biological Ref Ranges	Specimen
ANTI-THYROID PEROXIDASE 27.06 ANTIBODY (aTPO) Method: ECLIA		IU/mL	Newborn : <117 I 6days-3 months : <47 I 4months-12 months : <32 I 1-6 years : <13 I 7-11 years : <18 I 12-20 years : <26 I Healthy subjects : <34 I	Serum

Figure 6. Case 3- Antibody titres post Homoeopathic intervention





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PROCESSED AT :
Thyrocare
 D-37/1, TTC MIDC, Turbhe,
 Navi Mumbai-400 703

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REPORT

NAME : [REDACTED]
REF. BY : SELF
TEST ASKED : AMA

SAMPLE COLLECTED AT :
 FLAT NO 402, BLOCK -A, BALAJI PRESTINE
 APARTMENT, WHITEFIELD MAIN ROAD, BESIDES
 GOLDS GYM, WHITEFIELD - 560066

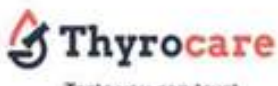
TEST NAME	TECHNOLOGY	VALUE	UNITS
ANTI MICROSOMAL ANTIBODY (AMA) Reference Range : Negative : < 9 Positive : > 9	C.L.I.A	21.5	IU/mL

(AMA are also called as Anti-TPO Antibodies).
Method : FULLY AUTOMATED CHEMI LUMINESCENT IMMUNO ASSAY
Please correlate with clinical conditions.

-- End of report --

Figure 10: Case 5- Baseline antibody titres

PROCESSED AT :
Thyrocare,
 5CA-711, 3rd Floor,
 HRBR 2nd Block,
 Hennur, Bengaluru-560043

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NAME : [REDACTED]
REF. BY : [REDACTED]
TEST ASKED : AMA

SAMPLE COLLECTED AT :
 (5600979030), NISHIKA HOMEO CLINIC, 537,
 DURGADevi, TEMPLE RD, HMT LAYOUT 3RD BLOCK,
 VIDYARANYAPURA, BENGALURU, KARNATAKA
 560097, 560097

TEST NAME	TECHNOLOGY	VALUE	UNITS
ANTI MICROSOMAL ANTIBODY (AMA) Bio. Ref. Interval. :- Negative : < 9 Positive : >=9 (AMA are also called as Anti-TPO Antibodies). Clinical Significance: Microsomes are found inside thyroid cells. The body produces antibodies against microsomes when there has been some damage caused to thyroid cells. Autoimmunity induces the immune system to produce antibodies against host tissue causing inflammation or impairing thyroid function. Presence of antimicrosomal antibody (AMA) is generally associated with autoimmune disorder. A positive test for AMA can indicate Hashimoto's thyroiditis or granulomatous thyroiditis or Rheumatoid arthritis or Autoimmune hemolytic anaemia (rarely) etc.	C.L.I.A	6.9	IU/mL

Figure 11: Case 5- Post homoeopathic intervention antibody titres





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Neudery
REFERENCE LABORATORIES

Visit Id: R6082298

Cert. No.: SAC - 2734

Sample Source: CGHSAB B'LORE

Sample Collected/Received at: No.461, HMT Layout, 3rd Block, Vidhyaranapura, Bangalore-560097.

Name: [REDACTED]

Age: 74 Year(s) Gender: F Contact No.: 9886389184

UID: Referring Dr.: DR VIJAY KRISHNA .V

Registered: 02/11/2022 08:13
Reported: 02/11/2022 12:40
Report Status: Final

Test Name	Test Result	Biological Reference Range	Sample
ANTI THYRO PEROXIDASE ANTIBODIES (ANTI TPO) CHEMILUMINESCENCE	295.00 U/ml	<60 Negative >60 Positive U/ml	SER
FREE THYROXINE (FT4) CHEMILUMINESCENCE	1.04 ng/dl	0.89 - 1.76 (Ref Tietz 4th ED) ng/dl	SER
FREE TRI IODOTHYRONINE (FT3) CHEMILUMINESCENCE	2.0 pg/ml	2.3 - 4.2 pg/ml	SER

----- End of HIGHER CHEMISTRY Report -----

Reviewed By: Dr. Prathibha K

Dr. Prathibha K
Biochemist
Reported On: 22/09/2019 12:41
KMC NO.: - 77400

Figure 12: Case 6- Baseline antibody titres

Reference: Dr. JAYALAKSHMI CGHS
Sample Collected At: VIDHYARANPURA, BANGALORE NORTH

Tel No.: 9886389184
PIN No: 560097
PID NO: P1832300486550
Age: 77.0 Year(s) Sex: Female

VID: 230183000490261
Registered On: 03/05/2023 07:33 AM
Collected On: 03/05/2023 7:36 AM
Reported On: 03/05/2023 12:48 PM

Investigation	Observed Value	Unit	Biological Reference Interval
Microsomal (TPO) Antibody Titre, Serum (Serum, Chemiluminescence)	30.9	IU/mL	< 34.0

Interpretation-

1. Anti-thyroid peroxidase (anti-TPO) antibodies are specific against TPO, which catalyses iodine oxidation & iodination reactions in the thyroid gland.
2. 10-15% of normal individuals & during pregnancy can have raised anti-TPO antibody titres.

Anti-TPO antibodies are the most common anti-thyroid autoantibody, present in approximately 90% of Hashimoto's thyroiditis, 75% of Graves' disease and 10-20% of nodular goitre or thyroid carcinoma. Relatives of patients with an autoimmune thyroid disorder (40%-50%) may have elevated serum TPOAb levels. High serum antibodies are found in active phase chronic autoimmune thyroiditis & antibody titer can be used to assess disease activity. Other autoimmune disorders often associated with elevated TPOAb include: Sjogren's syndrome, lupus, rheumatoid arthritis, diabetes mellitus (type1) and pernicious anemia.

Figure 13: Case 6- Post homoeopathic intervention antibody titres



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R.V. [Redacted] Name [Redacted] Ref. [Redacted] Corporate : METRO POLIS (GOKULA)		Reg. Date : 03/08/2022 11:17 Age / Sex : 63 Year(s) / Female
TEST REPORT		Referred In Sample
Biochemistry		
Test Name	Result(s)	Biological Reference Interval
ANTI THYRO PEROXIDASE ANTIBODIES (Anti TPO) / MICROSOMAL (Chemiluminescence)	306.69 IU/ml	< 5.61 IU/mL
End Of Report		03/08/2022
Verified By Scientific Officer - NRS	Your paragraph text Dr. RaviKumar H N MD DCP PATHOLOGIST	

Figure 14: Case 7- Baseline antibody titres

No.21, NTI Layout, Vidyaranyapura, Bangalore - 97, Ph: 080 23649780			
Name	[Redacted]	Ref By	DR. VIJAYAKRISHNA V
Age/Sex	64 Year(s)/Female	Reg Date	05/02/2023 17:00
Lab. No	[Redacted]	Reported on	05/02/2023 18:25

Test Name	Observed Values	Reference Range	Page 1 of 1
SEROLOGY REPORT			
Anti Thyroperoxidase Antibody (Anti TPO)	3.50 IU/mL	<5.61	
----- End of Report -----			
 Mrs. Lekshmi Bijoy Medical Bio-Chemist			

Figure 15: Case 7- Post homoeopathic intervention antibody titres

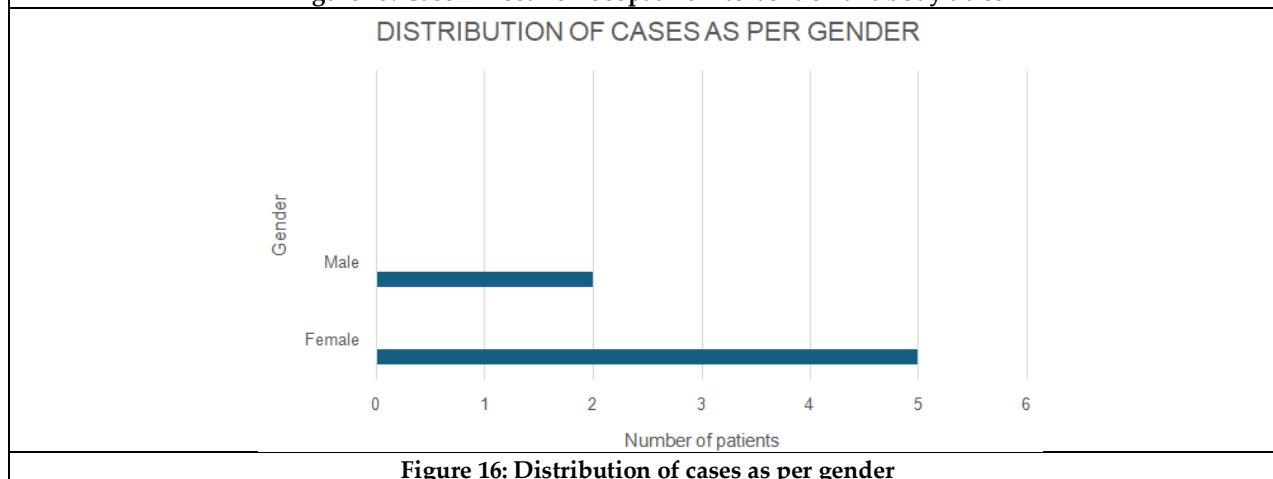


Figure 16: Distribution of cases as per gender





DISTRIBUTION OF CASES AS PER AGE

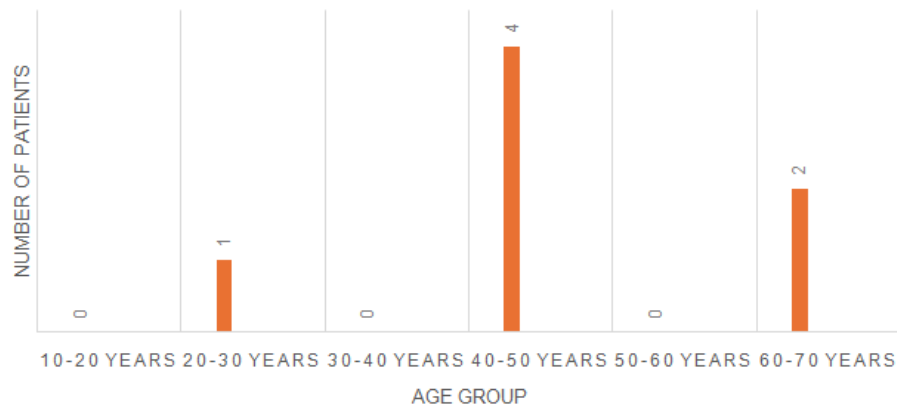


Figure 17: Distribution of cases as per age

DISTRIBUTION OF CASES AS PER OCCUPATION

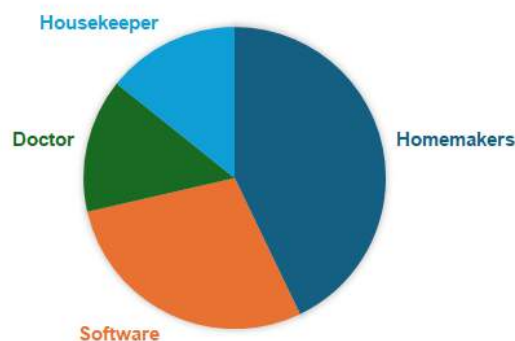


Figure 18: Distribution of cases as per occupation

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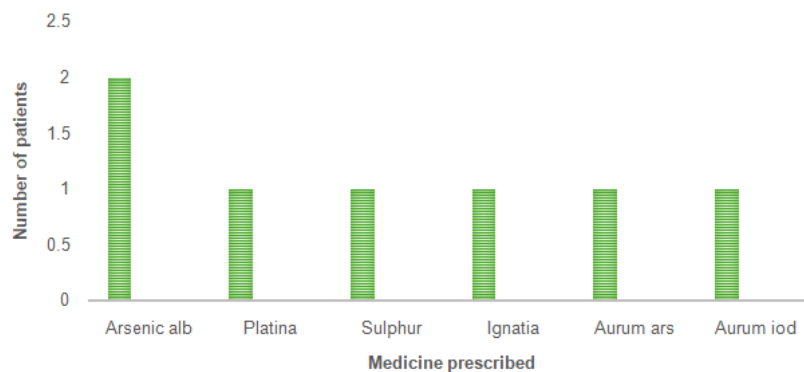
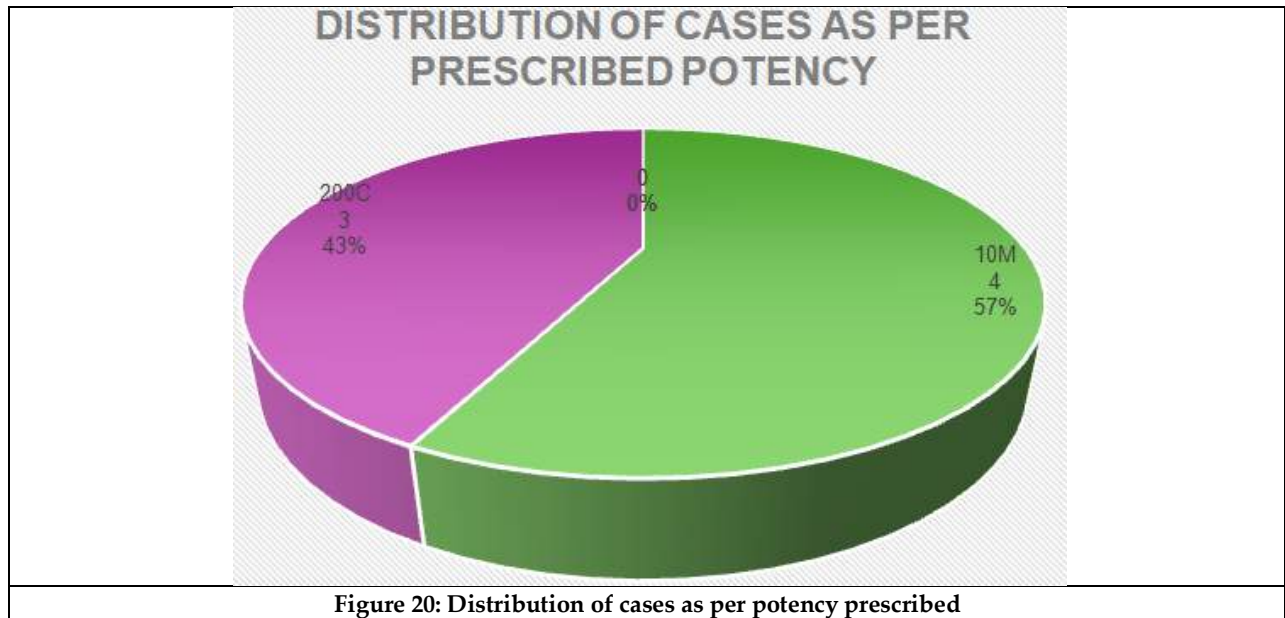


Figure 19: Distribution of cases as per Medicine prescribed





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RESEARCH ARTICLE

Neutrosophic Subalgebras of Several types in UP – Algebras

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ABSTRACT

Characterizations of an $(\in, \in)$ -neutrosophic subalgebra and an $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -neutrosophic subalgebra are provided. Given special sets, so called neutrosophic $\in$ -subsets, neutrosophic q -subsets and neutrosophic $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -subsets, conditions for the neutrosophic $\in$ -subsets, neutrosophic q -subsets and neutrosophic $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -subsets to be subalgebras are discussed. Conditions for a neutrosophic set to be a $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -neutrosophic subalgebra are considered.

Keywords: Neutrosophic set, neutrosophic $\in$ -subset, neutrosophic q -subset, neutrosophic $\in \vee q$ -subset, $(\in, \in)$ -neutrosophic subalgebra, $(\in, q)$ -neutrosophic subalgebra, $(q, \in)$ -neutrosophic subalgebra, $(q, \in)$ -neutrosophic subalgebra, $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -neutrosophic subalgebra, $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -neutrosophic subalgebra.

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INTRODUCTION

The Sheffer operation, also known as the Sheffer stroke or NAND operator was first introduced by H. M. Sheffer [2]. This operation holds significance because it can be used on its own, without any other logical operators, to construct a logical system. This means that any axiom of a logical system can be restated using only the Sheffer operation. Because of this property, it becomes easier to control certain properties of the newly constructed logical system.





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Additionally, it's worth noting that the axioms of Boolean algebra, which is the algebraic counterpart of classical propositional calculus, can be expressed solely using the Sheffer operation. This highlights the fundamental nature and versatility of the Sheffer operation in logical and algebraic systems. In this paper, characterizations of an $(\in, \in)$ -neutrosophic subalgebra and an $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -neutrosophic subalgebra are provided. Given special sets, so called neutrosophic $\in$ -subsets, neutrosophic q -subsets and neutrosophic $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -subsets, conditions for the neutrosophic $\in$ -subsets, neutrosophic q -subsets and neutrosophic $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -subsets to be subalgebras are discussed. Conditions for a neutrosophic set to be a $(q(k_T, k_I, k_F), \in \vee q(k_T, k_I, k_F))$ -neutrosophic subalgebra are considered

Preliminaries

Definition 2.1: [2] Let $H = \langle H, | \rangle$ be a groupoid. The operation $|$ is said to be a Sheffer stroke operation if it satisfies the following conditions:

$$(S1) \ x|y = y|x$$

$$(S2) \ (x|x)|(x|y) = x$$

$$(S3) \ x|((y|z)|(y|z)) = ((x|y)|(x|y))|z$$

$$(S4) \ (x|((x|x)|(y|y))|(x|((x|x)|(y|y)))) = x.$$

Definition 2.2: [1] A Sheffer stroke Hilbert algebra is a structure $\langle H, | \rangle$ of type (2), in which H is a non-empty set and $|$ is a Sheffer stroke operation on H such that the following identities are satisfied for all $x, y, z \in H$:

$$1. \left(\left(\left((z|z) \right) \right) \right) \left| \left(\left(\left((z|z) \right) \right) \right) \right) = x| (x),$$

$$2. \text{If } x|(y|y) = y|(x|x) = x|(x|x) \text{ then } x = y.$$

Proposition 2.3:[1] Let $\langle A, | \rangle$ be a Sheffer stroke Hilbert algebra. Then the binary relation $x \leq y$ if and only if $(x|(y|y)) = 1$ is a partial order on A .

Definition 2.4: A nonempty subset G of a Sheffer stroke Hilbert algebra of X is called a subalgebra of X if $(x|(y|y))|(x|(y|y)) \in G$ for all $x, y \in G$. A neutrosophic set in X is a structure of the form $A = \{ \langle x, A_T(x), A_I(x), A_F(x) \rangle : x \in X \}$, where $A_T : X \rightarrow [0, 1]$ is a truth membership function, $A_I : X \rightarrow [0, 1]$ is an indeterminate membership function, and $A_F : X \rightarrow [0, 1]$ is a false membership function. For the sake of simplicity, we use the symbol $A = (A_T, A_I, A_F)$ for the neutrosophic set $A = \{ \langle x, A_T(x), A_I(x), A_F(x) \rangle : x \in X \}$.

Neutrosophic subalgebras of several types

Given a neutrosophic set $A = (A_T, A_I, A_F)$ in a set X , $\alpha, \beta \in (0, 1]$ and $\gamma \in [0, 1)$, we consider the following sets:

$$T_{\in}(A, \alpha) = \{x \in X : A_T(x) \geq \alpha\},$$

$$I_{\in}(A, \beta) = \{x \in X : A_I(x) \geq \beta\},$$

$$F_{\in}(A, \gamma) = \{x \in X : A_F(x) \leq \gamma\},$$

$$T_q(A, \alpha) = \{x \in X : A_T(x) + \alpha > 1\},$$

$$I_q(A, \beta) = \{x \in X : A_I(x) + \beta > 1\},$$

$$F_q(A, \gamma) = \{x \in X : A_F(x) + \gamma < 1\},$$

$$T_{\in \vee q}(A, \alpha) = \{x \in X : A_T(x) \geq \alpha \text{ or } A_T(x) + \alpha > 1\},$$

$$I_{\in \vee q}(A, \beta) = \{x \in X : A_I(x) \geq \beta \text{ or } A_I(x) + \beta > 1\},$$

$$F_{\in \vee q}(A, \gamma) = \{x \in X : A_F(x) \leq \gamma \text{ or } A_F(x) + \gamma < 1\}.$$

We say $U_{\in}(A, \alpha)$, $I_{\in}(A, \beta)$ and $F_{\in}(A, \gamma)$ are neutrosophic $\in$ -subsets of X , and $U_q(A, \alpha)$, $I_q(A, \beta)$ and $F_q(A, \gamma)$ are neutrosophic q -subsets of X and $U_{\in \vee q}(A, \alpha)$, $I_{\in \vee q}(A, \beta)$ and $F_{\in \vee q}(A, \gamma)$ are neutrosophic $\in \vee q$ -subsets of X . For $\Phi \in \{\in, q, \in \vee q\}$, the element of $T_{\Phi}(A, \alpha)$ (resp. $I_{\Phi}(A, \beta)$, $F_{\Phi}(A, \gamma)$) is called a neutrosophic T_{Φ} -point (resp. neutrosophic I_{Φ} -point, neutrosophic F_{Φ} -point) with value α (resp. β , γ). It is clear that

$$T_{\in \vee q}(A, \alpha) = T_{\in}(A, \alpha) \cup T_q(A, \alpha),$$

$$I_{\in \vee q}(A, \beta) = I_{\in}(A, \beta) \cup I_q(A, \beta),$$





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$$F_{\in \vee q}(A, \gamma) = F_{\in}(A, \gamma) \cup F_q(A, \gamma).$$

Definition 3.1: Given $\Phi, \Psi \in \{\in, q, q \in \vee q\}$, a neutrosophic set $A = (A_T, A_I, A_F)$ in a UP-algebra X is called an (Φ, Ψ) -neutrosophic subalgebra of X if the following assertions are valid:

$$\begin{aligned} x \in T_{\Phi}(A, \alpha_x), y \in T_{\Phi}(A, \alpha_y) &\Rightarrow (x|(y|y))|(x|(y|y)) \in T_{\Psi}(A, \alpha_x \wedge \alpha_y), \\ x \in I_{\Phi}(A, \beta_x), y \in I_{\Phi}(A, \beta_y) &\Rightarrow (x|(y|y))|(x|(y|y)) \in I_{\Psi}(A, \beta_x \wedge \beta_y), \\ x \in F_{\Phi}(A, \gamma_x), y \in F_{\Phi}(A, \gamma_y) &\Rightarrow (x|(y|y))|(x|(y|y)) \in F_{\Psi}(A, \gamma_x \vee \gamma_y), \end{aligned} \quad (3.1)$$

for all $x, y \in X, \alpha_x, \alpha_y, \beta_x, \beta_y \in (0, 1]$ and $\gamma_x, \gamma_y \in [0, 1)$.

Theorem 3.2: A neutrosophic set $A = (A_T, A_I, A_F)$ of X is an $(\in, \in)$ -neutrosophic subalgebra of X if and only if

$$(\forall x, y \in X)(A_T((x|(y|y))|(x|(y|y)))) \geq A_T(x) \wedge A_T(y) \wedge A_I((x|(y|y))|(x|(y|y))) \geq A_I(x) \wedge A_I(y) \wedge A_F((x|(y|y))|(x|(y|y))) \leq A_F(x) \vee A_F(y) \quad (3.2)$$

Theorem 3.3: If $A = (A_T, A_I, A_F)$ is an $(\in, \in)$ -neutrosophic subalgebra of X , then the subsets $T_{q_{k_T}}(A, \alpha), I_{q_{k_T}}(A, \beta)$ and $F_{q_{k_T}}(A, \gamma)$ are subalgebras of X for all $\alpha, \beta \in (0, 1]$ and $\gamma \in [0, 1)$ whenever they are nonempty.

Proof: Let $x, y \in T_{q_{k_T}}(A, \alpha)$. Then $A_T(x) + \alpha + k_T > 1$ and $A_T(y) + \alpha + k_T > 1$.

It follows that $A_T((x|(y|y))|(x|(y|y))) + \alpha + k_T \geq (A_T(x) \wedge A_T(y)) + \alpha + k_T = (A_T(x) + \alpha + k_T) \wedge (A_T(y) + \alpha + k_T) > 1$ and so that $(x|(y|y))|(x|(y|y)) \in T_{q_{k_T}}(A, \alpha)$. Hence $T_{q_{k_T}}(A, \alpha)$ is a subalgebra of X . Similarly, we can prove that $I_{q_{k_I}}(A, \beta)$ is a subalgebra of X . Now let $x, y \in F_{q_{k_F}}(A, \beta)$. Then $A_F(x) + \beta + k_F < 1$ and $A_F(y) + \beta + k_F < 1$, which imply that $A_F((x|(y|y))|(x|(y|y))) + \beta + k_F \leq (A_F(x) \vee A_F(y)) + \beta + k_F = (A_F(x) + \beta + k_F) \vee (A_F(y) + \beta + k_F) < 1$. Hence $(x|(y|y))|(x|(y|y)) \in F_{q_{k_T}}(A, \gamma)$ and $F_{q_{k_T}}(A, \gamma)$ is a subalgebra of X .

Theorem 3.4: If $A = (A_T, A_I, A_F)$ is a $(q_{(k_T, k_I, k_F)}, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X , then the subsets $T_{q_{k_T}}(A, \alpha), I_{q_{k_I}}(A, \beta)$ and $F_{q_{k_F}}(A, \gamma)$ are subalgebras of X for all $\alpha \in (\frac{1-k_T}{2}, 1], \beta \in (\frac{1-k_I}{2}, 1]$ and $\gamma \in [0, \frac{1-k_F}{2})$ whenever they are nonempty.

Proof: Let $x, y \in T_{q_{k_T}}(A, \alpha)$. Then $(x|(y|y))|(x|(y|y)) \in T_{\in \vee q_{k_T}}(A, \alpha)$, and so $(x|(y|y))|(x|(y|y)) \in T_{\in}(A, \alpha)$ or $(x|(y|y))|(x|(y|y)) \in T_{q_{k_T}}(A, \alpha)$. If $(x|(y|y))|(x|(y|y)) \in T_{\in}(A, \alpha)$, then $A_T((x|(y|y))|(x|(y|y)))) \geq \alpha > 1 - \alpha$ since $\alpha > \frac{1-k_T}{2}$. Hence $(x|(y|y))|(x|(y|y)) \in T_{q_{k_T}}(A, \alpha)$. Therefore $T_{q_{k_T}}(A, \alpha)$ is a subalgebra of X . Similarly, we prove that $I_{q_{k_I}}(A, \beta)$ is a subalgebra of X . Let $x, y \in F_{q_{k_F}}(A, \gamma)$. Then $(x|(y|y))|(x|(y|y)) \in F_{\in \vee q}(A, \gamma)$, and so $(x|(y|y))|(x|(y|y)) \in F_{\in}(A, \gamma)$ or $(x|(y|y))|(x|(y|y)) \in F_{q_{k_F}}(A, \gamma)$. If $(x|(y|y))|(x|(y|y)) \in F_{\in}(A, \gamma)$, then $A_F((x|(y|y))|(x|(y|y)))) \leq \gamma < 1 - \gamma$ since $\gamma \in [0, \frac{1-k_F}{2})$. Hence $(x|(y|y))|(x|(y|y)) \in F_{q_{k_F}}(A, \gamma)$, and therefore $F_{q_{k_F}}(A, \gamma)$ is a subalgebra of X .

Theorem 3.5: A neutrosophic set $A = (A_T, A_I, A_F)$ of X is an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X if and only if

$$\begin{aligned} (\forall x, y \in X) \left(A_T((x|(y|y))|(x|(y|y)))) &\geq \Lambda \left\{ A_T(x) \wedge A_T(y), \frac{1-k_T}{2} \right\} \wedge A_I((x|(y|y))|(x|(y|y)))) \\ &\geq \Lambda \left\{ A_I(x) \wedge A_I(y), \frac{1-k_I}{2} \right\} \wedge A_F((x|(y|y))|(x|(y|y)))) \leq \vee \left\{ A_F(x) \vee A_F(y), \frac{1-k_F}{2} \right\} \end{aligned} \quad (3.3)$$

Proof: Suppose that $A = (A_T, A_I, A_F)$ is an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X and let $x, y \in X$. If $A_T(x) \wedge A_T(y) < \frac{1-k_T}{2}$, then we have $A_T((x|(y|y))|(x|(y|y)))) \geq A_T(x) \wedge A_T(y)$. Suppose that $A_T((x|(y|y))|(x|(y|y)))) < A_T(x) \wedge A_T(y)$ and choose α_t such that $A_T((x|(y|y))|(x|(y|y)))) < \alpha_t < A_T(x) \wedge A_T(y)$. Then $x \in T_{\in}(A, \alpha_t)$ and $y \in T_{\in}(A, \alpha_t)$ but $(x|(y|y))|(x|(y|y)) \notin T_{\in}(A, \alpha_t)$. Also $A_T((x|(y|y))|(x|(y|y)))) + \alpha_t < 1 - k_T$, that is, $(x|(y|y))|(x|(y|y)) \in T_{q_{k_T}}(A, \alpha_t)$. Thus $(x|(y|y))|(x|(y|y)) \notin T_{\in \vee q_{k_T}}(A, \alpha_t)$, a contradiction. Therefore





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$A_T((x | (y | y)) | (x | (y | y))) \geq \vee \left\{ A_T(x), A_T(y), \frac{1-k_T}{2} \right\}$ whenever $A_T(x) \wedge A_T(y) < \frac{1-k_T}{2}$. Now suppose that $A_T(x) \wedge A_T(y) \geq \frac{1-k_T}{2}$. Then $x \in T_{\in} \left(A, \frac{1-k_T}{2} \right)$ and $y \in T_{\in} \left(A, \frac{1-k_T}{2} \right)$, which imply that $(x | (y | y)) | (x | (y | y)) \in T_{\in \vee k_T} \left(A, \frac{1-k_T}{2} \right)$. Hence $A_T((x | (y | y)) | (x | (y | y))) \geq \frac{1-k_T}{2}$. Otherwise, $A_T((x | (y | y)) | (x | (y | y))) + \frac{1-k_T}{2} < \frac{1-k_T}{2} + \frac{1-k_T}{2} = 1 - k_T$, a contradiction. Consequently, $A_T((x | (y | y)) | (x | (y | y))) \geq \vee \left\{ A_T(x), A_T(y), \frac{1-k_T}{2} \right\}$ for all $x, y \in X$. Similarly, $A_I((x | (y | y)) | (x | (y | y))) \geq \vee \left\{ A_I(x), A_I(y), \frac{1-k_I}{2} \right\}$ holds for all $x, y \in X$. Suppose that $A_F(x) \vee A_F(y) > \frac{1-k_F}{2}$. If $A_F((x | (y | y)) | (x | (y | y))) > A_F(x) \vee A_F(y) = \gamma_s$, then $x, y \in F_{\in}(A, \gamma_s)$, not $(x | (y | y)) | (x | (y | y)) \notin F_{\in}(A, \gamma)$ and $A_F((x | (y | y)) | (x | (y | y))) + \gamma > 2\gamma > 1 - k_F$, that is, $(x | (y | y)) | (x | (y | y)) \notin F_{q_{k_F}}(A, \gamma)$, a contradiction.

Hence $A_F((x | (y | y)) | (x | (y | y))) \leq \wedge \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\}$ whenever $A_F(x) \vee A_F(y) > \frac{1-k_F}{2}$. Now, assume that $A_F(x) \vee A_F(y) \leq \frac{1-k_F}{2}$. Then $x, y \in F_{\in} \left(A, \frac{1-k_F}{2} \right)$ and so $(x | (y | y)) | (x | (y | y)) \in F_{\in \vee q_{k_T}} \left(A, \frac{1-k_F}{2} \right)$. Thus $A_F((x | (y | y)) | (x | (y | y))) \leq \frac{1-k_F}{2}$ or $A_F((x | (y | y)) | (x | (y | y))) + \frac{1-k_F}{2} < 1 - k_F$. If $A_F((x | (y | y)) | (x | (y | y))) > \frac{1-k_F}{2}$, then $A_F((x | (y | y)) | (x | (y | y))) + \frac{1-k_F}{2} > \frac{1-k_F}{2} + \frac{1-k_F}{2} = 1 - k_F$, a contradiction. Thus $A_F((x | (y | y)) | (x | (y | y))) \leq \frac{1-k_F}{2}$, and so $A_F((x | (y | y)) | (x | (y | y))) \leq \vee \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\}$ whenever $A_F(x) \vee A_F(y) \leq \frac{1-k_F}{2}$. Therefore $A_F((x | (y | y)) | (x | (y | y))) \leq \wedge \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\}$ for all $x, y \in X$. Conversely, let $A = (A_T, A_I, A_F)$ be a neutrosophic set in X which satisfies the condition (3.3). Let $x, y \in X$ and $\alpha_x, \alpha_y, \beta_x, \beta_y, \gamma_x, \gamma_y \in [0, 1]$. If $x \in T_{\in}(A, \alpha_x)$ and $y \in T_{\in}(A, \alpha_y)$, then $A_T(x) \geq \alpha_x$ and $A_T(y) \geq \alpha_y$. If $A_T((x | (y | y)) | (x | (y | y))) < \alpha_x \wedge \alpha_y$, then $A_T(x) \wedge A_T(y) \geq \frac{1-k_T}{2}$. Otherwise, we have $A_T((x | (y | y)) | (x | (y | y))) \geq \wedge \left\{ A_T(x), A_T(y), \frac{1-k_T}{2} \right\} = A_T(x) \wedge A_T(y) \geq \alpha_x \wedge \alpha_y$, a contradiction. It follows that $A_T((x | (y | y)) | (x | (y | y))) + \alpha_x \wedge \alpha_y > 2A_T((x | (y | y)) | (x | (y | y))) \geq 2 \wedge \left\{ A_T(x), A_T(y), \frac{1-k_T}{2} \right\} = 1 - k_T$ and so that $(x | (y | y)) | (x | (y | y)) \in T_{q_{k_T}}(A, \alpha_x \wedge \alpha_y) \subseteq T_{\in \vee q_{k_T}}(A, \alpha_x \wedge \alpha_y)$. Similarly, if $x \in I_{\in}(A, \beta_x)$ and $y \in I_{\in}(A, \beta_y)$, then $(x | (y | y)) | (x | (y | y)) \in I_{\in \vee q_{k_I}}(A, \beta_x \wedge \beta_y)$. Now, let $x \in F_{\in}(A, \gamma_x)$ and $y \in F_{\in}(A, \gamma_y)$. Then $A_F(x) \leq \gamma_x$ and $A_F(y) \leq \gamma_y$. If $A_F((x | (y | y)) | (x | (y | y))) > \gamma_x \vee \gamma_y$, then $A_F(x) \vee A_F(y) \leq \frac{1-k_F}{2}$ because if not, then $A_F((x | (y | y)) | (x | (y | y))) \leq \vee \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\} \leq A_F(x) \vee A_F(y) \leq \gamma_x \vee \gamma_y$; which is a contradiction.

Hence $A_F((x | (y | y)) | (x | (y | y))) + \gamma_x \vee \gamma_y < 2A_F((x | (y | y)) | (x | (y | y))) \leq 2 \vee \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\} = 1 - k_F$; and so $(x | (y | y)) | (x | (y | y)) \in F_{q_{k_F}}(A, \gamma_x \vee \gamma_y) \subseteq F_{\in \vee q_{k_F}}(A, \gamma_x \vee \gamma_y)$. Therefore $A = (A_T, A_I, A_F)$ is an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X .

Theorem 3.6: If $A = (A_T, A_I, A_F)$ is an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X , then the subsets $T_{q_{k_T}}(A, \alpha)$, $I_{q_{k_I}}(A, \beta)$ and $F_{q_{k_F}}(A, \gamma)$ are subalgebras of X for all $\alpha \in (\frac{1-k_T}{2}, 1]$, $\beta \in (\frac{1-k_I}{2}, 1]$ and $\gamma \in [0, \frac{1-k_F}{2})$ whenever they are nonempty.

Proof: Assume that $T_{q_{k_T}}(A, \alpha)$, $I_{q_{k_I}}(A, \beta)$ and $F_{q_{k_F}}(A, \gamma)$ are nonempty for all $\alpha \in (\frac{1-k_T}{2}, 1]$, $\beta \in (\frac{1-k_I}{2}, 1]$ and $\gamma \in [0, \frac{1-k_F}{2})$. Let $x, y \in T_{q_{k_T}}(A, \alpha)$. Then $A_T(x) + \alpha + \frac{1-k_T}{2} > 1$ and $A_T(y) + \alpha + \frac{1-k_T}{2} > 1 - k_T$. It follows from Theorem 3.5 that $A_T((x | (y | y)) | (x | (y | y))) + \alpha + \frac{1-k_T}{2} \geq \wedge \left\{ A_T(x), A_T(y), \frac{1-k_T}{2} \right\} + \alpha = \wedge \left\{ A_T(x) + \alpha, A_T(y) + \alpha, \frac{1-k_T}{2} + \alpha \right\} > 1 - k_T$; that is, $(x | (y | y)) | (x | (y | y)) \in T_{q_{k_T}}(A, \alpha)$. Hence $T_{q_{k_T}}(A, \alpha)$ is a subalgebra of X . By the similar way, we can induce that $I_{q_{k_I}}(A, \beta)$ is a subalgebra of X . Now, let $x, y \in F_{q_{k_F}}(A, \gamma)$. Then $A_F(x) + \gamma + \frac{1-k_F}{2} < 1 - k_F$ and $A_F(y) + \gamma + \frac{1-k_F}{2} < 1 - k_F$. Using Theorem 3.5, we have $A_F((x | (y | y)) | (x | (y | y))) + \gamma + \frac{1-k_F}{2} \leq \vee \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\} + \gamma = \vee \left\{ A_F(x) + \gamma, A_F(y) + \gamma, \frac{1-k_F}{2} + \gamma \right\} < 1 - k_F$; and so $(x | (y | y)) | (x | (y | y)) \in F_{q_{k_F}}(A, \gamma)$. Therefore $F_{q_{k_F}}(A, \gamma)$ is a subalgebra of X .





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Theorem 3.7: A neutrosophic set $A = (A_T, A_I, A_F)$ is an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X if and only if the subsets $T_\in(A, \alpha)$, $I_\in(A, \beta)$ and $F_\in(A, \gamma)$ are subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$ whenever they are nonempty.

Proof: Let $A = (A_T, A_I, A_F)$ be an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X . For any $x, y \in X$, let $\alpha \in (0, \frac{1-k_T}{2}]$ be such that $x, y \in T_\in(A, \alpha)$. Then $A_T(x) \geq \alpha$ and $A_T(y) \geq \alpha$. It follows from 3.4 that $A_T((x | (y | y)) | (x | (y | y))) \geq \alpha \wedge \{A_T(x), A_T(y), \frac{1-k_T}{2}\} \geq \alpha \wedge \frac{1-k_T}{2} = \alpha$ and so that $(x | (y | y)) | (x | (y | y)) \in T_\in(A, \alpha)$. Hence $T_\in(A, \alpha)$ is a subalgebra of X . By the similar way, we can induce that $I_\in(A, \beta)$ is a subalgebra of X for all $\beta \in (0, \frac{1-k_I}{2}]$. Now, let $\gamma \in [\frac{1-k_F}{2}, 1)$ be such that $x, y \in F_\in(A, \gamma)$. Then $A_F(x) \leq \gamma$ and $A_F(y) \leq \gamma$. It follows from 3.4 that $A_F((x | (y | y)) | (x | (y | y))) \leq \gamma \vee \{A_F(x), A_F(y), \frac{1-k_F}{2}\} \leq \gamma \vee \frac{1-k_F}{2} = \gamma$ and so that $(x | (y | y)) | (x | (y | y)) \in F_\in(A, \gamma)$. Hence $F_\in(A, \alpha)$ is a subalgebra of X . Conversely, let $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$ be such that $T_\in(A, \alpha)$, $I_\in(A, \beta)$ and $F_\in(A, \gamma)$ are subalgebras of X . If there exist $a, b \in X$ such that $A_T((a | (b | b)) | (a | (b | b))) < \alpha \wedge \{A_T(a), A_T(b), \frac{1-k_T}{2}\}$, then we can take $\alpha \in (0, 1)$ such that $A_T((a | (b | b)) | (a | (b | b))) < \alpha < \{A_T(a), A_T(b), \frac{1-k_T}{2}\}$. Thus $a, b \in T_\in(A, \alpha)$ and $\alpha < \frac{1-k_T}{2}$, and so $(a | (b | b)) | (a | (b | b)) \in T_\in(A, \alpha)$. But, the left inequality in induces $(a | (b | b)) | (a | (b | b)) \notin T_\in(A, \alpha)$, a contradiction. Hence $A_T((x | (y | y)) | (x | (y | y))) \geq \{A_T(x), A_T(y), \frac{1-k_T}{2}\}$ for all $x, y \in X$. Similarly, we can show that $A_I((x | (y | y)) | (x | (y | y))) \geq \{A_I(x), A_I(y), \frac{1-k_I}{2}\}$ for all $x, y \in X$. Now suppose that $A_F((a | (b | b)) | (a | (b | b))) > \gamma \vee \{A_F(a), A_F(b), \frac{1-k_F}{2}\}$ for some $a, b \in X$. Then there exists $\gamma \in (0, 1)$ such that $A_F((a | (b | b)) | (a | (b | b))) > \gamma > \{A_F(a), A_F(b), \frac{1-k_F}{2}\}$. It follows that $\gamma \in (\frac{1-k_F}{2}, 1)$ and $a, b \in F_\in(A, \gamma)$. Since $F_\in(A, \gamma)$ is a subalgebra of X , $(a | (b | b)) | (a | (b | b)) \in F_\in(A, \gamma)$ and so $A_F((a | (b | b)) | (a | (b | b))) \leq \gamma$. This is a contradiction, and thus $A_F((x | (y | y)) | (x | (y | y))) \leq \{A_F(x), A_F(y), \frac{1-k_F}{2}\}$ for all $x, y \in X$. Hence $A = (A_T, A_I, A_F)$ is an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X .

Using Theorems 3.6 and 3.7, we have the following corollary.

Corollary 3.8: For a neutrosophic set $A = (A_T, A_I, A_F)$ of X , if the nonempty subsets $T_{\in \vee q_{k_T}}(A, \alpha)$, $I_{\in \vee q_{k_T}}(A, \beta)$ and $F_{\in \vee q_{k_T}}(A, \gamma)$ are subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [0, \frac{1-k_F}{2})$, then the subsets $T_\in(A, \alpha)$, $I_\in(A, \beta)$ and $F_\in(A, \gamma)$ are subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$.

Theorem 3.9: Given a neutrosophic set $A = (A_T, A_I, A_F)$ of X , the nonempty subsets $T_\in(A, \alpha)$, $I_\in(A, \beta)$ and $F_\in(A, \gamma)$ of X are subalgebras of X for all $\alpha \in (\frac{1-k_T}{2}, 1]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [0, \frac{1-k_F}{2})$ if and only if

$$(\forall x, y \in X) \left(A_T((x | (y | y)) | (x | (y | y))) \vee \frac{1-k_T}{2} \geq A_T(x) \wedge A_T(y) \wedge A_I((x | (y | y)) | (x | (y | y))) \vee \frac{1-k_T}{2} \right. \\ \left. \geq A_I(x) \wedge A_I(y) \wedge A_F((x | (y | y)) | (x | (y | y))) \wedge \frac{1-k_T}{2} \leq A_F(x) \vee A_F(y) \right) \quad (3.4)$$

Proof: Assume that the nonempty subsets $T_\in(A, \alpha)$, $I_\in(A, \beta)$ and $F_\in(A, \gamma)$ of X are subalgebras of X for all $\alpha \in (\frac{1-k_T}{2}, 1]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [0, \frac{1-k_F}{2})$. Suppose that there are $a, b \in X$ such that $A_T((a | (b | b)) | (a | (b | b))) \vee \frac{1-k_T}{2} < A_T(a) \wedge A_T(b) = \alpha$. Then $\alpha \in (\frac{1-k_T}{2}, 1]$ and $a, b \in T_\in(A, \alpha)$. Since $T_\in(A, \alpha)$ is a subalgebra of X , $(a | (b | b)) | (a | (b | b)) \in T_\in(A, \alpha)$, that is, $A_T((a | (b | b)) | (a | (b | b))) \geq \alpha$, a contradiction. Thus $A_T((x | (y | y)) | (x | (y | y))) \vee \frac{1-k_T}{2} \geq A_T(x) \wedge A_T(y)$ for all $x, y \in X$. Similarly, $A_I((x | (y | y)) | (x | (y | y))) \vee \frac{1-k_I}{2} \geq A_I(x) \wedge A_I(y)$ holds for all $x, y \in X$. Now, if $A_F((x | (y | y)) | (x | (y | y))) \wedge \frac{1-k_F}{2} > A_F(x) \vee A_F(y)$ for some $x, y \in X$, then $x, y \in F_\in(A, \gamma)$ and $\gamma \in [0, \frac{1-k_F}{2})$ where $\gamma = A_F(x) \vee A_F(y)$. But, $(x | (y | y)) | (x | (y | y)) \notin F_\in(A, \gamma)$, a contradiction. Hence $A_F((x | (y | y)) | (x | (y | y))) \wedge \frac{1-k_F}{2} \leq A_F(x) \vee A_F(y)$ for all $x, y \in X$. Conversely, let $A = (A_T, A_I, A_F)$ be a neutrosophic set in X satisfying the condition (3.4). Let $x, y, a, b \in X$ and $\alpha \in (\frac{1-k_T}{2}, 1]$, $\beta \in (0, \frac{1-k_I}{2}]$ be such that $x, y \in T_\in(A, \alpha)$ and $a, b \in I_\in(A, \beta)$. Then $A_T((x | (y | y)) | (x | (y | y))) \vee \frac{1-k_T}{2} \geq A_T(x) \wedge A_T(y) \geq \alpha > \frac{1-k_T}{2}$, $A_I((a | (b | b)) | (a | (b | b))) \vee \frac{1-k_I}{2} \geq A_I(a) \wedge$





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$A_I(b) \geq \beta > \frac{1-k_I}{2}$. It follows that $A_T((x | (y | y)) | (x | (y | y))) \geq \alpha$ and $A_I((a | (b | b)) | (a | (b | b))) \geq \beta$, that is, $(x | (y | y)) | (x | (y | y)) \in T_\epsilon(A, \alpha)$ and $(a | (b | b)) | (a | (b | b)) \in I_\epsilon(A, \beta)$. Now, let $x, y \in X$ and $\gamma \in [0, \frac{1-k_F}{2})$ be such that $x, y \in F_\epsilon(A, \gamma)$. Then $A_F((x | (y | y)) | (x | (y | y))) \vee \frac{1-k_F}{2} \leq A_F(x) \vee A_F(y) \leq \gamma < \frac{1-k_F}{2}$ and so $A_F((x | (y | y)) | (x | (y | y))) \leq \gamma$, that is, $(x | (y | y)) | (x | (y | y)) \in F_\epsilon(A, \gamma)$.

Theorem 3.10: For a neutrosophic set $A = (A_T, A_I, A_F)$ of X , if the nonempty subsets $T_{\epsilon \vee q}(A, \alpha)$, $I_{\epsilon \vee q}(A, \beta)$ and $F_{\epsilon \vee q}(A, \gamma)$ are subalgebras of X for all $\alpha, \beta \in (0, 1]$ and $\gamma \in [0, 1)$, then $A = (A_T, A_I, A_F)$ is an $(\epsilon, \epsilon \vee q_{(k_T, k_I, k_F)})$ neutrosophic subalgebra of X .

Proof: Let $T_{\epsilon \vee q}(A, \alpha)$ be a subalgebra of X and $A_T((x | (y | y)) | (x | (y | y))) < \alpha \wedge \{A_T(x), A_T(y), \frac{1-k_T}{2}\}$ for some $x, y \in X$. Then there exists $\alpha \in (0, \frac{1-k_T}{2}]$ such that $A_T((x | (y | y)) | (x | (y | y))) < \alpha \leq \alpha \wedge \{A_T(x), A_T(y), \frac{1-k_T}{2}\}$. It follows that $x, y \in T_\epsilon(A, \alpha) \subseteq T_{\epsilon \vee q}(A, \alpha)$, and so that $(x | (y | y)) | (x | (y | y)) \in T_{\epsilon \vee q}(A, \alpha)$. Hence $A_T((x | (y | y)) | (x | (y | y))) \geq \alpha$ or $A_T((x | (y | y)) | (x | (y | y))) + \alpha > 1$, a contradiction, and so $A_T((x | (y | y)) | (x | (y | y))) \geq \alpha \wedge \{A_T(x), A_T(y), \frac{1-k_T}{2}\}$ for all $x, y \in X$. Similarly, $A_I((x | (y | y)) | (x | (y | y))) \geq \alpha \wedge \{A_I(x), A_I(y), \frac{1-k_I}{2}\}$ holds for all $x, y \in X$. Now let $F_{\epsilon \vee q}(A, \gamma)$ be a subalgebra of X and assume that $A_F((x | (y | y)) | (x | (y | y))) > \gamma \vee \{A_F(x), A_F(y), \frac{1-k_F}{2}\}$ for some $x, y \in X$. Then

$$A_F((x | (y | y)) | (x | (y | y))) > \gamma \geq \gamma \vee \{A_F(x), A_F(y), \frac{1-k_F}{2}\} \quad (3.5)$$

for some $\gamma \in [\frac{1-k_F}{2}, 1)$, which implies that $x, y \in F_\epsilon(A, \gamma) \subseteq F_{\epsilon \vee q}(A, \gamma)$. Thus $(x | (y | y)) | (x | (y | y)) \in F_{\epsilon \vee q}(A, \gamma)$. From (3.5), $(x | (y | y)) | (x | (y | y)) \notin F_\epsilon(A, \gamma)$ and $A_F((x | (y | y)) | (x | (y | y))) + \gamma > \epsilon \geq 1$, that is, $(x | (y | y)) | (x | (y | y)) \notin F_q(A, \gamma)$, a contradiction, and hence $A_F((x | (y | y)) | (x | (y | y))) \leq \gamma \vee \{A_F(x), A_F(y), \frac{1-k_F}{2}\}$ for all $x, y \in X$. By Theorem 3.5, $A = (A_T, A_I, A_F)$ is an $(\epsilon, \epsilon \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X .

Theorem 3.11: If $A = (A_T, A_I, A_F)$ is an $(\epsilon, \epsilon \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X , then the nonempty subsets $T_{\epsilon \vee q}(A, \alpha)$, $I_{\epsilon \vee q}(A, \beta)$ and $F_{\epsilon \vee q}(A, \gamma)$ are subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$.

Proof: Assume that $T_{\epsilon \vee q}(A, \alpha)$, $I_{\epsilon \vee q}(A, \beta)$ and $F_{\epsilon \vee q}(A, \gamma)$ are nonempty for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$. Let $x, y \in T_{\epsilon \vee q}(A, \alpha)$. Then $x \in T_\epsilon(A, \alpha)$ or $x \in T_q(A, \alpha)$, and $y \in T_\epsilon(A, \alpha)$ or $y \in T_q(A, \alpha)$. Hence we have the following four cases:

- $x \in T_\epsilon(A, \alpha)$ and $y \in T_\epsilon(A, \alpha)$,
- $x \in T_\epsilon(A, \alpha)$ and $y \in T_q(A, \alpha)$,
- $x \in T_q(A, \alpha)$ and $y \in T_\epsilon(A, \alpha)$,
- $x \in T_q(A, \alpha)$ and $y \in T_q(A, \alpha)$.

The first case implies that $(x | (y | y)) | (x | (y | y)) \in T_{\epsilon \vee q}(A, \alpha)$. For the second case, $y \in T_q(A, \alpha)$ induces $A_T(y) > 1 - \alpha \geq \alpha$, that is, $y \in T_\epsilon(A, \alpha)$. Thus $(x | (y | y)) | (x | (y | y)) \in T_{\epsilon \vee q}(A, \alpha)$. Similarly, the third case implies $(x | (y | y)) | (x | (y | y)) \in T_{\epsilon \vee q}(A, \alpha)$. The last case induces $A_T(x) > 1 - \alpha \geq \alpha$ and $A_T(y) > 1 - \alpha \geq \alpha$, that is, $x \in T_\epsilon(A, \alpha)$ and $y \in T_\epsilon(A, \alpha)$. Hence $(x | (y | y)) | (x | (y | y)) \in T_{\epsilon \vee q}(A, \alpha)$. Therefore $T_{\epsilon \vee q}(A, \alpha)$ is a subalgebra of X for all $\alpha \in (0, \frac{1-k_T}{2}]$.

By the similar way, we show that $I_{\epsilon \vee q}(A, \beta)$ is a subalgebra of X for all $\beta \in (0, \frac{1-k_I}{2}]$. Let $x, y \in F_{\epsilon \vee q}(A, \gamma)$. Then $A_F(x) \leq \gamma$ or $A_F(x) + \gamma < 1$, and $A_F(y) \leq \gamma$ or $A_F(y) + \gamma < 1$. If $A_F(x) \leq \gamma$ and $A_F(y) \leq \gamma$, then $A_F((x | (y | y)) | (x | (y | y))) \leq \gamma \vee \{A_F(x), A_F(y), \frac{1-k_F}{2}\} \leq \gamma \vee \{\gamma, \frac{1-k_F}{2}\} = \gamma$ by Theorem 3.5, and so $(x | (y | y)) | (x | (y | y)) \in F_\epsilon(A, \gamma) \subseteq F_{\epsilon \vee q}(A, \gamma)$. If $A_F(x) \leq \gamma$ and $A_F(y) + \gamma < 1$, then $A_F((x | (y | y)) | (x | (y | y))) \leq \gamma \vee \{A_F(x), A_F(y), \frac{1-k_F}{2}\} \leq$





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$\forall \left\{ \gamma, 1 - \gamma, \frac{1-k_F}{2} \right\} = \gamma$ by Theorem 3.5. Thus $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_\epsilon(A, \gamma) \subseteq F_{\epsilon \vee q}(A, \gamma)$. Similarly, if $A_F(x) + \gamma < 1$ and $A_F(y) \leq \gamma$, then $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_{\epsilon \vee q}(A, \gamma)$. Finally, assume that $A_F(x) + \gamma < 1$ and $A_F(y) + \gamma < 1$. Then $A_F((x \mid (y \mid y)) \mid (x \mid (y \mid y))) \leq \vee \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\} \leq \vee \left\{ 1 - \gamma, \frac{1-k_F}{2} \right\} = \frac{1-k_F}{2} < \gamma$. Hence $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_\epsilon(A, \gamma) \subseteq F_{\epsilon \vee q}(A, \gamma)$. Consequently, $F_{\epsilon \vee q}(A, \gamma)$ is a subalgebra of X for all $\gamma \in [\frac{1-k_F}{2}, 1)$.

Theorem 3.12: If $A = (A_T, A_I, A_F)$ is an $(q, \epsilon \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X , then the nonempty subsets $T_{\epsilon \vee q}(A, \alpha)$, $I_{\epsilon \vee q}(A, \beta)$ and $F_{\epsilon \vee q}(A, \gamma)$ are subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$.

Proof: Assume that $T_{\epsilon \vee q}(A, \alpha)$, $I_{\epsilon \vee q}(A, \beta)$ and $F_{\epsilon \vee q}(A, \gamma)$ are nonempty for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$. Let $x, y \in T_{\epsilon \vee q}(A, \alpha)$. Then $x \in T_\epsilon(A, \alpha)$ or $x \in T_q(A, \alpha)$. and $y \in T_\epsilon(A, \alpha)$ or $y \in T_q(A, \alpha)$. If $x \in T_q(A, \alpha)$ and $y \in T_q(A, \alpha)$, then obviously $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in T_{\epsilon \vee q}(A, \alpha)$. Suppose that $x \in T_\epsilon(A, \alpha)$ and $y \in T_q(A, \alpha)$. Then $A_T(x) + \alpha \geq 2\alpha > 1$, that is, $x \in T_q(A, \alpha)$. It follows that $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in T_{\epsilon \vee q}(A, \alpha)$. Similarly, if $x \in T_q(A, \alpha)$ and $y \in T_\epsilon(A, \alpha)$, then $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in T_{\epsilon \vee q}(A, \alpha)$. The proof for $I_{\epsilon \vee q}(A, \beta)$ is similar. Now, let $x, y \in F_{\epsilon \vee q}(A, \gamma)$. Then $x \in F_\epsilon(A, \gamma)$ or $x \in F_q(A, \gamma)$, and $y \in F_\epsilon(A, \gamma)$ or $y \in F_q(A, \gamma)$. If $x \in F_\epsilon(A, \gamma)$ and $y \in F_\epsilon(A, \gamma)$, then clearly $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_{\epsilon \vee q}(A, \gamma)$. If $x \in F_\epsilon(A, \gamma)$ and $y \in F_q(A, \gamma)$, then $A_F(x) + \gamma \leq 2\gamma < 1$, that is, $x \in F_q(A, \gamma)$. It follows that $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_{\epsilon \vee q}(A, \gamma)$. Similarly, if $x \in F_q(A, \gamma)$ and $y \in F_\epsilon(A, \gamma)$, then $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_{\epsilon \vee q}(A, \gamma)$. Finally, assume that $x \in F_q(A, \gamma)$ and $y \in F_q(A, \gamma)$. Then $A_F(x) + \gamma \leq 2\gamma < 1$ and $A_F(y) + \gamma \leq 2\gamma < 1$, that is, $x \in F_\epsilon(A, \gamma)$ and $y \in F_\epsilon(A, \gamma)$. Therefore $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_{\epsilon \vee q}(A, \gamma)$. Consequently, $T_{\epsilon \vee q}(A, \alpha)$, $I_{\epsilon \vee q}(A, \beta)$ and $F_{\epsilon \vee q}(A, \gamma)$ are subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$.

Theorem 3.13: For a neutrosophic set $A = (A_T, A_I, A_F)$ of X , if the nonempty subsets $T_q(A, \alpha)$, $I_q(A, \beta)$ and $F_q(A, \gamma)$ are subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in (0, \frac{1-k_F}{2}]$, then

$$\begin{aligned} x \in T_\epsilon(A, \alpha_x), y \in T_\epsilon(A, \alpha_y) &\Rightarrow ((y) \mid ((y))) \in T_q(A, \alpha_x \wedge \alpha_y), \\ x \in I_\epsilon(A, \beta_x), y \in I_\epsilon(A, \beta_y) &\Rightarrow ((y) \mid ((y))) \in I_q(A, \beta_x \wedge \beta_y), \quad 3.6 \\ x \in F_\epsilon(A, \gamma_x), y \in F_\epsilon(A, \gamma_y) &\Rightarrow (x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in F_q(A, \gamma_x \vee \gamma_y), \quad \text{For all } x, y \in X, \alpha_x, \alpha_y \in (\frac{1-k_T}{2}, 1], \beta_x, \beta_y \in (\frac{1-k_I}{2}, 1] \text{ and } \gamma_x, \gamma_y \in [0, \frac{1-k_F}{2}] \end{aligned}$$

Proof. Let $x, y, a, b, u, v \in X$, let $\alpha_x, \alpha_y \in (\frac{1-k_T}{2}, 1]$, $\beta_a, \beta_b \in (\frac{1-k_I}{2}, 1]$ and $\gamma_u, \gamma_v \in (0, \frac{1-k_F}{2})$ be such that $x \in T_\epsilon(A, \alpha_x)$, $y \in T_\epsilon(A, \alpha_y)$, $a \in I_\epsilon(A, \beta_a)$, $b \in I_\epsilon(A, \beta_b)$, $u \in F_\epsilon(A, \gamma_u)$ and $v \in F_\epsilon(A, \gamma_v)$. Then $A_T(x) \geq \alpha_x > 1 - \alpha_x$, $A_T(y) \geq \alpha_y > 1 - \alpha_y$, $A_I(a) \geq \beta_a > 1 - \beta_a$, $A_I(b) \geq \beta_b > 1 - \beta_b$, $A_F(u) \leq \gamma_u < 1 - \gamma_u$ and $A_F(v) \leq \gamma_v < 1 - \gamma_v$. It follows that $x, y \in T_q(A, \alpha_x \wedge \alpha_y)$, $a, b \in I_q(A, \beta_a \wedge \beta_b)$ and $u, v \in F_q(A, \gamma_u \vee \gamma_v)$. Since $\alpha_x \wedge \alpha_y \in (\frac{1-k_T}{2}, 1]$, $\beta_a \wedge \beta_b \in (\frac{1-k_I}{2}, 1]$ and $\gamma_u \vee \gamma_v \in (0, \frac{1-k_F}{2})$, we have $(x \mid (y \mid y)) \mid (x \mid (y \mid y)) \in T_q(A, \alpha_x \wedge \alpha_y)$, $(a \mid (b \mid b)) \mid (a \mid (b \mid b)) \in I_q(A, \beta_a \wedge \beta_b)$ and $(u \mid (v \mid v)) \mid (u \mid (v \mid v)) \in F_q(A, \gamma_u \vee \gamma_v)$.

Given a subset S of X , consider a neutrosophic set $A_S = (A_{S_T}, A_{S_I}, A_{S_F})$ in X defined by

$$A_S(x) = \{(1, 1, 1) \text{ if } x \in S, (0, 0, 1) \text{ otherwise}\} \text{ That is,}$$

$$A_{S_T}(x) = \{1 \text{ if } x \in S, 0 \text{ otherwise}\}, A_{S_I}(x) = \{1 \text{ if } x \in S, 0 \text{ otherwise}\}, A_{S_F}(x) = \{0 \text{ if } x \in S, 1 \text{ otherwise}\},$$

Theorem 3.14: A nonempty subset S of X is a subalgebra of X if and only if the neutrosophic set $A_S = (A_{S_T}, A_{S_I}, A_{S_F})$ is an $(\epsilon, \epsilon \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X .

Proof: Let S be a subalgebra of X . Then the subsets $T_\epsilon(A_S, \alpha)$, $I_\epsilon(A_S, \beta)$ and $F_\epsilon(A_S, \gamma)$ are obviously subalgebras of X for all $\alpha \in (0, \frac{1-k_T}{2}]$, $\beta \in (0, \frac{1-k_I}{2}]$ and $\gamma \in [\frac{1-k_F}{2}, 1)$. Hence $A_S = (A_{S_T}, A_{S_I}, A_{S_F})$ is an $(\epsilon, \epsilon \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X . Conversely, assume that $A_S = (A_{S_T}, A_{S_I}, A_{S_F})$ is an $(\epsilon, \epsilon \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X . Let $x, y \in S$. Then





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$$A_{S_T}((x | (y | y)) | (x | (y | y))) \geq \wedge \left\{ A_{S_T}(x), A_{S_T}(y), \frac{1-k_T}{2} \right\} = 1 \wedge \frac{1-k_T}{2} = \frac{1-k_T}{2}, A_{S_I}((x | (y | y)) | (x | (y | y))) \geq \wedge \left\{ A_{S_I}(x), A_{S_I}(y), \frac{1-k_I}{2} \right\} = 1 \wedge \frac{1-k_I}{2} = \frac{1-k_I}{2}, A_{S_F}((x | (y | y)) | (x | (y | y))) \leq \vee \left\{ A_{S_F}(x), A_{S_F}(y), \frac{1-k_F}{2} \right\} = 1 \vee \frac{1-k_F}{2} = \frac{1-k_F}{2},$$

which imply that $A_{S_T}((x | (y | y)) | (x | (y | y))) = 1$, $A_{S_I}((x | (y | y)) | (x | (y | y))) = 1$ and $A_{S_F}((x | (y | y)) | (x | (y | y))) = 0$. Hence $(x | (y | y)) | (x | (y | y)) \in S$, and so S is a subalgebra of X .

Theorem 3.15: Let S be a subalgebra of X . For every $\alpha \in (\frac{1-k_T}{2}, 1]$, $\beta \in (\frac{1-k_I}{2}, 1]$ and $\gamma \in [0, \frac{1-k_F}{2})$, there exists an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra $A = (A_T, A_I, A_F)$ of X such that $T_\in(A, \alpha) = S$, $I_\in(A, \beta) = S$ and $F_\in(A, \gamma) = S$.

Proof: Let $A = (A_T, A_I, A_F)$ be a neutrosophic set in X defined by

$$A_S(x) = \{(\alpha, \beta, \gamma) \text{ if } x \in S (0,0,1) \text{ otherwise}$$

that is,

$A_{S_T}(x) = \{\alpha \text{ if } x \in S 0 \text{ otherwise}, A_{S_I}(x) = \{\beta \text{ if } x \in S 0 \text{ otherwise}, A_{S_F}(x) = \{0 \text{ if } x \in S \gamma \text{ otherwise}$, Obviously, $T_\in(A, \alpha) = S$, $I_\in(A, \beta) = S$ and $F_\in(A, \gamma) = S$. Suppose that $A_T((a | (b | b)) | (a | (b | b))) < \wedge \left\{ A_T(a), A_T(b), \frac{1-k_T}{2} \right\}$ for some $a, b \in X$. Since $Im(A_T) = 2$, it follows that $\left\{ A_T(a), A_T(b), \frac{1-k_T}{2} \right\} = \alpha$ and $A_T((a | (b | b)) | (a | (b | b))) = 0$. Hence $A_T(a) = \alpha = A_T(b)$, and so $a, b \in S$. Since S is a subalgebra of X , $(a | (b | b)) | (a | (b | b)) \in S$. Thus $A_T((a | (b | b)) | (a | (b | b))) = \alpha$, a contradiction. Therefore $A_T((x | (y | y)) | (x | (y | y))) \geq \wedge \left\{ A_T(x), A_T(y), \frac{1-k_T}{2} \right\}$ for all $x, y \in X$. Similarly, we can verify that $A_I((x | (y | y)) | (x | (y | y))) \geq \wedge \left\{ A_I(x), A_I(y), \frac{1-k_I}{2} \right\}$ for all $x, y \in X$. Assume that there exist $a, b \in X$ such that $A_F((a | (b | b)) | (a | (b | b))) > \vee \left\{ A_F(a), A_F(b), \frac{1-k_F}{2} \right\}$. Then $A_F((a | (b | b)) | (a | (b | b))) = 1$ and $\vee \left\{ A_F(a), A_F(b), \frac{1-k_F}{2} \right\} = \gamma$ since $Im(A_F) = 2$. It follows that $A_F(a) = \gamma = A_F(b)$ and so that $a, b \in S$. Hence $(a | (b | b)) | (a | (b | b)) \in S$, and so $A_F((a | (b | b)) | (a | (b | b))) = \gamma$, which is a contradiction. Thus $A_F((x | (y | y)) | (x | (y | y))) \leq \vee \left\{ A_F(x), A_F(y), \frac{1-k_F}{2} \right\}$ for all $x, y \in X$. Therefore $A = (A_T, A_I, A_F)$ is an $(\in, \in \vee q_{(k_T, k_I, k_F)})$ -neutrosophic subalgebra of X .

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RESEARCH ARTICLE

Performance Analysis of an Evacuated Tube Solar Water Heater with Thermosyphon Heat Pipe Integrated with Compound Parabolic Concentrator Using Different Working Fluids

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ABSTRACT

The main objective of this study is to presents an innovative approach to improve the performance of evacuated tube heat pipe solar water heaters by optimizing key variables in outdoor settings. These objectives are accomplished by experimentally focusing on the mass flow rate tilt angle, and filling ratio to maximize system efficiency. The selection of an appropriate working fluid and the optimization of operational parameters are critical for enhancing evacuated tube solar water heater system performance. The primary goal of this investigation is to evaluate the effectiveness of different working fluids, including acetone, methanol, and water, under varying operational conditions. Evacuated tube solar water heaters present an environmentally friendly option compared to traditional water heating methods. Research conducted in Navsari, India, from December to May, assessed the effectiveness of a solar collector incorporating a compound parabolic concentrator. The most important results indicate that the efficiency of ETSWH is influenced by heat pipe working fluid, tilt angle, filling ratio, and mass flow rate. Acetone was found to be the most efficient working fluid among the tested substances (water, acetone, and methanol) under the examined conditions of tilt angles (25°, 35°, and 45°), filling ratios (30%, 40%, and 50%), and mass flow rates (0.0042, 0.0047, and 0.0056 kg/s). The significance of the obtained results lies in the highest thermal efficiency, 44% was obtained using a 50% acetone mixture and a 45-degree tilt angle. Parametric analysis indicates that most important parameter is working fluid inside heat pipe, which is followed by liquid filling ratio in addition to inclination angle of heat pipe. As mass flow rate increased, heat pipe efficiency declined and increased with liquid filling level.

Keywords: Solar water heater, Thermal System, Heat Pipe, Working Fluid





INTRODUCTION

Solar water heaters, which employ sunlight to heat water for variety of residential and commercial uses, are an eco-friendly alternative to conventional water heaters that burn fossil fuels. Solar water heaters capture sun's abundant energy by converting sunlight into thermal energy by employing solar panels. Solar water heaters usually employ heat pipe or glass systems [1]. Evacuated tube solar water heater (ETSWH) represents a significant advancement in solar water heating technology. Unlike conventional flat-plate collectors, evacuated tube collectors are constructed from sealed glass tubes that have metal layers inside that absorb energy. When it comes to thermal efficiency and performance, heat pipe design is superior to water-in-glass system. System's overall efficiency is raised and heat loss is decreased by vacuuming these tubes [2]. Many investigations have been performed on evacuated tube heat pipe solar water heaters. Researchers examine how various tilt angles, fill ratios, and working fluids affect performance. Optimizing these systems involves careful consideration of the working medium selection, which directly impacts thermal performance. The effect of several liquids along with their water solutions on evacuated tube heat pipe solar collector efficiency had been investigated by Mukuna et al. [3] and Gryzagoridis et al. [4]. Pure water showed higher efficiency compared to other liquids, while acetone surpassed pure water. Heat transmission in evacuated tube solar collector can be improved by nanofluids, like water and multiwalled carbon nanotubes [5]. Energy and exergy efficiency are also influenced by flow rate and nanofluid concentration [6]. It has been discovered that hybrid nanofluids, such as "magnesium oxide/multi-walled carbon nanotubes (MgO/MWCNT)", enhance thermal performance; an increase in weight ratio of MWCNT nanoparticles considerably enhance collector efficiency [7]. It has been demonstrated that heat transfer and efficiency can be increased by modifying heat pipes with particular internal geometries as well as working fluids [8].

Researcher have conducted in-depth studies on various working fluids and nanofluids concentrations. For optimum performance, other factors including temperature, pressure, and heat transfer mechanisms must be taken into consideration. Optimizing efficiency of solar water heaters requires more investigation into working fluids along with their characteristics [9]. One important parameter for optimization is solar irradiance, which has a direct effect on thermal performance and energy efficiency of heat pipe ETSWHs [10]. Solar energy received by evacuated tubes determines temperature and rate of heat transfer fluid [11]. Higher solar radiation increases heat absorption, raising the temperature of the leaving water and enhancing system performance [12]. Optimizing the tilt angles of collectors based on solar irradiance data maximizes useable energy collection and energy savings [13]. Higher solar radiation leads to higher energy production and less reliance on conventional sources, significantly impacting the system's cost savings and payback period [14]. Therefore, optimizing solar radiation is crucial for cost-effectiveness and efficiency of evacuated tube heat pipe solar water heaters. A heat pipe solar water heater's tilt angle significantly influences effectiveness of heat exchange between water tank and heat-absorbing pipe. Optimizing tilt angles and brackets can reduce water flow resistance, improving heat exchange efficiency [15]. Inclination angle of heat collection tube determines angle of incidence (ϕ) of solar radiation, affecting system's solar energy utilization efficiency [16]. Studies show optimal tilt angle for maximum sun share is about $\phi+(0\rightarrow10^\circ)$ for northern regions as well as $\phi+(0\rightarrow20^\circ)$ for southern regions [17]. Adjusting the tilt angle based on geographical location or season can improve thermal performance and energy production [18]. Various studies demonstrate that adjusting the collector's inclination angle can maximize energy and cost savings [19].

According to experiments conducted in various locations, optimal inclination angle for solar water-heated two-phase closed thermosiphon heat pipes (TPCT) is 26° ; higher angles decrease efficiency as well as capability of heat transfer [13]. Tilt angle has no discernible effect on performance, according to studies on evacuated tube solar collectors, while 30° produces marginally better results than 15° [20]. Modified coaxial heat pipe experiments showed that inclination "angle of evacuated tube influences thermal efficiency of solar collector, necessitating optimal angle [21]. Yang et al. [22] discovered that concentrated evacuated tube heat pipe solar collectors perform well thermally when tilted 60 degrees from horizontal. According to Sobhansarbandi et al. [23], an evacuated tube solar air collector with reflector performed better thermally at a tilt angle of 30° than at 45° . For heat pipe-based evacuated tube solar



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collector with" Al_2O_3 -water 0.1% nanofluid as working medium, Putra et al. [24] discovered that a 30° tilt angle offers best thermal performance [25]. Ratio of volume of working fluid to total volume of heat pipe is known as filling level. Sarafraz et al. [26] discovered that 0.6 was optimal filling ratio for their collection. Joudi and Al-Joboory [5] discovered that system's overall efficiency increased with load conditions, and that system with a 22mm heat pipe and 1800mm evaporator length performed best. When Kabeel et al. [27] experimented with various filling ratios, they discovered that "heat pipe solar collector's thermal efficiency rose as filling ratio did. Thus, thermal efficiency as well as overall performance of evacuated tube heat pipe solar water heaters can be increased by regulating filling ratio. Thermal performance of evacuated tube heat pipe solar water heaters is" directly impacted by mass flow rate, rendering it a crucial parameter for system optimization. Higher thermal efficiencies and energy transmission to solar working fluid can be achieved by optimizing system through changes in mass flow rate [28]. Amount of working fluid that flows through system is determined by mass flow, which also influences working fluid's temperature rise and outflow temperature [29].

Furthermore, two-phase flow in the outer tube may be influenced by mass flow, which could lower system's efficiency [30]. System can function at maximum efficiency and generate required outlet temperature by assessing optimal mass flow [12]. For evacuated tube heat pipe solar water heaters to operate as effectively and efficiently as possible, mass flow optimization is essential. Since thermal performance of heat transfer devices and systems varies depending on location, it is required to experiment with various parameters and working fluids. Researchers can learn how various parameters impact system's overall performance as well as heat transfer efficiency by adjusting mass flow rates, filling ratio, heat input, along with adiabatic length [31]. Use of different working fluids allows comparing their thermal properties and performance. This research introduces a novel method to enhance these systems by fine-tuning variables like tilt angle, mass flow rate, in addition to filling ratio in outdoor environments. Increasing efficiency of evacuated tube heat pipe solar water heaters requires optimizing working fluid with efficient parameters. Working fluid, optimal tilt angle, filling ratio, as well as mass flow rate are key components that are examined in current investigation of ETSWH systems. Primary objective is to assess experimentally effectiveness and performance of different working fluids, like acetone, methanol, as well as water. To evaluate thermal performance of these fluids, study involves monitoring and recording solar radiation, ambient temperature, and heat transfer rates. It is expected that findings would advance current research in this area by offering insightful information about best way to choose various parameters and operating fluids for ETSWH systems.

Experimental Setup and Procedure**Experimental Setup**

Two concentric borosilicate glass tubes make up evacuated tube solar collectors. Receiver tube measures 1800mm in length and 58mm in diameter. Thermosiphon heat pipe has been placed in a vacuum tube that serves as receiving tube. Vacuum tube contains thermosiphon heat pipe. Elmosbahi et al [33] state that vacuum tube specifications were basis for selection of thermosiphon heat pipe specifications. Copper thermosiphon heat pipe employed in this experiment measured 1700mm in length and 8mm in diameter. Initial step involved utilizing a rotating vacuum pump for creating vacuum in copper pipe having pressure of up to 5Pa. To prevent heat loss to environment and guarantee efficient heating, condenser portion, which measured 215mm in length, of which 155mm was located inside storage tank and remaining 60mm was insulated outside with Armaflex. The 2.67-liter storage tank that holds condenser is filled with distilled water. Tank is galvanized cylinder made of 3mm thick wall. Interior surface was thoroughly cleaned using distilled ethanol as a cleaning solution, and a pressure gauge was affixed to end of condenser to assist with evacuation as well as fluid injection. Air is effectively purged from the heat pipe by a mechanical evacuated pump operating at 5 Pa. The liquid payload was boiled to eliminate non-condensable gases after the air was removed. They were successfully removed, as evidenced by fact that working fluid had been injected into pipe once an evacuation was created. A filling degree of 30%, 40%, and 50% of injected working medium must be achieved, which corresponds to copper pipe's total volume. Heat pipe is heated by the absorber's absorption of solar radiation, which causes liquid inside to evaporate. Resultant vapor rises to heat pipe's top condenser, where



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it cools down from the water reservoir as well as condenses. After that, condensed liquid gravitationally reaches evaporator again.

Experimental setup utilized to assess performance of solar collectors with CPC at different parameters that most significantly affect system performance is depicted in Figure 1. An evacuated tube positioned in center of CPC apparatus, a water circulation system, and data collection system make up experimental setup. A water storage tank, part of circulating water system, collects heat through evacuated tube. Water's inlet and outlet are monitored by a temperature sensor. Flow rate is controlled by a flow control valve. Thermosyphon heat pipe serves as an absorber in this evacuated tube test apparatus. Working fluid fills a portion of the heat pipe while leaving the remaining portion empty. The two sections of the evacuated tube are the condenser and evaporator sections. These sections contain the Thermosyphon heat pipe installation. Heat from the thermosyphon heat pipe can be harvested by the circulating water system by placing the condenser inside evacuated tube. To adjust collector's tilt angle and optimize solar energy collection, evacuated tube with CPC is directed southward. A metal frame that is angled from 0-90 degrees toward the horizontal supports the model. The system's tilt angle is changed to 25, 35, and 45 degrees during the test. Using acetone, methanol, and water as working fluids, goal is to examine thermal efficiency of a gravity-assisted 2-phase thermosyphon under same conditions (tilt angle and liquid filling amounts of 30, 40, and 50%).

Choice of working fluid for a heat pipe ETSWH should consider several factors, like material compatibility, temperature range, as well as heat transfer characteristics. Strong heat transfer properties, low viscosity, and a high boiling point are desirable characteristics for the working fluid. Heat pipe absorbers have good heat conduction and a low heat capacity in solar collector systems used to produce hot water in Gujarat. Use an evacuation tube to mount on solar water heater and change tilt angle according to the season to optimize the production of solar energy. Over several days, the working liquid volume was adjusted to be between 15 to 24 ml, as a filling charge ratio. Temperature and solar radiation data are collected by data collection system from multiple locations within evacuated tubes. A METRAVI 207 solar power meter, which was mounted at side of solar collector, had been employed for measuring amount of solar radiation. To guarantee precise data collection, 7 K-type thermocouples were placed in experimental setup, labelled T1-T7, and calibrated. To assess temperature distribution, 3 thermocouples were positioned on heat pipe at top T5 and bottom T3 sections. A single T2 thermocouple was positioned on evacuated tube's surface. 2 thermocouples were also placed at water collecting system's entrance T1 and output T7, which collect heat energy through evacuated tube. Finally, atmospheric temperature had been measured using a K-type thermocouple T4.

Experimental procedure

Each experiment carried out outside of the residence (73.04 E, 21.07 N) was carried out in Gujarat. ANSI/ASHRAE 2003 standard (Section 6.1), European Standard 2001, and ISO 1994 standard are most often employed standards for stationary "testing of glazed solar thermal collectors. An instantaneous thermal efficiency test, incident angle modifier test", in addition to collector time constant test are mandated by three standards. Collector performance measurements provided by these standards can be used to assess minor variations in requirements over long term. Location receives no more than nine hours of sunlight between 9 a.m. and 5 p.m. Therefore, all experimental trials will be conducted throughout same time frame, which is December 25, 2021, to May 22, 2022. Thermal performance of the evacuated tube collector by varying the mass flow rate of water. The flow rates were set at 0.0042, 0.0047, and 0.0056 kg/s to determine the optimal balance between useful energy gain, outlet temperature, and overall thermal efficiency. In addition to water temperature at inlet and outlet, temperature at several points along a thermosyphon heat pipe was observed. The entire solar heater experiment was redesigned using a method design and the identical experimental protocol was followed. According to a literature review, numerous studies have been conducted on heat pipe performance. With a constant, uniform heat source and fluctuating heat fluxes, majority of tests employed short test durations. In this case, solar energy was employed to cool water jacket for heat pipe condenser and heat evaporator.





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Efficiency calculations

$$Q_s = I * A \text{ kW} \quad (1)$$

where Incident solar energy, represented by Q_s , is calculated using equation (1). The projected area receiving solar radiation is denoted by A , with I representing the solar irradiation density. Equation (2) expresses length of evaporator (L_e) section of evacuated tube, as well as area can be determined by employing aperture width (B)

$$A = B * L_e \text{ m}^2 \quad (2)$$

Heat energy absorbed by moving water within EHP has been determined by utilizing the specific heat (C_w), mass flow rate (M_w), and temperature variances between outlet as well as inlet, as outlined in equation (3).

$$Q_w = M_w C_w (T_{wO} - T_{wI}) \text{ kW} \quad (3)$$

The assessment of immediate efficiency of solar system entails calculating the proportion of “heat energy absorbed by water from absorber tube to total solar radiation reaching CPC collector. Equation (4) represents instantaneous efficiency”. [32]

$$\eta_{inst} = \frac{Q_w}{Q_s} \quad (4)$$

RESULTS AND DISCUSSIONS

Impact of tilt angle on ETSC's thermal characteristics and instantaneous efficiency is covered in this section with regard to composite parabolic concentrators. Between December 25, 2021, and May 22, 2021, experiments were conducted using tilt angle changes of 25°, 35° and 45°. Effectiveness of evacuated tubes used in thermosiphon heat pipe and CPC solar collectors is investigated and compared with relevant research findings (CPCs). Prior research on similar systems has reported efficiencies ranging from 30 to 50 percent, especially when standard working fluids like water were employed. Under various operating conditions and solar radiation angles, the study's working fluids, acetone and methanol had average efficiencies that were relatively close to one another. These devices probably performed better when a CPC and other working fluids were included, which direct sunlight onto evacuated tube over a large angle of incidence. Operating angle was changed to align with average sun angle at each site, increasing efficiency. This is consistent with previous studies that emphasized significance of increasing tilt angle when considering local solar angles. Many investigations examine CPC's wide acceptance angle and robustness, even though it can maintain high efficiencies over a larger range of solar incidence angles. Absence of a working heat pipe mechanism or an unintegrated system frequently results in temperature gradients along tube. Findings indicate better homogenous heat transmission as well as absorption.

According to research, performance is impacted by cloudy weather and specific times of the day. Configuration's dependability highlights the advantages of combining a heat pipe mechanism and CPC having evacuated tube system. Overall, system functioned well, with very little convection loss and some reflection loss. Numerous studies show that comparable losses are commonly experienced and that it is difficult to eradicate these inefficiencies everywhere. Less loss occurs in these systems, though, which increases benefits even further. When contrasted with similar systems reported in literature, integrated evacuated tube design having thermosiphon heat pipe solar collectors as well as CPC indicated superior performance under a range of operating circumstances and working fluid types. Investigation highlights potential of this integrated approach as a benchmark for future solar thermal system design and development. The daily variation in sun radiation intensity starting at 9:00 a.m. is depicted in Fig. 2. until 5:00 p.m.

Since temperature increases with increasing solar power, Fig. 3 shows how intensity of solar radiation significantly affects temperature of heat pipe walls. More usable energy is produced as a result of this influence. Working fluid condenses, transferring heat obtained through absorber or evaporator section to tank. Cooling water in tank will get heat by natural convection through copper wall and conduction through condenser wall. These results are displayed in Figure 4, where acetone is utilized as working fluid at mass flow rate of 0.004167kg/s and inclination angle of 35°, while water's ambient temperature remains nearly constant. However, hot water's temperature will fluctuate in





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tandem with sun's intensity. It's clear that during noon, the maximum temperature of hot water reaches roughly 32°C, a difference of nearly 10 °C from the ambient temperature.

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The Effect of Various Factors on Efficiency

Effect of filling ratio for a different working fluid

The heat pipe solar water heater's optimal overall efficiency as shown in Figure 5, was determined by experimentation with many configurations, using acetone “as working fluid, a 50% filling ratio, a 35° inclination angle, and mass flow rate” of 0.0042. Methanol, on other hand, reached a maximum efficiency of 54% in Figure 7 with a 50% filling ratio, a 25° inclination angle, and a 0.0042 mass flow rate. With water as working fluid, a 35° inclination angle, mass flow rate of 0.01442, and 30% filling ratio, the working fluid achieved a 43% efficiency, as demonstrated in Figure 6.

Effect of Mass Flow Rate for a Different Working Fluid

Fig. 8 illustrates how mass flow rate affected heat pipe solar water heater's overall efficiency. However, acetone reached a maximum efficiency of 60% at a 35° inclination angle and 50% filling ratio; at that time, mass flow rate was 0.0042kg/s. Under same conditions, methanol seemed to have a maximum efficiency of 54%, but water had such a maximum efficiency of 38%. There is a correlation between maximum efficiency of a setup and the temperature difference. As a result, temperature difference in acetone peaks at 0.0042 kg/s, or around 10°C, as seen in Fig. 9. On the other hand, methanol displays a temperature difference of around 8 °C at 0.0042kg/s mass flow rate, which is comparable to acetone, while water displays a temperature difference of 6 °C at 0.0055 lit per hour in Figure 10. According to fig.11, acetone and methanol as working fluids attain maximum efficiency at an inclination angle of 35 degrees. See fig.12 water, on the other hand, performs best at a 45-degree angle. This implies that best performance of heat pipes at different inclinations is significantly influenced by working fluid selection. Figure 13 shows how altering inclination angle affects temperature difference between incoming and outflow water. It is crucial to remember that setup's maximum efficiency is directly correlated with temperature difference. As a result, the temperature differential in acetone peaks at an angle of 35 degrees, or around 10 degrees Celsius. Water, on the other hand, has a temperature differential

Optimization of Impact of Various Parameter on EHPSWH

Non-Dimensional Parameter

$$x'_i = 2 \times \left(\frac{x_i - x_{av}}{x_{max} - x_{min}} \right) \quad (7)$$

$$x^{av} = \left(\frac{x_{max} + x_{min}}{2} \right)$$

here X_i denotes “ith value of X, X_{min} denotes minimum value of X and X_{max} denotes maximum value of X. Full factorial design” dictated that 81 experiments were needed, or 4 variables with 3 levels apiece, for complete analysis. Every experiment needed to be conducted twice to ensure that findings could be repeated. Experimental design-based method of Taguchi's L-27 orthogonal array was employed for reducing number of experiments carried out in current





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investigation. MINITAB was employed for optimizing combination of several parameters, resulting in a set of 27 experiments. Codes "+1" and "-1" indicated two levels of variable. Between these two levels the third level's central level is "0". The response surface model was constructed using a Taguchi's L-27 orthogonal array that had five replicates and four variables at its centre. Fig.14 illustrates the specific steps that were taken for the analysis. A total of 81 experiments were carried out using various combinations of mass flow rate (B), filling ratio (A), working fluid (D), and heat pipe inclination (C), as advised by the application of RSM. The responses were examined using MINITAB software to establish association between efficiency (η) and various study parameters. Quadratic regression model that follows was created by taking into account the relationships between the various variables.

$$\eta = \beta_0 + \sum_{i=1}^3 \beta_i \cdot X_i + \sum_{i=1}^3 \beta_i \cdot X_i^2 + \sum_{i=1}^3 \sum_{j=i+1}^3 \beta_{ij} \cdot X_i X_j \quad (9)$$

where the uncoded independent variables are X_i and X_j , and "regression coefficients for intercept, linear, quadratic, and interaction terms are β_0 , β_i , β_{ii} , and β_{ij} , respectively. By employing multiple regression analysis, response (η) was associated with 3 independent variables by employing second-order quadratic polynomial as per equation" (9). Equation (10) shows that expansion of equation (9) produced 15 terms. Five relevant terms encompassing constant, B, AD, BC, and B2 were suggested by MINITAB software. Table 2 shows that 4 terms are significant at 95% confidence level, having minimum significance level (p) < 0.05.

$$\begin{aligned} \eta = & 49.6278 + 0.0756 A_1 + 0.2574 A_2 - 0.3330 A_3 + 0.7405 B_1 - 0.0424 B_2 - 0.6981 B_3 - 0.4170 C_1 - 0.0592 C_2 + \\ & 0.4761 C_3 + 8.1738 D_1 + 1.7276 D_2 - 9.9014 D_3 + 0.126 A_1 \cdot B_1 + 0.060 A_1 \cdot B_2 - 0.186 A_1 \cdot B_3 - 0.119 A_2 \cdot B_1 - \\ & 0.068 A_2 \cdot B_2 + 0.187 A_2 \cdot B_3 - 0.007 A_3 \cdot B_1 + 0.008 A_3 \cdot B_2 - 0.001 A_3 \cdot B_3 - 0.035 A_1 \cdot C_1 + 0.103 A_1 \cdot C_2 - 0.068 \\ & A_1 \cdot C_3 + 0.140 A_2 \cdot C_1 - 0.153 A_2 \cdot C_2 + 0.013 A_1 \cdot C_3 - 0.105 A_2 \cdot C_1 + 0.050 A_2 \cdot C_2 + 0.055 A_2 \cdot C_3 + 0.124 \\ & A_1 \cdot D_1 - 0.056 A_1 \cdot D_2 - 0.068 A_1 \cdot D_3 + 0.078 A_2 \cdot D_1 - 0.061 A_2 \cdot D_2 - 0.017 A_2 \cdot D_3 - 0.201 A_3 \cdot D_1 + 0.116 \\ & A_3 \cdot D_2 + 0.085 A_3 \cdot D_3 - 0.183 B_1 \cdot C_1 + 0.020 B_1 \cdot C_2 + 0.163 B_1 \cdot C_3 + 0.059 B_2 \cdot C_1 - 0.033 B_2 \cdot C_2 - 0.026 \\ & B_2 \cdot C_3 + 0.124 B_3 \cdot C_1 + 0.013 B_3 \cdot C_2 - 0.137 B_3 \cdot C_3 + 0.007 B_1 \cdot D_1 + 0.011 B_1 \cdot D_2 - 0.017 B_1 \cdot D_3 - 0.105 \\ & B_2 \cdot D_1 + 0.079 B_2 \cdot D_2 + 0.026 B_2 \cdot D_3 + 0.098 B_3 \cdot D_1 - 0.090 B_3 \cdot D_2 - 0.008 B_3 \cdot D_3 - 1.027 C_1 \cdot D_1 - 1.571 \\ & C_1 \cdot D_2 + 2.597 C_1 \cdot D_3 + 0.024 C_2 \cdot D_1 - 0.078 C_2 \cdot D_2 + 0.054 C_2 \cdot D_3 + 1.003 C_3 \cdot D_1 + 1.648 C_3 \cdot D_2 - 2.651 \\ & C_3 \cdot D_3 \quad (10) \end{aligned}$$

where, η denotes efficiency, A denotes fluid filling ratio, B denotes mass flow rate, C denotes working fluid and IA denotes inclination of heat pipe.

Interdependent Parameters' Effect

Figures 15 and 16 demonstrate how altering liquid filling ratio and heat pipe inclination angle affects heat pipe's efficiency by employing interactive (2-D and 3-D) graphs made with MINITAB software. There is a benefit to raising the liquid filling ratio. This effect was found to be more promising in vacuum conditions, even though it affects efficiency at all pressures. This occurs as a result of working fluid's saturation temperature dropping at low pressure, which raises latent heat of vaporization and causes steam generation to begin early. Stronger steam development is also a result of the higher filling level. As a result, the heat transfer to the liquid is increased by both factors. Consequently, in certain conditions, higher performance was obtained with a larger filling ratio. Steam formation was delayed and latent heat was reduced as a result of the saturation temperature rising in tandem with the pressure. At a 50% fill level and a 45° inclination angle, the maximum efficiency was approximately 0.44. Efficiency increased almost linearly as the filling degree and inclination angle were increased. Increasing both parameters at the same time improved efficiency as well. The reason for this is that when the filling level is increased, a lot of steam is produced, necessitating a quick movement of the condensed steam from condenser to evaporator section.

To facilitate condensed vapor's backward movement and replenish the liquid to enable quick heat removal at the evaporator, angle of inclination (and consequently force of gravity) was increased. The combined impact of altering mass flow rate of 0.0042 and fill ratio of 50% on ETHPSC efficiency is demonstrated in Fig.17 and 18. The



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performance of the ETHPSC was found to be positively impacted by both parameters. The efficiency rises (non-linearly) with increasing filling ratio at mass flow rate of 0.0042. This is because an almost linear increase in efficiency was obtained by both decreasing water mass flow as well as increasing filling ratio. Efficiency increased almost linearly with a decrease in flow rate as the tilt angles shown in Figures 19 and 20 increased.

This is because, as the slope rose, the condensed vapor's gravity-assisted reflux increased as well, leading to a faster replenishment of liquid and quicker heat removal at evaporator. Additionally, as anticipated, a steeper slope turned out to be more advantageous. Efficiency was also improved, albeit not as much, by simultaneous rise in both parameters, except vertical orientation (i.e. E. heat pipe's 45° inclination. This is a result of gravity effect controlling the condensed vapor's transition in this instance from the condenser to the evaporator region. The efficiency for both parameters was found to be more dependent on the mass flow than on the inclination angle Table 3 & 4 displays quadratic response surface model's analysis of variance (ANOVA) sum of squares, between- and within-group degrees of freedom, mean square, and grand total. Statistical study on basis of ANOVA model shows that proposed mathematical model may be applied to samples with a 95 percent confidence level. Both R-squared and adjusted R-squared values for model were 0.9844 and 0.9739, respectively. Null hypothesis is rejected, indicating that current model is statistically significant, as indicated by observed p-value of 0.0001.

Optimization & Validation of the mathematical model

Purpose of “response surface optimization is to find optimal values for independent variables where response can be either maximum or minimum.” Highest ETHPSC efficiency value that could be found in this investigation was found using MINITAB software. The maximum ETHPSC efficiency, as determined by the RSM results, was 44% at fill ratio of 50%, mass flow rate of 0.0042, and 45° inclination. Experimental findings showed an efficiency of 0.4407, greatest value under these operating conditions. A comparison between ETSC efficiency derived from experimental investigations and efficiency “predicted by quadratic model provided in Equation (10), is presented in Fig. 21. Fact that more than 90% of operational points were observed to be within $\pm 10\%$ of experimental values” indicates that quadratic model and experimental data agreed quite well.

CONCLUSIONS

The following are study's main conclusions:

- Parametric analysis indicates that most important parameter is working fluid inside heat pipe, which is followed by liquid filling ratio in addition to inclination angle of heat pipe.
- As mass flow rate increased, heat pipe efficiency declined and increased with liquid filling level.
- The tilt angle of the ETSC was found to have an impact on its performance. Over time, the thermosiphon heat pipe's efficiency increased in tandem with its inclination.
- For acetone, a filling ratio of 50%, mass flow rate of 0.04142kg/s, and a 45° inclination proved to be the ideal set of parameters. The efficiency at this point, as determined by the experiments and predicted by the model, was 0.46, which indicates a 2.93 percent deviation. When the experimental results at various operating conditions are compared with the efficiency predicted by an empirical model, a deviation of approximately 10 percent is discovered. As a result, justice is ensured.

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Data availability:

Data will be accessible upon request.



**Authors' Contribution Statement:**

Jignesh J. Patel: "Writing – review & editing, Writing – original draft, Resources, Methodology, Conceptualization, Investigation; Dr. Vijay D. Dhiman: Review & editing, Supervision, Software, Project administration, Formal" analysis.

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Table 1. Different experiment variables and Range

IA(C)	FR(B)	FILL(A)	WF(D)
1 =25	1=0.0041667	1=30	1=ACETONE
2= 35	2=0.0047220	2=40	2=METHENOL
3=45	3=0.06981	3=50	3=WATER

Table 2. ANOVA for response surface quadratic model

"Source"	DF	Adj SS	Adj MS	F-Value	P-Value"	% Contributions
Inclination angle	2	8.89	1.45	0.88	0.04	14.54
Flow rate	2	12.2	5.60	3.39	0.04	19.94
Filling ratio	2	24.6	11.35	6.87	0.02	40.37
Inclination angle*flow rate	4	2.75	0.69	0.42	0.79	4.50
Inclination angle*filling ratio	4	0.94	0.23	0.14	0.96	1.53
Flow rate*filling ratio	4	7.47	1.87	1.13	0.41	12.21
Error	8	2.22	1.65			3.63
Total	26	61.16				

Table 3. Response Surface Design

"Model Summary			
S	R-sq	R-sq(adj)	R-sq(pred)"
0.93	98.44%	97.39%	95.54%

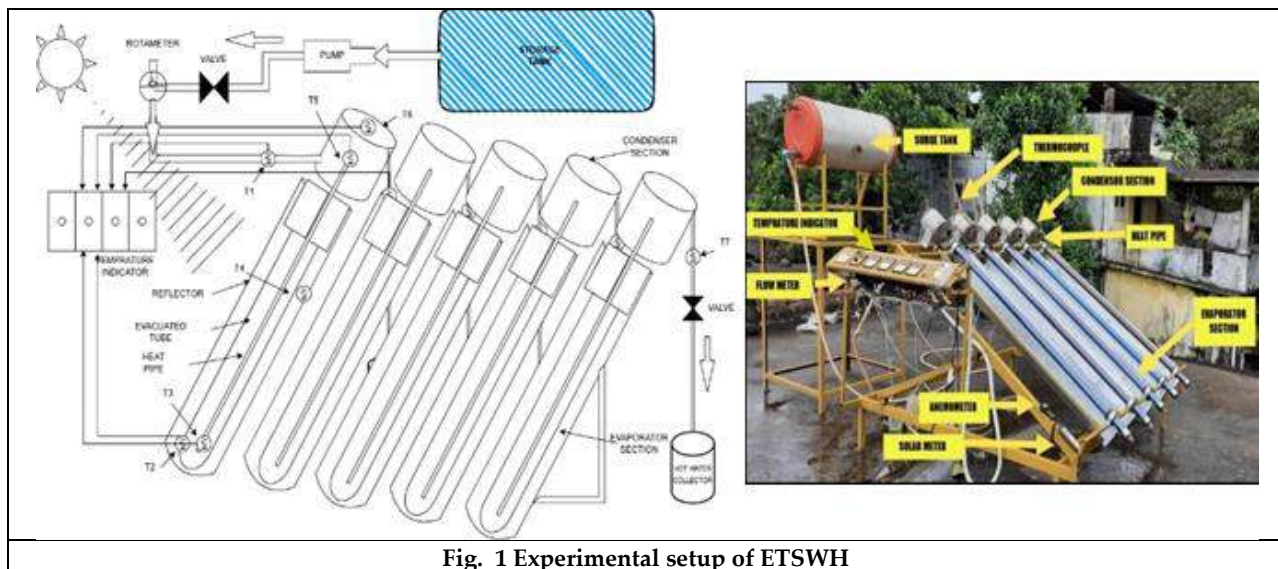


Fig. 1 Experimental setup of ETSWH



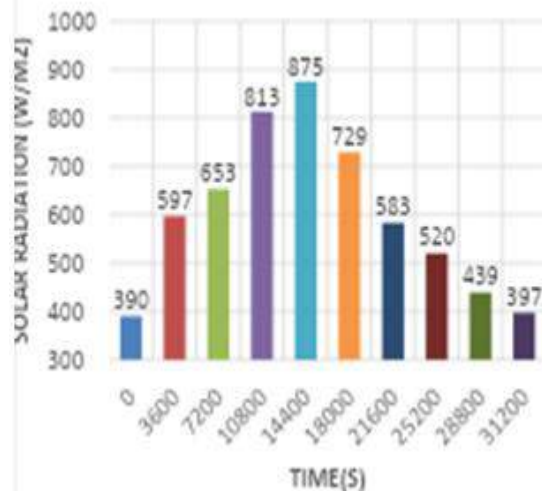


Fig. 2 Solar Radiation Recorded Throughout Day

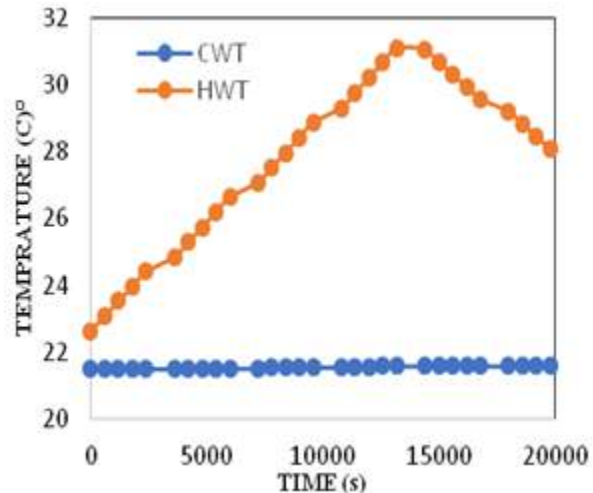


Fig. 3 Temperature difference between inlet and outlet water

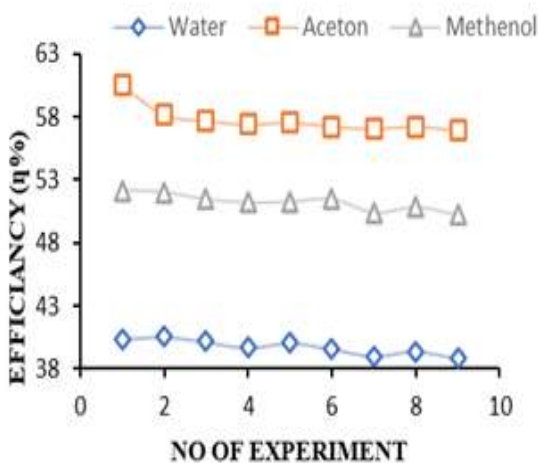


Fig. 5 Influence of a 40% filling ratio on a different working fluid

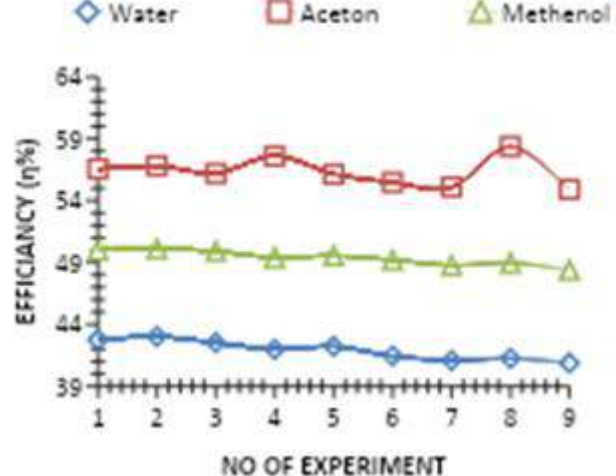


Fig. 6 Influence of a 30% filling ratio on a different working fluid

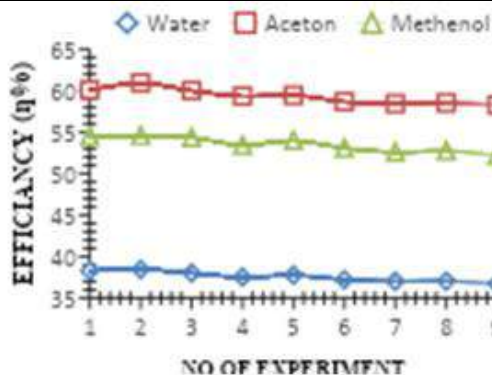


Fig. 7 Influence of a 50% filling ratio on a different working fluid

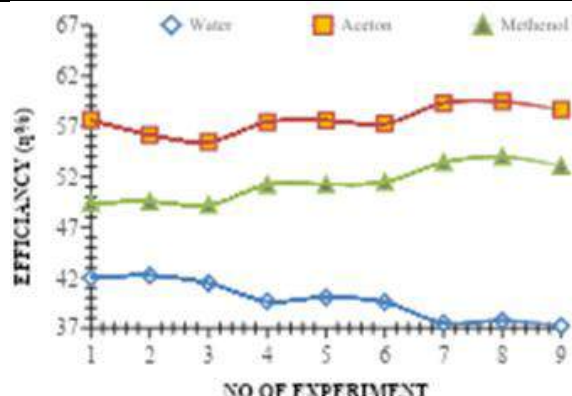


Fig. 8 Influence of a 0.0042 kg/s mass flow rate on a different working fluid



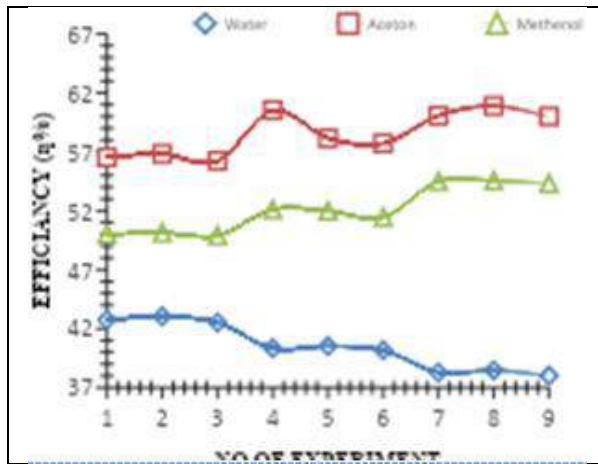


Fig. 9 Influence of a 0.0047 kg/s mass flow rate on a different working fluid

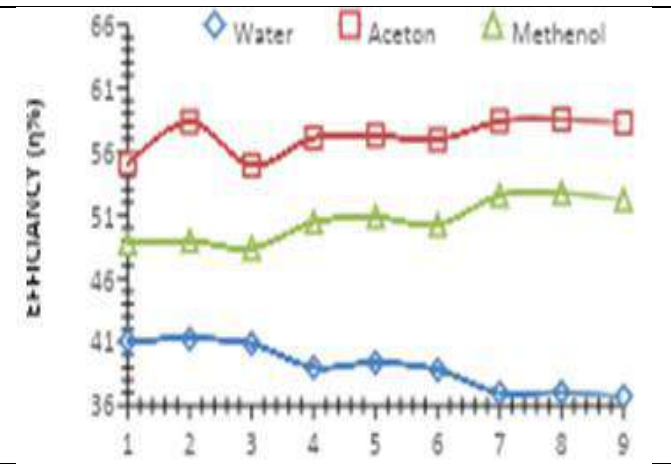


Fig. 10 Influence of a 0.0056 kg/s mass flow rate on a different working fluid

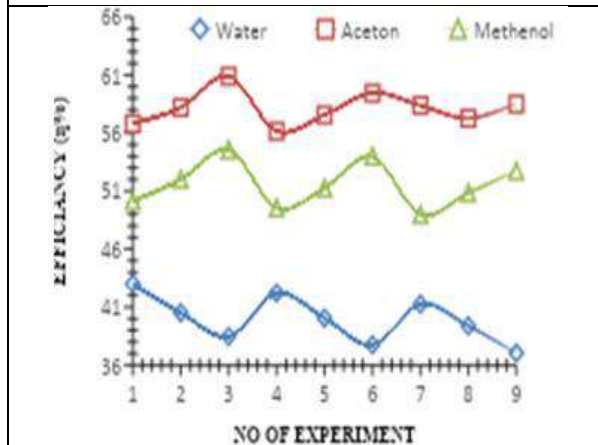


Fig. 11 Influence of a 35 Degree inclination on a different working fluid

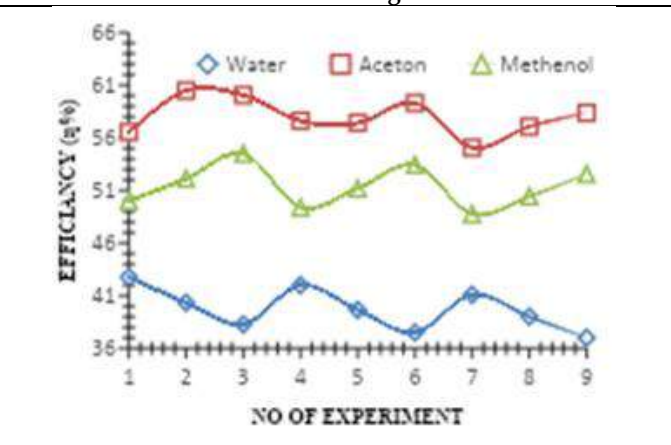


Fig. 12 Influence of a 25 Degree inclination on a different working fluid

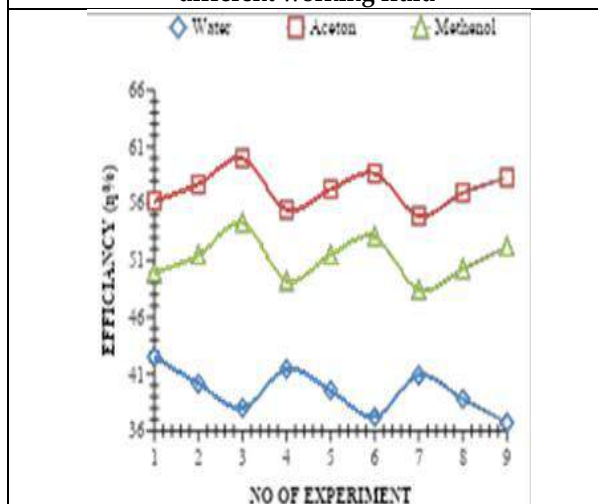


Fig. 13 Influence of a 45 Degree inclination on a different working fluid

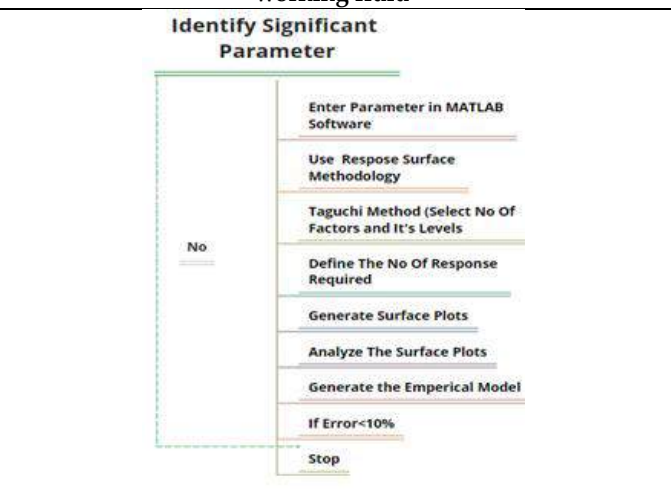


Fig. 14 Steps Taken for ANNOVA Analysis



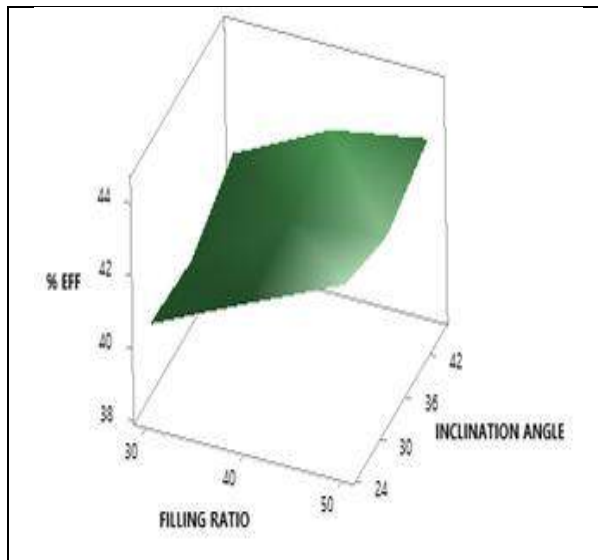


Fig. 15 Surface Plot of %Efficiency Vs Inclination Angle, Filling Ratio

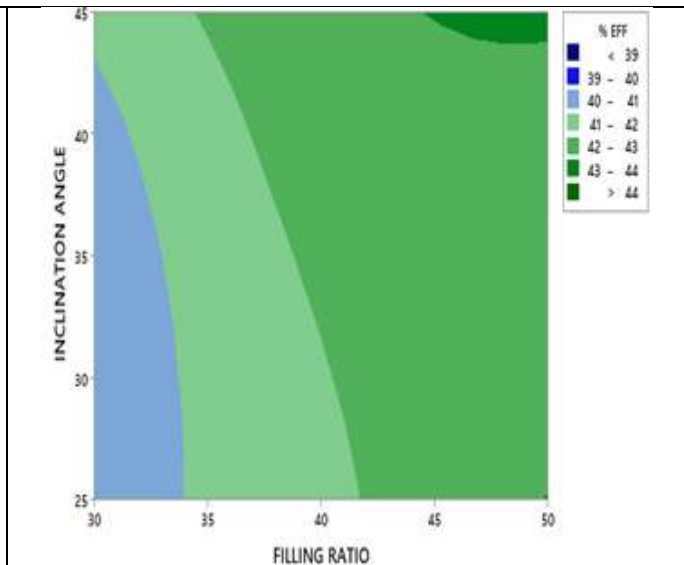


Fig. 16 Contour Plot Of %Efficiency Vs Inclination Angle, Filling Ratio

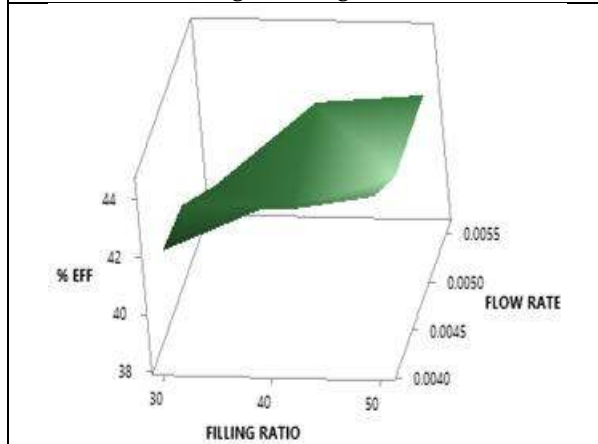


Fig. 17 Surface Plot of %Efficiency Vs Flow Rate, Filling Ratio

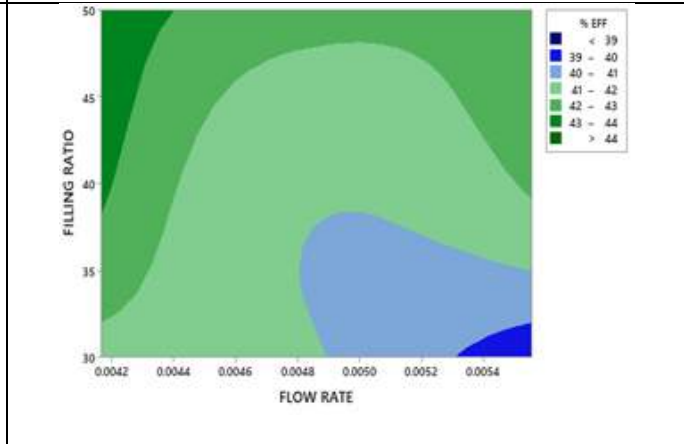


Fig. 18 Contour Plot Of %Efficiency Vs Flow Rate, Filling Ratio

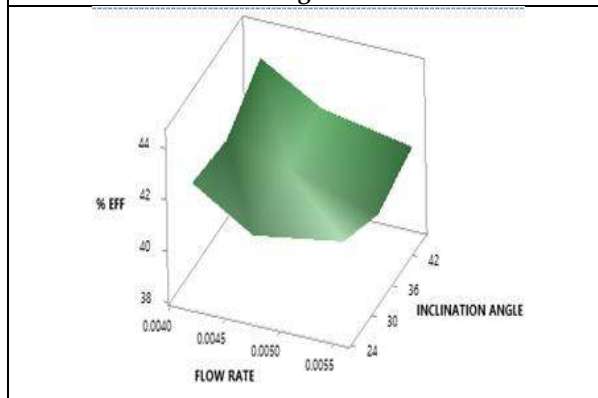


Fig. 19 Surface Plot of %Efficiency Vs Flow Rate, Inclination Angle

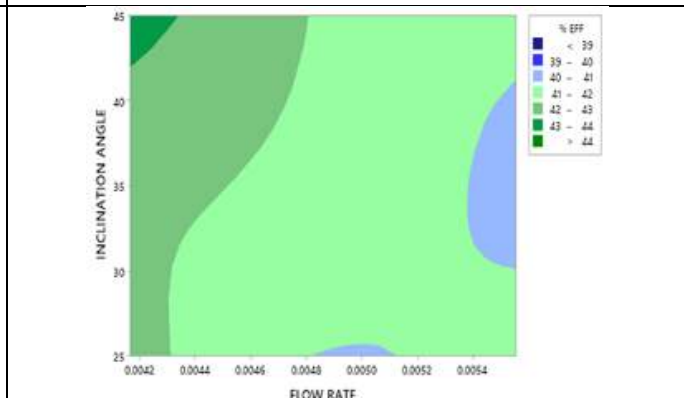


Fig. 20 Contour Plot Of %Efficiency Vs Flow Rate, Inclination Angle





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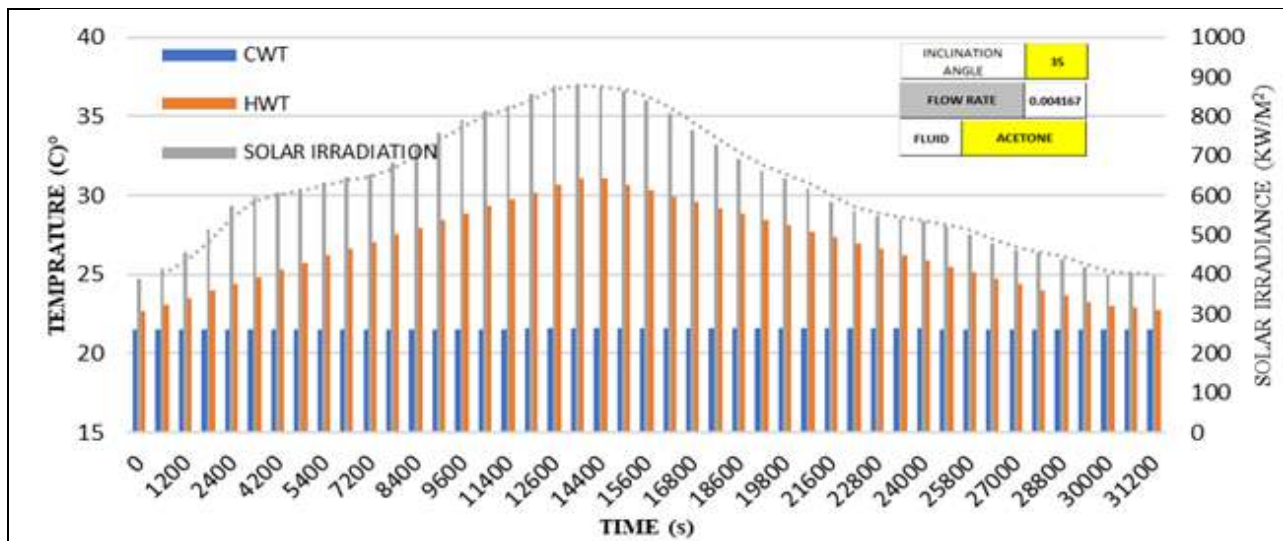


Fig 21: The Effect of Various Factors on Efficiency

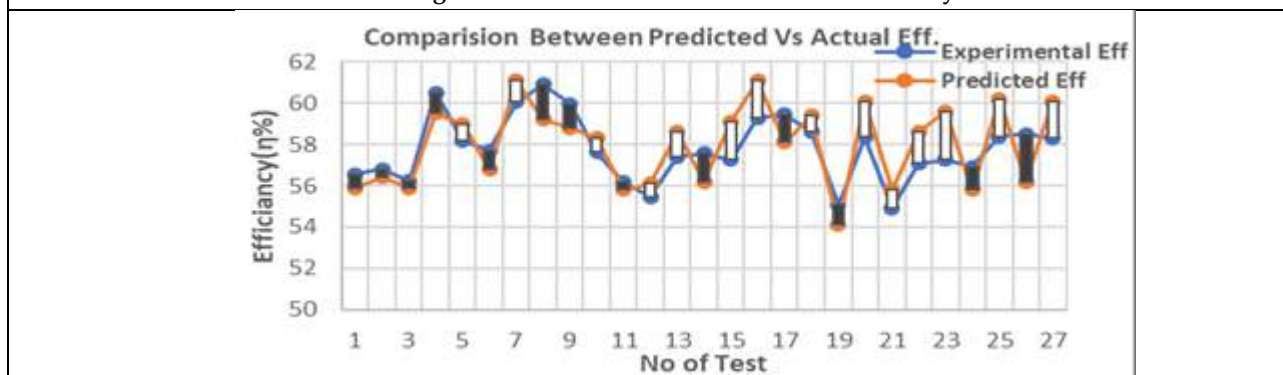


Fig 22: Optimization & Validation of the mathematical model

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RESEARCH ARTICLE

Effects of Dynamic-Static Stretching Versus Static Stretching with Myofascial Release for Hamstring Flexibility in Adolescent Cricketers : A Randomised Controlled Trial

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ABSTRACT

Before exercise, warm-up routines often include stretching protocols. This includes improving joint flexibility and reducing muscle stiffness, thereby improving the overall performance. The various stretching technique includes, static stretching (SS), dynamic stretching (DS), ballistic stretching (BS), and proprioceptive neuromuscular facilitation (PNF). To study the effect of dynamic and static stretching with myofascial release on hamstring flexibility of recreational cricket players. A four-week comparative study was conducted to evaluate the effectiveness of different interventions on hamstring flexibility. Hamstring tightness was measured using the Active Knee Extension Test (AKET) and the Sit and Reach Test, while lower limb strength was assessed through the Squat and Jump Test. Thirty recreational cricket players exhibiting hamstring tightness were selected and randomly assigned to two groups. Group A received a combination of dynamic and static stretching, whereas Group B underwent static stretching along with myofascial release therapy. Outcome measures were recorded at the end of the four-week intervention period. Results from within-group analysis showed significant improvements in hamstring flexibility in both groups. Group A demonstrated a mean improvement of 5.73° in the AKE test and 3.00cm in the Sit and Reach test ($p < 0.001$ for both), while Group B showed greater gains, with increases of 7.40° and 4.40 cm, respectively ($p < 0.001$ for both). However, both groups experienced a significant decline in Squat Jump performance: Group A by 6.27cm and Group B by 6.07 cm ($p < 0.001$ for both). Baseline comparisons confirmed no significant differences between



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groups in any outcome measure (AKE:p=0.205;SitandReach:p=0.948;SquatJump:p=0.312). Post-intervention, although Group B showed slightly greater improvements in flexibility, these differences were not statistically significant (AKE:p=0.621;SitandReach:p=0.152;SquatJump:p=0.147). Both the intervention showed significant results in improving hamstring flexibility. However, the lower limb power performance was found to be reduced in both the groups as evidenced by Squat Jump scores. **Conclusion:** This study examined the comparative effects of dynamic-static stretching and static stretching combined with myofascial release on hamstring flexibility in recreational cricket players with hamstring tightness. Over a four-week intervention, both methods significantly improved flexibility, as measured by the Active Knee Extension and Sit and Reach tests. Although the group receiving static stretching with myofascial release showed slightly greater gains, the difference was not statistically significant. However, both groups experienced a significant decline in Squat Jump performance, suggesting that increased flexibility may come at the cost of reduced explosive lower limb power. These results highlight the need to consider the timing of static-based interventions in performance-focused contexts. In conclusion, both approaches are effective for improving flexibility.

Keywords: Recreational players, Active knee extension test(AKET),sit and reach test, squat and jump test.

INTRODUCTION

Cricket requires a great deal of physical effort to play and includes extended periods of time engaged with short bursts of activity, including sprinting, bowling, and rapid movement [1]. Movement patterns specific to the sport include both concentric and eccentric muscular activity and include sudden shifts in joint angles and significant amounts of force produced; therefore, they are capable of producing tremendous amounts of mechanical and neuromuscular stress to the lower limb [2]. Of all lower body structures, the hamstrings (the semitendinosus, semimembranosus, and biceps femoris long head) play a vital role in performing hip extension, knee flexion, stabilizing the pelvis, and generating force while running and bowling [3,4]. This vulnerability results from the hamstring's unique bi-articular arrangement, postural function, and susceptibility to repeated high-tensile force and eccentric loading during high-speed running and the delivery stride in bowling [5]. The epidemiological data proves consistent with reports of high rates of lower limb injuries among cricketers (especially among youth and adolescent cricketers), with hamstring strain injuries being among the most frequently reported types of soft tissue injury at all levels of cricket [6]. Bowling and fielding are particularly dangerous activities that involve repetitive, explosive and high-speed movements [7-10]. There are several factors that contribute to the high incidence of hamstring injuries [11,12]. These include not just the anatomical structure of hamstrings but also the physical factors that may cause strain on these muscles [13,14]. Physical risk factors include a decrease in flexibility, a loss of muscle elasticity, inadequate preparation for physical activity, and underlying issues associated with fatigue, weakness, and imbalance in strength [15-18].

Flexibility is an essential element of fitness and provides optimal joint function and efficiency of movement and contributes to minimising an individual's likelihood of developing a musculoskeletal injury [19]. A decrease in flexibility of the hamstrings is associated with altered movement mechanics of the lower limb, decreased capacity to perform efficiently, and increased risk of muscle strain and overuse injury [20]. To maximise extensional capacity and minimise musculotendinous stiffness, stretch interventions are regularly implemented into warm-up and preconditioning programs of athletes [21]. Dynamic stretching has recently received increased recognition in terms of its ability to improve range of motion and enhance neuromuscular activation and the "readiness" of an athlete to perform at maximum capacity. It has been shown in research studies that dynamic stretching produces both



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immediate and long-term improvements in the range of motion of the hamstrings and decreases passive stiffness at the musculotendinous level; therefore, dynamic stretching is a tool used by many to prepare the hamstrings before physical exertion [22]. In recent years, self-myofascial release techniques (using foam rollers) have also been widely accepted as a means to increase muscle flexibility, similar to static stretching, by improving the elastic properties of the tissue, reducing restriction of the fascia, and increasing the tolerable amount of stretch during the exercise [23]. Other studies have shown that when using static stretching or self-myofascial release, both methods produce significant improvements in hamstring flexibility [24]. Therefore, it may be beneficial to combine these two techniques to take advantage of the benefits that each can have on the overall effectiveness of the program. However, very few studies have directly compared the effect of combined static stretching with dynamic stretching and myofascial release techniques on performance in adolescent recreational athletes. Thus, this experimental comparative study aims to assess and compare the effectiveness of static stretching and dynamic stretching, as well as static stretching and myofascial release, on the flexibility of the hamstrings in adolescent recreational cricket players, with the hypothesis that there will be a marked difference between the two treatment protocols.

MATERIALS AND METHODS

Study design

This research was designed as a randomised clinical trial that received ethical approval from the Institutional Ethical Committee. The study was conducted over a six-month period from May to August 2025. The study complies with the CONSORT extension reporting guideline [25] and the TIDieR checklist for reporting of interventions [26]. This is depicted in **Table 1**.

Sample Size Calculation

Using G*Power software, a sample size calculation was performed using previously reported effect sizes for hamstring flexibility studies. The α level of 0.05 and a power of 80% determined a minimum number of 24 participants [22]. To compensate for possible attrition, 30 participants were recruited for this study.

Study setting

The subjects were taken from the college who had been playing cricket for the past year. A total of forty-eight male cricket players who were actively engaged in regular training were initially screened to determine their eligibility.

Eligibility Criteria

Inclusion criteria targeted individuals willing to participate, aged 10 to 25 years, only males, and a playing experience for more than 1 year. All the players, such as batsmen, bowlers, and fielders, were recruited. Exclusion criteria consisted of individuals who had experienced any musculoskeletal injuries, such as injury to the spine or lower limb, any fracture/dislocation or any surgical history of the lower extremity or spinal region within the previous year, or congenital anomalies of the lower extremity or spine [22].

Screening Procedure

The initial screening phase used the Active Knee Extension (AKE), [27] sit and reach test [28] and squat and jump test [29] to identify whether participants had hamstring muscle tightness. Participants with hamstring tightness reported from the screening phase subsequently participated in this research project with an evaluation conducted on both the baseline and the conclusion of the 4-week exercise program with the same evaluation tools used at the screening stage.



**AKE test**

For AKE, the subject was asked to lie supine; the hip being tested was at 90 degrees of flexion and was stabilised in that position while the opposite leg was extended. A goniometer was placed on the outside of the knee (lateral femoral condyle) while the subject actively extended their knee from 90 degrees (from being bent) until they felt a firm resistance. The subject held this position for 2-3 seconds, and knee extension range of motion (ROM) was measured in degrees. The test was repeated after a one-minute rest period [27].

Sit-and-reach test

The sit-and-reach test assesses the flexibility of hamstrings and other posterior chain muscles; for this, the participants were asked to sit on the floor with their legs straight and reach forward as far as possible. The distance reached was recorded to assess flexibility, with longer reaches indicating greater flexibility [28].

Squat and Jump (SJ) test

For the static SJ test, the participants were asked to 'pause' in a flexed, semi-squat position for several seconds before initiating the upward/concentric phase and jump [29]. All outcome measures used in the present study have demonstrated good to excellent reliability in previous literature, with reported intraclass correlation coefficients ranging from 0.78 to 0.97 for the AKE test, >0.90 for the Sit-and-Reach test, and >0.85 for squat and jump-based performance assessments, supporting their suitability for evaluating hamstring flexibility and lower-limb function in athletic populations [27-29]

Participants flow and attrition

Out of 48 participants screened, 30 players met the inclusion criteria. All of them completely agreed and willingly signed the written consent. The subjects were randomly divided into 2 groups. Group A was given dynamic and static stretching, & Group B was given static stretching with myofascial release. This procedure was followed for 4 weeks. A post-assessment of the subjects was taken at the end of 4 weeks. Consequently, a total of 30 participants completed the entire study and supported analyses of the outcomes. This is depicted in **Figure 1**. **Table 2** exhibits the demographic details of the patients.

Intervention Protocol**Static stretching**

Static stretching of the hamstring muscles was performed following dynamic stretching (Group A) or as part of the combined protocol with myofascial release (Group B). Participants were positioned in a long sitting posture with knees fully extended and the trunk upright. They were instructed to slowly bend forward from the trunk while reaching toward the toes until a comfortable stretch was felt in the posterior thigh region [30].

This procedure is depicted in **Figure 2a**.

Dynamic stretching

Dynamic hamstring stretching was conducted with functional, controlled mobility to prepare the muscles through controlled mobility with functional movements. Participants were instructed to stand with their correct postural alignment and perform dynamic hamstring stretches that included controlled forward stepping and hip flexion-extension movements. The limbs were moved in a rhythmic fashion through the available range of motion without bouncing to ensure the motions were smooth and continuous [30]. This procedure is depicted in **Figure 2b**.

Myofascial Release

The participants sat in a long sitting position, and their tested limb had a foam roller placed beneath its hamstring region. The participants used both their lower and upper limbs to stabilize themselves while rolling, as they had to maintain their balance. Participants were instructed to use their body weight to create pressure and to roll slowly and in a controlled manner from the ischial tuberosity to the posterior aspect of the knee. The pressure used was adjusted to each participant's comfort level; however, it was supposed to be not painful or uncomfortable for participants [31].





This procedure is depicted in **Figure 2c**.

Group A: Static and Dynamic Stretching

- 3 repetitions with a 30-second hold, each separated by 15 seconds of rest.
- 3 days per week.

Group B: Static Stretching with Myofascial Release

- Static stretching of 3 repetitions with a 30-second hold followed by myofascial release; the rolling duration was set at 30s each for 4 sets separated by 30s of rest.
- 3 days per week.

Statistical Analysis

The data was analysed using SPSS Version 20. Shapiro-Wilk test was used to determine the normality of the data. Since the data was found to be normally distributed, parametric tests were used to compare the means of pre- and post-intervention values for statistical significance ($p < 0.05$).

RESULTS

Descriptive Statistics

Descriptive statistics at baseline for all outcome measures, indicating the presence of hamstring tightness in the participants, are displayed in **Table 3**. These values from baseline served as reference points to all other comparisons.

Within-Group Comparisons

Paired sample t-tests were conducted to examine pre- to post-intervention outcome measure changes. Statistically significant changes were identified following the intervention for Group A (Static and Dynamic Stretching) as demonstrated in **Table 4**. There was an average increase of 7.40 degrees ($p < 0.001$) in the AKE angle, a mean increase of 4.40 cm ($p < 0.001$) in the Sit and Reach test, and an increase of 6.07 cm ($p < 0.001$) with the SJ test revealing the improvement of hamstring flexibility and lower limb performance due to the intervention. Statistically significant changes were also found post-intervention, as evidenced by the results presented in **Table 5** for Group B (Static Stretching and MFR). There was an average increase of 7.40 degrees ($p < 0.001$) in the AKE angle; there was a 4.40-cm ($p < 0.001$) increase in Sit and Reach; SJ test increased by 6.07 cm ($p < 0.001$). These results confirm the benefit of static stretching and myofascial release in improving lower limb flexibility and performance.

Between group comparisons

Outcomes from the two groups were evaluated using independent t-tests. There were no significant statistical differences between the groups in baseline measures of Active Knee Extension, Sit and Reach, and Squat and Jump ($p > 0.05$), meaning both groups were similar in regard to these measures before the start of the intervention (**Table 5**). For AKE ($p = 0.621$), Sit and Reach ($p = 0.152$), and Squat and Jump ($p = 0.147$). These results indicate that both interventions were equally beneficial for improving hamstring flexibility and functional performance.

DISCUSSION

The present research examined the comparative efficacy of dynamic and static stretching versus static stretching with myofascial release for improving hamstring flexibility and lower limb performance in recreational cricket players with tightness in their hamstrings. After four weeks of treatment, both groups showed statistically significant improvements in their level of flexibility as indicated by the mean total scores for the AKE and sit and reach tests of the participants. This supports the findings of previous studies that indicated the usefulness of both dynamic and static stretching in addition to myofascial release in enhancing muscles' flexibility. Dynamic stretching, which was incorporated into Group A's intervention protocol, has been found to provide more prolonged exposure to the increased benefits of enhanced hamstring flexibility and decreased muscle stiffness compared with either static



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stretching or myofascial release alone. The Iwata et al. study demonstrated that dynamic stretching improved R.O.M. and decreased passive mechanical stiffness in the hamstring immediately after exercise, with benefits lasting as long as 90 minutes post-treatment. These findings may explain why Group A had greater increases than Group B for both AKE (5.73°) and sit and reach (3.00 cm). Conversely, Group A's significant improvement in flexibility was not associated with an enhancement of Squat Jump performance, which is consistent with earlier research showing static stretching (particularly before power-oriented activities) limits neuromuscular output and results in decreased explosiveness when empowering dynamic actions into a power-oriented movement. Thus, the inclusion of both forms of stretching may explain why Group A did not achieve the expected enhancements to their performance for squat jump as a result of the dynamic component of their protocol as compared to the static component of their protocol due to the inhibiting effects of adding static to the dynamic component of their protocol[28].

While Group B (the group that received static stretching and myofascial release) witnessed a significantly greater increase in flexibility (average AKE increase of 7.40°; average Sit and Reach increase of 4.40 cm) as compared to Group A, these findings provide additional support for prior research by Lokesh et al., where myofascial release via foam rolling has been shown to improve flexibility similarly to static stretching. In addition, the inclusion of MFR likely facilitated increased mobility of soft tissue and decreased restrictions of fascia (the connective tissue surrounding muscles), providing an opportunity for increased flexibility to occur. However, it is important to note that the drop in Squat Jump performance shown by Group B (as well as Group A) indicates that although myofascial release aids flexibility there may be no compensatory effect on the performance limitations created by static stretching within the same session.

There were no statistically significant differences between groups regarding any of the outcome measures, suggesting that both strategies were equally successful. While Group B did show slightly greater improvements in flexibility than Group A, none reached statistical significance. These findings support the findings of a systematic review and meta-analysis by Medeiros et al. (2015), concluding that static stretching increases hamstring flexible significantly, but evidence of how well it works in conjunction with myofascial release or dynamic stretching is still uncertain [32]. Thus, the current study found both to demonstrate similar levels of effectiveness and therefore no preference for either approach. In conclusion, this study supports using both dynamic-static stretching and static stretching with myofascial release as effective ways to enhance hamstring flexibility in recreational athletes. Further research is needed to explore these findings in a cricket-specific context. Future studies should include larger groups of cricket players at various skill levels to better generalize the results. Additionally, future research should explore training interventions that simultaneously improve hamstring flexibility and lower limb power development. Such studies will help create a better understanding of how to enhance performance while reducing injury risk in cricket players.

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Table 1: TIDieR Checklist for reporting of interventions[26]

Item number	Item	Description
1.	Brief name	Dynamic-static stretching vs static stretching with MFR for hamstring flexibility
2.	Why	Hamstring tightness is highly prevalent among cricket players and is a recognised risk factor for lower-limb injuries. Even though, there are various stretching techniques involved in improving the hamstring flexibility, still there is a lack of evidence comparing the effect of static-dynamic stretching v/s static stretching with MFR in improving hamstring flexibility in recreational cricket players
3.	What (Materials)	Consent form, assessment form, measuring tape, universal goniometer, sit-and-reach box, foam roller, stopwatch, plinth, mat
4.	What (Procedures)	Group A received dynamic stretching followed by static stretching of the hamstring muscles. Group B received static stretching followed by self-myofascial release using a foam roller targeting the hamstrings.
5.	Who provided	Provided by a trained physiotherapist
6.	How	One-on-one, therapist-guided and supervised intervention
7.	Where	Musculoskeletal Physiotherapy OPD, Nootan College of Physiotherapy, Sankalchand Patel University, Visnagar, Gujarat, India
8.	When and how much	Conducted for 4 weeks, 3 sessions per week
9.	Tailoring	Stretch intensity and pressure during myofascial release were adjusted based on individual tolerance
10.	Modifications	No modifications
11.	How well (Planned)	Regular attendance was taken.
12.	How well (Actual)	30 participants fully completed the intervention period.

Table 2: Demographic details of the participants

Variable	Group A (n = 15) Mean ± SD	Group B (n = 15) Mean ± SD
Age (years)	21.0 ± 1.3	21.6 ± 1.2
Height (cm)	171.6 ± 4.0	173.3 ± 4.9
Weight (kg)	68.7 ± 9.3	61.3 ± 8.5
BMI (kg/m ²)	22.7 ± 2.6	20.7 ± 2.7





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Table 3: Descriptive Statistics for active knee extension, sit and reach test, squat and jump test.

	N	Minimum	Maximum	Mean	Standard Deviation
Activeknee extension(degree)	30	27	48	38	5.414
Sit and reach (cm)	30	18	27	22.50	2.751
Squat and jump (cm)	30	34	42	37.10	2.310

Table 4: Within-Group Comparison of Outcome Measures (Paired Sample t-test)

Outcome Measure	Group	Mean Difference (Pre-Post)	Std. Deviation	Std. Error Mean	t-value	p-value	Significance
Active Knee Extension (°)	A & B	7.40	1.055	0.273	27.151	0.001	Significant
Sit and Reach (cm)	A & B	-4.40	0.632	0.163	-26.944	0.001	Significant
Squat and Jump (cm)	A & B	-6.07	0.799	0.206	-29.414	0.001	Significant

Table 5: Between-Group Comparison of Outcome Measures (Independent Sample t-test)

Outcome Measure	Time Point	Mean Difference	Std. Error	t-value	p-value	Significance
Active Knee Extension (°)	Pre-intervention	-2.533	1.954	1.126	0.205	Not significant
Active Knee Extension (°)	Post-intervention	0.867	1.734	-0.500	0.621	Not significant
Sit and Reach (cm)	Pre-intervention	-0.067	1.022	-0.065	0.948	Not significant
Sit and Reach (cm)	Post-intervention	-1.467	0.997	-1.471	0.152	Not significant
Squat and Jump (cm)	Pre-intervention	0.867	0.843	1.029	0.312	Not significant
Squat and Jump (cm)	Post-intervention	1.067	0.715	1.492	0.147	Not significant



Figure 1: Static Stretching





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Figure 2: Dynamic Stretching



Figure 3: Myofascial Release

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CASE STUDYARTICLE

Homoeopathic Management of Recurrent Follicular Tonsillitis Complicated with Psychological Trauma - A Clinical Case Study

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ABSTRACT

Plants act as a basic source in preparation of Homoeopathic remedies, they go through a tailored procedure of potentization which transform crude botanical material into dynamic Homoeopathic preparation. As per Homoeopathic literature, these dynamic preparation directly act upon Vital force as per Homoeopathic principle i.e. Similia Similibus Curentur (like cures like). Homoeopathy sustain innate association with botanical/natural sciences by scrutinizing that each plant have its own structural and functional characteristics that closely similar to specific therapeutic application this concept termed as Doctrine of Signature. Pulsatilla pratensis from Ranunculaceae family illustrate this principle. The plant have distinctive features like velvet, bell shaped, pendulous delicate flowers with soft hairy appearance. In Homeopathy these botanical characteristics correlate constitutionally with "*Pulsatilla pratensis*"- Individuals with blond hair, blue eyes, fair complexion, gentle appearance, emotionally delicate and a inclination towards weepiness. Therefore, this case study show the therapeutic application of Pulsatilla in 200 potency in "recurrent follicular tonsillitis" prescribed on the basis of patients botanical constitutional alliance. This approach show the integration between clinical evidence based classical homoeopathic approach with natural science, therefore contributing in expanding evidence based homoeopathic research.

Keywords: Ranunculaceae, Pulsatilla Pratensis, Homoeopathy, Tonsillitis.



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INTRODUCTION

Follicular tonsillitis is an acute infection of the palatine tonsils, commonly caused by *Streptococcus pyogenes*. It is characterized by enlarged tonsils with yellowish-white follicular exudates, accompanied by sore throat, fever, and pain on swallowing.^[1] *Pulsatilla Pratensis*, a well-known homeopathic medicine derived from a perennial herb of the family Ranunculaceae, has been extensively described in classical materia medica for its wide therapeutic applicability. Botanically, The plant contains active constituents such as protoanemonin, which are responsible for its pharmacological and toxicological properties in crude form.^[2] In homeopathic literature, *Pulsatilla* in its potentized dynamic form traditionally indicated in conditions presenting with marked changeability of symptoms, mild and yielding disposition, and aggravation in warm environments with relief in open air. Its sphere of action predominantly includes the respiratory, gastrointestinal, and female reproductive systems.

Case Study

A 20 yearold female patient reported in hospital OPD on 10th December 2025 presented with complaints of terribly enlarged tonsils with redness, burning, hoarseness, scraping sensation in throat, difficulty in swallowing liquids/solid food and even saliva since 4 years.

History of presenting complaints:

Patient approached to OPD with a complaints which commenced 4 years back as after eating fried/oily food, ice-cream, cold food and drinks her tonsils get severely hypertrophied with intense inflammatory redness with white pus filled spots appear like pearls, burning pain with scraping sensation, difficulty in swallowing even saliva and high fever (102 degree F). She has been on allopathic medication from 4 years but the complaints were only suppressed and reappear when eat anything cold, oily, greasy food. Weeping also trigger enlargement of tonsils. She had first episode at the age of 17 years after she ate lots of fried food and cold items like ice-cream, juices in a house gathering party.

Conventional Treatment and Medication History:

Patient consumed conventional medication (Cephalexin 75mg/kg orally twice daily) over 6-8 months for follicular tonsillitis. Despite of consuming medication for so long there was constant recurrent episodes of follicular tonsillitis prodding her to switch for constitutional homoeopathic medication.

Physical Symptoms:

The patient showed reduced appetite, primarily due to constant throat pain during swallowing. A strong aversion to sour foods- specifically curd and buttermilk. Thirst is reported to be diminished, with water intake confined to around twice per day, precisely for cold water regardless of sensitivity to chill. Perspiration is significantly noted over the top lip and axillary region. The patient illustrate a fluctuating desire for food with continual variations in taste preferences- mainly incessant craving for fried and street food.

Psychological Profile/Mental Symptoms:

The patient reported marked emotional delicacy towards reprimand, and show a tendency to cry despite corrected in a gentle tone. Susceptible to high pitched raised voices or scolding that activate psychological responses include:

- Uncontrollable weeping,
- Sensation of chest heaviness
- Accelerated breathing with respiratory agony
- Inability to enunciate speech clearly
- Chest pain with trembling of extremities
- Extreme fear and anxiety of being physically harm



**Riya Jodha and Deepti Sharma****Trauma History:**

Her psychosocial antecedent disclose a history of a violent family atmosphere, with a father who was addicted to drink alcohol daily and show abusive, harsh behavior toward her mother. Furthermore, the patient also illustrate a personal history of physically abused by her father, which give rise to her current disposition marked by fear of reprimand, timidity, and a strong weeping tendency. Emotionally, she expresses extreme desire for love, attention, affection and consolation, specifically during episodes of distress, which remarkably relief her symptoms. In a familiar, social and supportive atmosphere, she is cheerful, talkative, and maintains a pleasant behaviour. Anger is mainly expressed by weeping, and symptomatic amelioration is noticed following consolation. She express anxiety and aversion towards doctors, hospitals, blood, injections, and corpse, which may produce giddiness and intensified anxiety (described sensitive core) Additionally, she exhibit ravenous eating, specifically of fried food, during episodes of emotional disturbance and weeping. It was observed that her eyes filled with tears while telling her mental sufferings.

Provisional Diagnosis:

Follicular Tonsillitis

Diagnostic criteria:

Several of the complaints like enlarge tonsils, red inflamed tonsils with white pus filled pearly spots, burning pain, difficulty while swallowing even saliva, high grade fever indicate diagnosis towards follicular tonsillitis.

Repertorial approach:

In Homoeopathy repertorization is a systematic, evidence based structured process of analyzing symptoms of patient using a software termed as repertory (an armamentarium of symptoms as rubrics and remedies) to select the most effective and suitable homoeopathic medicine.

Homoeopathic intervention with justification:

Pulsatilla Pratensis 200C (Stat Dose) was prescribed based on patient's heightened sensitivity, totality of symptoms and systematic repertorization (Fig 1.1) and overall constitutional profile. Although remedies such as *Lycopodium clavatum*, *Calcarea carbonica* and *Sulphur* covered an equal number of rubrics (six) in the repertorial analysis, they were excluded. In accordance with homoeopathic principle *similia similibus curentur*, these remedies does not correspond to the patient's characteristic mental, emotional disposition and physical general, whereas *Pulsatilla pratensis* demonstrated the closest similitude.

DISCUSSION

In Homoeopathy according to Dr. Rajan Sankaran's model, plant remedies are characterized by heightened sensitivity and reactivity. Patients requiring plant remedies often exhibit emotional expressiveness, rapid mood changes, and strong responses to external stimuli such as criticism, consolation, or environmental factors (like in this case weeping is a constant immediate response)[4] In the present case *Pulsatilla Pratensis*, a plant based remedy, exhibits a soft structure with soft pendulous flowers which readily sway in the direction of wind. This characteristic correlates with the patient's marked physical and emotional changeability. The plant thrives in well drained sandy soil, which may be associated with the patient's thirstlessness. Furthermore, *Pulsatilla* typically prefer habitats with nearby trees that offer protection from frost. Paralleling the patients sensitivity towards chilliness.[5] Thus, the morphological attributes of *Pulsatilla Pratensis*, demonstrate a close correspondence with the patients symptomatology, supporting its selection in accordance with homoeopathic principles.





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CONCLUSION

This clinical evidence based case study contribute to the homeopathic literature by methodically documenting the implementation of constitutional prescribing in recurrent follicular tonsillitis intricated with psychological sufferings/trauma. The distinctive coalition between the patients multi-dimensional picture and prescription of constitutional pulsatilla guided by botanical knowledge, psychological understanding and homoeopathic indications- exhibit clinical effectiveness of this approach in finding homoeopathic simillimum.

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Table 1: Tabulation of follow up details

Follow up visit date	Indications	Medication with dose
26/12/25	Fear of reprimand ⁺³ Anxiety signs after reprimand ⁺³ Timidity, Weeping disposition ⁺³ Fear of different things ⁺³ Tonsils red and inflamed, pustular spots ⁺³ Craving fried food ⁺³ Throat pain on swallowing ⁺² Appetite and Thirst reduced ⁺²	Pulsatilla Pratensis 200 (Stat dose)
10/01/26	Fear of reprimand ⁺³ Timidity, Weeping disposition ⁺³ Fear of different things ⁺³ Anxiety signs after reprimand ⁺² Tonsils red and inflamed, pustular spots ⁺² Craving fried food ⁺² Throat pain on swallowing ⁺¹ Appetite and Thirst reduced ⁺¹	Rubrum 30 (4-0-4-0)
25/02/26	Fear of reprimand ⁺³ Timidity, Weeping disposition ⁺³ Fear of different things ⁺³ Tonsils red and inflamed ⁺² Pustular spots ⁺² Craving fried food ⁺¹ (eat homemade food on frequent basis)	Rubrum 30 (4-0-4-0)





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12/03/26	Anxiety signs after reprimand ⁺¹ Fear of reprimand ⁺³ Timidity, Weeping disposition ⁺² Fear of different things ⁺² Pustular spots ⁺² (No change)	Pulsatilla Pratensis 200 (Stat dose)
27/03/26	Fear of reprimand- improved Timidity- reduced Weeping disposition- decreased in frequency and intensity Fear of different things significantly reduced Pustular spots ⁺²	Rubrum 30 (4-0-4-0)

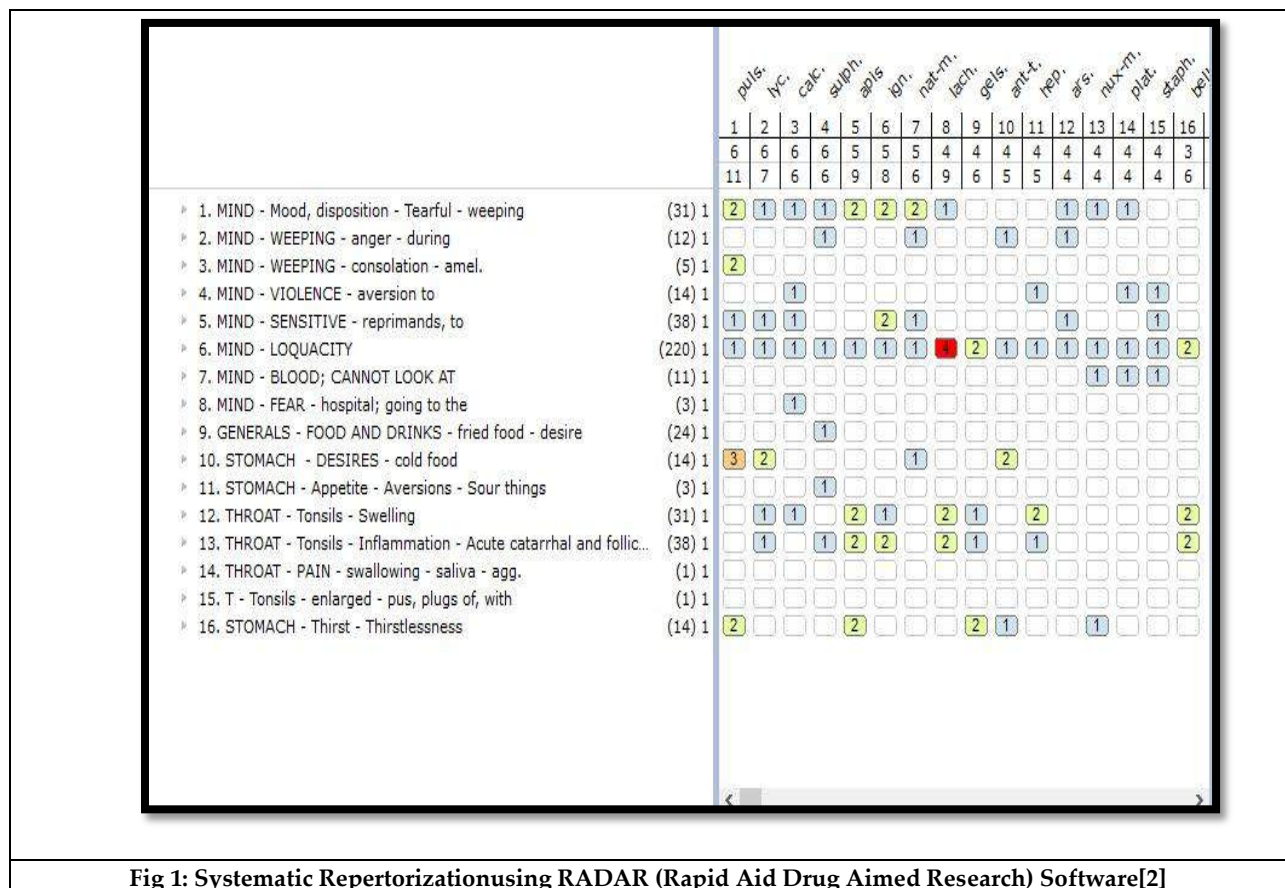
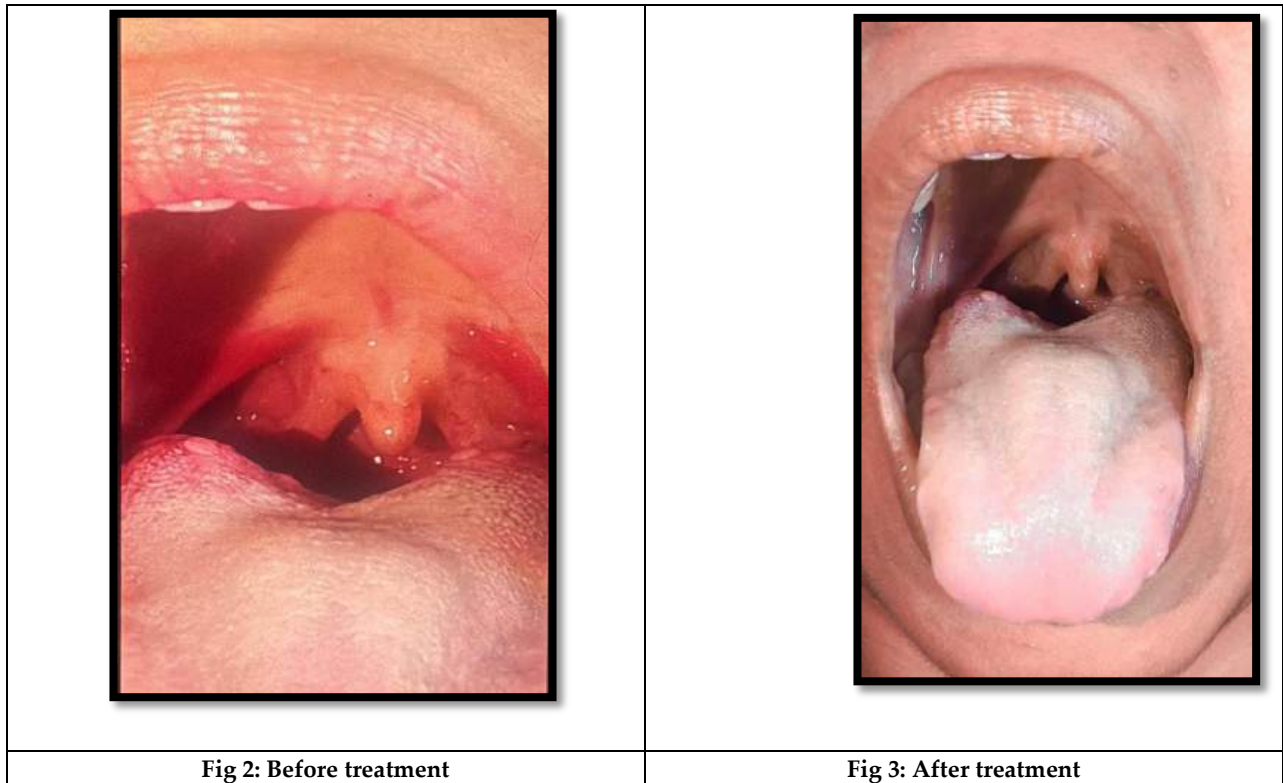


Fig 1: Systematic Repertorization using RADAR (Rapid Aid Drug Aimed Research) Software[2]





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RESEARCH ARTICLE

A Multilingual, Clause-Aligned Corpus of the Constitution of India

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ABSTRACT

This paper describes the first multilingual, clause-aligned parallel corpus of the Indian Constitution in all 22 scheduled languages and English. By combining official ground truth texts with neural translation and an innovative hybrid alignment strategy, we achieve granular precision to fill a critical gap in domain-specific Indic NLP resources. We provide a quantitative analysis of the statistics of alignment and discuss linguistic concerns such as "system-bound terms" and the problem of the "authoritative text." Finally, we show the utility of this corpus for legal MT and cross-lingual legal information retrieval (CLIR), forming a foundational resource for computational jurisprudence in India.

Keywords: Legal NLP, Parallel Corpus, Indic Languages, Constitution of India, Machine Translation, Clause Alignment, CLIR

INTRODUCTION

The Constitution of India is the highest law in the land, detailing schemes of governance and fundamental rights. Eminently linguistic, it recognizes 22 scheduled languages in the Eighth Schedule. But there lies a gap between this ideal and reality. While India speaks over 780 languages, the Supreme Court and High Courts function essentially in English—a barrier to justice. Judgments have begun to be published in regional languages, but this drive has revealed a bottleneck: the lack of superior computational tools and datasets in the Indian legal domain [19, 21]. There does not exist a parallel corpus of the Constitution in its original form across languages. While general-domain corpora have been developed as part of Indic NLP, none of them contain the entire Constitution aligned at a fine granularity across 22 languages. To bridge this gap, we present the first-ever clause-aligned parallel corpus of the Constitution of India, serving as a fundamental building block for the next generation of legal-tech applications.



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LITERATURE REVIEW

The paper is situated at the intersection of huge-scale Indian-natural language processing and advanced legal informatics, and multilingual corpus/dataset development. The necessity of such a corpus can be well-understood when one considers the constitution requirement in light of the deficiencies of extant data sets.

Motivation: Multilingual Mandate and the Accessibility Gap

The Constitution of India prescribes a complex linguistic arrangement. Against the backdrop of Part XVII (Articles 343–351) and the Eighth Schedule, explicitly recognizing 22 languages and making provisions for their development, Article 348(1) restricts the conduct of proceedings in the Supreme Court and High Courts in English. This generates a significant "accessibility gap" for the majority of its citizens. The President of India has identified language as a primary barrier to justice [9], and many top-down drives have been initiated from the Supreme Court to translate its judgments. This top-down drive, however, is symptomatic of a severe paucity of domain-specific computational tools. Unlike the European Union, which depends on the JRC-Acquis for multilingual legal processing [28], India does not have a foundational, granularly aligned corpus of its supreme legal document to train such systems raising ethical concerns regarding equitable access to justice [23].

Prior Art: General vs. Legal Corpora

The recent progress in Indic NLP has been tremendous but still not enough for the legal domain.

General-Domain Corpora: The AI4Bharat effort created the Bharat Parallel Corpus Collection, which made models such as IndicTrans2 possible [10]. Although very large (230M pairs), BPCC is derived from Wikipedia and web text, without the complex syntax of legal text. In addition, it is only sentence-aligned, which does not allow for the much more complex, multi-clause structure of many legal provisions, despite recent efforts to benchmark Indic languages [14]. Recent advances in general-domain multilingual NLP have shown remarkable progress in low-resource language modeling [26], and cross-lingual transfer learning techniques have demonstrated the potential for improving machine translation quality across language families [27]. However, these advances have not been systematically applied to domain-specific legal corpora, particularly for constitutional texts with their unique structural and terminological characteristics.

Legal Domain Corpora: The benchmark MILPaC, specific to law, provides a parallel corpus for Indian Acts [4]. Yet, it suffers from three limitations: 1) it covers only 9 of the 22 scheduled languages; 2) the Constitution itself is left out; and 3) It uses sentence-level tokenization, which is insufficient for parsing the hierarchical clause structures crucial for correct legal interpretation. While there are monolingual legal datasets, such as HLDC [12], and even pre-training tasks [13], the parallel alignment is missing for performing translation. Recent research on analyzing legal texts in Indian scenarios indicates the difficulty of performing natural language processing due to the complex nature of legal documents, as standard methods fall short of capturing the hierarchical structures involved in these documents [29]. Moreover, studies on legal information retrieval systems stress the importance of building domain-specific models with the knowledge of legal language and citations [30]. Our work bridges these gaps by providing the very first dataset that is not only comprehensive (for all 22 languages), domain-specific (constitutions), and finely aligned at the clause level but also outperforms LEGAL-BERT [25] which is mainly built using English-only data. With the rise of research interest in developing multilingual legal resources, parallel corpora have emerged as essential resources for building cross-lingual legal systems [31]. The proposed methodology in our paper considers recent work on aligning specialized legal language documents structurally and carefully [18].





METHODOLOGY

The dataset was developed with the help of a 3 phased pipeline to ensure fidelity and maximum language alignment. Legacy sentence alignment techniques used to fail due to the complex structure of legal language. We therefore employed a combination of automatic language parsing and "human-in-the-loop" technique.

Phase 1: Data Collection and Preparation

The fundamental "ground truth" texts were taken from the Legislative Department of the Government of India, we downloaded the official latest constitution from the official government for India. The initial dataset was available in the PDF format, which required comprehensive processing to transform it into a computer linguistics readable format.

Text Extraction: The PDF file was converted into a structured CSV file. Continuous text was necessary for this process, hence we removed headers, footers, and page numbers from the text.

Normalization: Unicode normalization was adopted to ensure standardization between the 22 Indic scripts.

Structural Tagging: High-level tags such as Parts, Articles, and Schedules were tagged prior to the alignment stage. This resulted in a "skeleton" of the dataset that followed the hierarchical structure of the initial document.

Phase 2: Translation Pipeline and Verification

We designed a machine-centric pipeline using the most advanced models to fill in the gaps due to lack of digitization in this particular area of Indic Natural Language Processing.

Neural Translation: We utilized high quality translation interface to generate possible translations of the source text in English. For each of the accepted 22 scheduled languages in the constitution of India, this provided a strong baseline.

Semantic Verification: The pipeline included a secondary verification pass by semantic similarity verification. We applied back-translation and semantic similarity scoring to locate instances of "semantic divergence/meaning divergence." This allowed us to red- flag the sections for human expert review where the machine output could have been substantially different in legal meaning from the source text.

Phase 3: Hybrid Alignment Algorithm

The core contribution of our work is to develop a novel hybrid alignment approach to solve the years old problems in standard sentence-aligned corpus/paragraphs. Legal texts often have "1:N" or "M:N" relationships between clauses, where one English clause corresponds either to multiple Indic clauses or vice versa, and that simple sentence splitters fail to capture the semantic meaning [18].

Structural Hierarchical Parsing: The approach first aligns at the macro-level text by parsing the constitutional hierarchy, that is, Parts, Articles, and Schedules. This means an article in the English language will be strictly matched with the corresponding article in the target language, thus setting a hard boundary for alignment.

Lexical Anchoring: Within these hard boundaries, we used lexical anchoring. The algorithm identifies invariant markers—specific legal terms that remain consistent across languages, such as article numbers and clause indices, for example "(a)" and "(1)," and specific phrases like "non-obstante" clauses, for example, "Notwithstanding anything in this article." The high complexity of structural word alignment in legal texts: our algorithm combines structural hierarchical parsing of parts, articles, and schedules with lexical anchoring through invariant markers like article numbers and "non-obstante" clauses to resolve complex 1:N and M:N clause relationships [18].

RESULTS AND DISCUSSION

Quantitative Analysis

Table 1 and Table 2 represent corpus volume and lexical richness, respectively. The data indicates that vocabulary size and corpus volume are negatively correlated. Urdu and Dogri are most verbose (close to 89,000 tokens),





reflecting their analytic structure. Malayalam, on the other hand, has the largest unique vocabulary of 9,842 words despite being compact (close to 48,000 tokens), confirming the agglutinative nature of Dravidian languages, wherein complex meanings are packed in dense tokens. This phenomenon is also well-seen in IndicBERT studies [15]. Figure 1 depicts that as the word count increases for Indo-Aryan languages, the unique vocabulary decreases.

Qualitative Analysis

The corpus includes specialized "system-bound terms", which have less equivalency in the culture itself, such as "special cases of mercy" and "enforceable in a court of law." Additionally, the corpus reflects the "Authoritative Text" issue (Article 348). Unlike symmetric datasets such as the Canadian Hansard, this corpus is legally asymmetric; the English text represents the hierarchical "ground truth," whereas the regional versions are derivative. Thus, MT models must learn a directional hierarchy, using English as the semantic anchor.

Applications

The development of a clause-aligned, multilingual constitution corpus creates a series of opportunities for both legal tech and computational law. This resource shall bridge the gap between English-centric court procedures and the multilingual reality of the Indian population in supporting the following critical applications:

Legal Machine Translation (Legal-MT): This corpus is most directly useful for training specialized Neural Machine Translation (NMT) models. Currently, general-domain models tend to make mistakes when translating "system-bound terms" like the "prerogative of mercy." This corpus allows training a model for which English is the semantic anchor so that it learns the appropriate formal register and domain-specific vocabulary related to Indian constitutional law.

CONCLUSION AND FUTURE WORK

This paper presents the first multilingual, clause-aligned parallel corpus of the Constitution of India, filling an important gap between large general-domain datasets and smaller sentence-aligned legal corpora. We combine official government texts with a hybrid hierarchical alignment strategy to provide an essential resource for the Indic NLP community [7, 10].

Limitations And Future Work

The first major limitation is that the initial translation is solely dependent on a machine-verification pipeline. Though essential to achieve scale, this in no way bypasses human-expert vetting. The immediate future work will thus involve moving from clause alignment to true syntactic alignment, thereby developing dependency parsers and treebanks for Indian legal text. Immediate applications include training specialized legal MT models and providing Cross-Lingual Legal Information Retrieval (CLIR), which caters to the highly crucial aspect of linguistic accessibility concerning the Indian justice system [24]. Furthermore, this corpus will enable downstream tasks such as legal question answering [16, 17], summarization [20], and classification [22], paving the way for a comprehensive Indian legal AI ecosystem.

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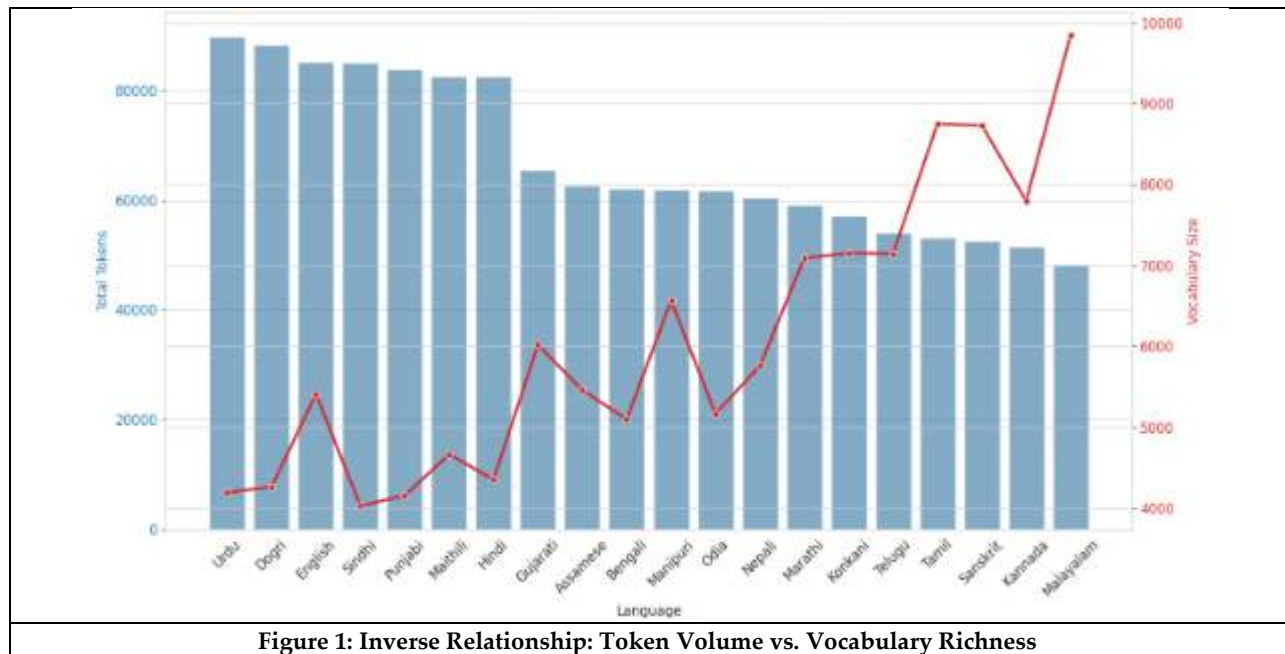
Tables

Language	Table 1: Corpus Volume and Token Distribution across Scheduled Languages			Table 2: Unique Vocabulary Size (Lexical Richness) per Language		
	Title Token	Description Tokens	Total Tokens	Title Vocabulary	Description Vocabulary	Total Unique Vocabulary
Urdu	4,294	85,492	89,786	912	4,065	4,196
Dogri	4,132	84,142	88,274	871	4,123	4,266
English	4,062	81,093	85,155	958	5,150	5,412
Sindhi	4,094	80,937	85,031	863	3,914	4,031
Punjabi	4,001	79,829	83,830	883	4,030	4,158
Maithili	4,060	78,443	82,503	873	4,536	4,668
Hindi	4,037	78,354	82,391	874	4,217	4,356
Gujarati	3,105	62,288	65,393	1,127	5,797	6,021
Assamese	3,136	59,496	62,632	949	5,322	5,461
Bengali	2,983	59,016	61,999	912	4,967	5,100
Manipuri	3,209	58,668	61,877	1,173	6,215	6,564




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Odia	3,045	58,688	61,733	943	5,001	5,168
Nepali	2,952	57,360	60,312	1,043	5,572	5,759
Marathi	2,876	56,129	59,005	1,163	6,802	7,087
Konkani	3,039	54,013	57,052	1,183	6,922	7,155
Telugu	2,879	51,057	53,936	1,059	6,901	7,145
Tamil	2,941	50,129	53,070	1,183	8,419	8,748
Sanskrit	2,484	50,052	52,536	1,141	8,252	8,732
Kannada	2,836	48,570	51,406	1,119	7,515	7,796
Malayalam	2,605	45,561	48,166	1,240	9,374	9,842
Total	66,770	1,279,317	1,346,087	20469	117,094	121,665



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RESEARCH ARTICLE

Poetry as a Tool for Vocabulary Development in children with learning Disabilities

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ABSTRACT

This study examined poetry-based activities to enhance vocabulary in 30 Grade 7–8 students with dyslexia and ADHD. Using multimodal tasks (reading cards, enactment, shuffled letters, whisper chain, music recall), participants showed improved word recognition, spelling, attention, and motivation. Limitations: small convenience sample and no control group; further research recommended.

Keywords: Learning Disabilities (LD), Vocabulary Enhancement, Poetry-Based Learning, Dyslexia, Attention Deficit Hyperactivity Disorder (ADHD), Language Acquisition

INTRODUCTION

The current study focuses on enhancement of vocabulary for children with learning disabilities. Education should cater to the needs of all the individuals in fulfilment with the valid condition of equal opportunity. Generally teachers teach according to the learners' speed. There are some individuals who, requires an appropriate instruction than usual way of getting education. These individuals are Learning Disabilities. The children need the way they can pay attention and learn.

"The term Learning Disability is used to describe a specific population of children, adolescence and adult who have problem in learning. These problems are generally in the areas of reading, writing, spelling, and mathematics" (Nakra 3). Which explains that a group of individuals who have difficulties in acquiring LSRW skills, logical reasoning or ability to doing mathematical problems due to a small disfunction in central nervous system.





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Researcher had taken Dyslexic children and ADHD children for the population of the study. Among various types of Learning Disabilities, ADHD and Dyslexia has more involvement in LSRW skills. These individuals have difficulties in listening, speaking, reading and writing.

Learning disabled individuals are described as having a short attention span and lacking on concentration. According to the educational psychiatrist, Onita Nakra, an individual may have short attention span for several reasons such as depression, stress, poor eyesight, hearing issue, all these problems can lead to lack of attention. A teacher cannot be confused with learning disabilities with such issues.

An educational psychologist, Dorothy Smith explains that some children have major problems in reading, writing, spelling or number, which are not usual of their age. Such children with learning difficulties often have low self esteem. They easily get frustrated and that leads to anger. They become depressed. These kind of emotional or psychological issues are faced by the children. According to Dorothy, "Peers may ridicule such students with learning difficulty. Teachers may feel extremely frustrated and incompetent when they cannot help a student with undiagnosed learning difficulty; the teacher may not understand why the student is not performing well" (Smith 23)

Poems are good for dealing with children with learning disabilities. The structure of poetry makes learning disability children to read easily because of its rhyme which makes them to express their opinion which is again helpful for learning. The attractive structure in the poetry makes LD children to learn the vocabulary quickly.

Poetry is a creative learning activity. It helped to keep the form of linguistic expression English as Second Language classroom whereas poetry endorses language acquisition. Poetry use in the classroom gives them a chance to get a practical and effective use of language learning. Grammar is not given importance here, which makes the children to give personal expression. It also helps the LD children to be creative. "Popular song scripts can also facilitate awareness of pronunciation, intonation and sentence flow, in addition to containing contemporary cultural commentary" (Finch1) thus the perspective on the use of poetry in the language classroom can provide meaningful and successful language learning. Hence poetry is taken as material for the current paper.

Participants: The researcher has chosen thirty learning disabilities children as samples for the study from Helixk open school, Salem. The samples are from 7th and 8th grade. Poetry is taken as material to teach them, since the participants are LD children; the instructor has given them few tasks to teach. For example, few tasks' description is given briefly,

Pick a card: Few cards were placed in front of the samples. Each should pick one card and they have to read it aloud. All the words written on the cards were taken from poems which are prescribed for the samples. Purpose of this activity is to identify the sample's reading skills. Instead of asking the children to read the words from the book, teacher should do this kind of activity to grasp the children's attention.

Pick a card and enact: This is similar to the first activity, children have to pick a card and read it aloud. In addition they should enact the word and the rest of the students should identify the word. Purpose of this activity is to identify whether the samples understand the meaning of given words or not.

Shuffled Letters: Subjects should form the given word from shuffled letters placed in front of them. Purpose of this activity is to know their knowledge of spelling. It can be tested either individually or group.

Pass the word: Basic instruction is for the samples to stand in circle form. Instructor also should stand along with them. Here, the instructor initiates the activity by whispering a word in to the student who is stand next to the instructor. The student should pass it to next person like wise it should be done for everybody. The person who stands at last should say the word aloud. Purpose of this activity is to identify the samples' attention and also to





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check whether the samples whether the samples were able to recognise the known words or not, because words used for the activity was already learned.

Music and word: Group of children can participate in this task. Instruction is to form a circle, stand near the chairs which were placed aside. They should run while the music plays and stop while the music stops. Those who did not get on the chair should do the given task; write the word given by the instructor. Purpose of this activity is to identify the samples' remembering capacity.

All the vocabularies were taken from prescribed poems for the samples. Through the activities the children were able to learn the vocabularies.

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RESEARCH ARTICLE

Fractured Psyche: Trauma and Self-Repair in Leila Aboulela's Minaret

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ABSTRACT

This study explains Leila Aboulela's novel *Minaret* through the theories of trauma and psychoanalysis and examines how displacement has disturbed the mind of the film's main character, Najwa. The analysis, instead of viewing her religious commitment as a re-enactment of tradition, considers it a survival strategy because of the discontinuity of her exile and because she is deprived as a member of a given class. This study infers the division between the ego and the processing of loss based on object relations and Lacanian associations between the secular past and the pious present of Najwa. The hijab in this instance is rather a psychic than a political boundary to protect the inner world against an unfriendly outer appearance and to balance the desire. The role of the transitional space, which is lacking in the reality of migrants, is played by the mosque community: the space that provides a holding. The repetitive feature of dependency, even in the instances of Najwa and Tamer, is explored as the fantasy of care conflicting with the vulnerabilities that have been formed by trauma. This argument alters the identity politics view to internalized identity of grieving because it applies psychic care through spirituality. Diaspora subjectivity is therefore perceived in the novel as an unceasing procedure of deconstructing and reconstituting, and religious practice is one way of surviving the circumstance of being degraded as Other.

Keywords: psychoanalysis, trauma, displacement, subjectivity, religious coping





INTRODUCTION

Psychological trauma has become one of the most pressing issues of the 21st century, especially in displaced communities, where identity disintegrates in the face of exile and loss. Cathy Caruth writes that it is not actually a wound, but rather an unprocessed instance that comes back to haunt the survivor and throws a kink in the chronological accounts of selfhood and memory (Caruth 4). This theory is critical to understanding the process of Leila Aboulela in *Minaret*, in which the main character, Najwa, experiences radical displacement in her psyche after her father is executed and consequently is exiled to London from her home in Khartoum. Aboulela does not simply describe this journey as migration but as a descent into a fractured psyche, in which the self must be reconstructed in the face of socioeconomic demotion (Aboulela 12). Political discontinuity is depicted to trigger internal discontinuity in the novel, which requires a psychoanalytic perspective to explain the survivor's reaction to such disastrous alterations.

Psychoanalysis is finding increasing applications in literary studies to interpret accounts of dislocation and repair. The concept of repetition compulsion, as proposed by Sigmund Freud, postulates that victims of traumatic events repeat the traumatizing experiences to overcome them, which, in most cases, is symbolic, through the use of symbolic gestures and ritualized behavior (Freud 15). Dori Laub has pointed out that testimony presupposes that the listener needs to rebuild the disrupted narrative of the self, and this process will help establish a space that is safe to heal and be acknowledged (Laub 71). In *Minaret*, the conversion of Najwa to Islam is a rebuilding strategy. It is not so much a political identity but a survival mechanism based on psychic necessity. The concept of the "holding environment" introduced by D. W. Nawar Al-Hassan has recently theorized the spiritual realism of Aboulela, such as faith overcoming the secular and sacred mutations to revive agency among the diaspora (Al-Hassan 23). Recent theorizing by Nawar Al-Hassan looks at the spiritual realism of Aboulela, such as faith overcoming the secular and sacred mutations to revive agency among the diaspora (Al-Hassan 23). This paper is based on such readings but focuses more on the trauma lens rather than theological or even a pure political debate.

Postcolonial critics tend to dwell on the issue of hybridity; however, Homi Bhabha points out that cultural boundaries are not absolute identities but forms of anxiety and negotiation; this paper goes beyond boundaries (Bhabha 2). Nonetheless, the paper outlines its limitations by going beyond the boundaries of identity politics to pin its main points on the inner world and inner ambiance of Najwa. According to Ann Cvetkovich, the body holds trauma, and it is not only public history that is justifying the interest in studying the ritual as a somatic repair, but also everyday practices (Cvetkovich 7). Therefore, Najwa's veiling is examined as psychic care, as opposed to religious binding and resistance. Fatima Mernissi draws attention to the space that women bargain on Islamic models, but in this case, the emphasis is on the psychological safety and not on patriarchy (Mernissi 45). According to Sara Ahmed, emotions give the bodies their surfaces, which is congruent with how Najwa uses prayer to control feelings of shame and emotional reactions to displacement (Ahmed 10). The analysis does not diminish faith in resistance by focusing on the essential aspect of psychology.

This systematic charting of psychic reconstruction will be done through eight thematic questions in the following sections. The loss of privilege and demotion of classes is examined as the first sign of Najwa's psychological separation during displacement. Second, the hijab is investigated as a defensive barrier against the hostile metropolitan gaze. Third, the mosque is viewed as a space of transition, where recognition and psychological holding are realized. Fourth, object relations theory can be applied to Najwa's changing subjectivity and ego splitting. Fifth, dependency fantasies in unequal relationships are manifested through interpersonal alliances. Sixth, the concept of spirituality is presented as an active grieving practice and re-identification. Seventh, religious ambivalence is investigated as an everyday opposition and moral restraint. Finally, subjectivity is reconstructed after trauma, which ends the analysis. With the help of this mapping, *Minaret* appears as a text in which spirituality is fundamental psychic care in a metropolis that continually inscribes the subject as Other.





Research Focus

This study examines the reflection of trauma narrative in *Minaret* through the symbolic representation of religious practice and spatial metaphors. The text describes the change in migration patterns of Najwa between Khartoum and London as a strong metaphor for greater psychic instability. This paper defines the themes of displacement, adjustment, and the interrelations between human and interior existence by examining the relationship between the distorted life track of Najwa and the human characters in the novel. This study illuminates how religious commitment is portrayed by Aboulela to portray the vulnerability of the ego as well as the urgent need to provide a healing response to the crisis of the self. The paper further explores how faith and rituals can handle psychological crises, the interplay between social inequality and psychological degradation, and the need to combine spiritual and local perspectives. Briefly, this study argues that *Minaret* not only creates awareness of the effects of any trauma on the self-ecosystems but also urges psychological action to be holistic. The overall research questions may include the following:

1. What did Aboulela mean by Najwa turning to faith to represent the psychic maneuvers of handling displacement and demotion of the classes?
2. How does the fragmentation of the self and transitional spaces in psychological reconstruction find its reflection in the novel?
3. How do interpersonal dependency and spiritual self-fashioning converge to inform issues of trauma recovery in the diaspora?

Trauma and Displacement in *Minaret*: Najwa's Psychological Rupture

Minaret by Leila Aboulela describes the phenomenon of displacement as not only geographical movement but a radical psychic injury. The narration of Najwa begins with a statement of descent: "I have come down in the world. I have slid to a place where the ceiling is low" (Aboulela, Part Two, Ch. 9). This geographical analogy emphasizes the psychological effects of exile, which is consistent with Cathy Caruth's claim that undergone trauma is unassimilated and haunts the survivor (Caruth 4). The reason for this break is the political coup in Khartoum, more precisely, the arrest and execution of Najwa's father. The instance of loss is viscerally described: "When Baba was hanged, the earth we were standing on split open and we tumbled down" (Aboulela, Part One, Ch. 8). This unforeseen disruption is indicative of Judith Herman's side of traumatic disempowerment, in which safety is broken beyond repair (Herman 33).

The loss of privilege is a secondary trauma that intensifies political discontinuity. In London, Najwa, an elite university student becomes a domestic worker in London, says, "I know how deferential a maid should be... I mustn't slip" (Aboulela, Part Two, Ch. 9). This demotion of the self is a silencing, and this can be likened to the repression necessary to deal with the unbearable reality that Sigmund Freud noted (Freud 15). The novel shifts between the years 1984 in Khartoum and 2003 in London, and this is not linear. The novel switches between the year 1984 Khartoum and 2003 London, which is not linear. Najwa recalls, "Years later, after everything fell, that photo remained" (Aboulela, Part One, Ch. 7), emphasizing the way the memory is sustained during the fall. Such a non-linear treatment confirms the theory of Dori Laub, according to which testimony involves having to reconstruct the fragmented narrative of the self (Laub 71).

Moreover, the text represents what Ann Cvetkovich defines as an archive of emotions in which trauma remains in daily practices and not only in the history of the people (Cvetkovich 7). The stored pain is answered by somatic responses in the religious rituals that Najwa undergoes. It is clear that fragmentation of identity takes place when she confesses, "I just think of myself as a Muslim" (Aboulela, Part Two, Ch. 15), indicating a change from national to spiritual subjectivity. Such a re-identification can be compared with the concept of working through trauma developed by Dominick LaCapra, who argues that people do not act out trauma (LaCapra 142). The psychological equation of the novel holds that healing takes place by accepting the break. As Najwa navigates the "antagonistic outside gaze" (Aboulela, Part Two, Ch. 10), she uses religion as a demarcation. According to Homi Bhabha, cultural boundaries are the arena of concern and bargaining (Bhabha 2). Lastly, the novel indicates that survival is a process





of never-ending reconstructions of the psyche. The endpoint of the journey that Najwa goes through is neither complete restoration, but an acceptable coexistence with loss, which demonstrates that "spirituality is psychic care" (Aboulela, Part Three, Ch. 32). This goes in line with the sentiments of Shoshana Felman, who believes that literature per se is a witnessing mode (Felman 5). Finally, *Minaret* traces the path of a fractured mind in search of solace, and the theme of abjection, in which the subject has to renegotiate boundaries in a bid to survive (Kristeva 4).

The Hijab as Symbol of Psychic Boundary and Self-Repair

The hijab in *Minaret* is more of a protectionist psychic shield than a political statement, primarily because it helps to survive trauma. The veiling of Najwa is also accompanied by her transformation into a domestic worker, thus signaling an end to the open and a new, closed invisibility. According to Cathy Caruth, trauma is something that cannot be digested and returns to haunt the survivor, requiring the use of protective mechanisms against recurrent shock (Caruth 4). The scarf functions as protection against the hostile metropolitan gaze that makes Najwa other. She notes, "Around me was a new gentleness. The builders who had leered down at me from scaffoldings could not see me anymore. I was invisible and they were quiet" (Aboulela, Part Five, Ch. 32). This invisibility is consistent with Sara Ahmed's theory, which believes that feelings influence the surfaces of the body where the veil increases the alteration of the way others perceive the body to minimize hostile affect (Ahmed 10).

Using a Lacanian register, the veil helps to mediate the conflict between internal desire and the exterior gaze. According to Jacques Lacan, the gaze disturbs the subject, and a screen is needed to cope with the anxiety of being observed (Lacan 83). This screening effect in Najwa is more of a rebuilding of dignity in a scenario of extreme class degradation. She reflects, "Something was removed, streamlined, restrained; something was deflated. And was this the real me? Without the curls I looked tidy, tame; I looked dignified and gentle" (Aboulela, Part Five, Ch. 32). This reorganization of the self resonates with Sigmund Freud's concept of repression as a means of dealing with intolerable reality and sustaining the functioning of the ego (Freud 15). The veil turns into a transitional item, akin to the "holding environment" by D. W. Winnicott, which offers the psychological security to the fragmented ego of Najwa against outer anarchy (Winnicott 115).

The material sensation of covering discloses the hijab as a place of somatic mending. According to Ann Cvetkovich, it is more accurate to assume that trauma is accumulated in the body and in our daily practices, which is why it is important to regard ritual as somatic repair and not as mere memory (Cvetkovich 7). The physical discipline in which Najwa is trained makes her in touch with reality: "I keep my eyes and head lowered like I trained myself to do... I know I must be careful in everything I do; I mustn't slip" (Aboulela, Part Two, Ch. 9). This science provides a framework that opposes the psychological disorder of exile. According to Homi Bhabha, cultural boundaries have been a place of anxiety and negotiation, but in this case, the boundary offers a sense of safety but not hybridity or conflict (Bhabha 2). The veil makes Najwa able to move through the world of the people with a feeling of not being exposed to the open world.

Moreover, the hijab is a uniform that controls the level of social expectations and secures the interior. Najwa observes, "The hijab is a uniform, the official, outdoor version of us. Without it, our nature is exposed" (Aboulela, Part Four, Ch. 24). This division keeps the inner self out of reach of the outside world and criticism. Fatima Mernissi emphasizes the negotiation of space by women in the context of Islamic structures. Still, in this case, it is a question of psychological protection instead of an outright criticism on the part of patriarchy (Mernissi 45). It becomes a process of seeing one's own survival in an unfavorable world. Dori Laub stresses the importance of testimony where a listener is to create a safe space so that the broken narrative about the self can be rebuilt (Laub 71). Lastly, Nawar Al-Hassan looks at the spiritual realism of Aboulela, the ability of religion to heal secular and sacred separations, and recover agency among the diaspora (Al-Hassan 23). Therefore, the veil is not only a religious requirement but also a remedial strategy for a psychiatrically shattered psyche due to displacement.





The Mosque as Transitional Space: Holding and Recognition

The mosque in *the minaret* serves as a Winnicottian holding environment, which provides the psychologically fragmented ego of Najwa the psychological containment it needs over external anarchy (Winnicott 115). Upon entering, Najwa notes, "The ladies' area is empty when I arrive... I put on the lights and pray two rakas' greeting to the mosque" (Aboulela 125). This rite of passage signifies the shift from the traumatic alienation of exile to a safe place. According to Cathy Caruth, the occurrence of trauma is unprocessed and therefore comes back to haunt the victim and requires defensive mechanisms against repeated shock (Caruth 4). This psychic disintegration is countered by the type of routine provided in the mosque. The mosque is a space of transition to which Najwa is relieved to rebuild a sense of self unrelated to her working as a domestic worker, where the needs of the secular world are ignored.

The acceptance of the mosque and the Othering that is metropolitan is extreme. On the bus, Najwa faces abuse: "He says, You Muslim scum, ' then the shock of cool liquid on my head and face" (Aboulela 136). This metropolitan Othering concurs with the theory of Sara Ahmed that emotions define the surfaces of bodies, with the outside world having various hostile effects on the migrant subject (Ahmed 10). For this, Najwa turns to escape: "I start to recite Say: I seek refuge in the Lord of Day break. I recite it again and again" (Aboulela 136). This incantation is a kind of psychic protection. Judith Herman views the rebuilding of safety and connection as a key ingredient to the recovery of trauma (Herman 33). The mosque is where she can find this safety, and in this way, Najwa can relax her defenses. She describes the impact of her religious practice: "Around me was a new gentleness. The builders who had leered down at me from scaffoldings couldn't see me anymore. I was invisible, and they were quiet" (Aboulela 136). This invisibility is not erasure but protection, mediated by the space of the mosque community.

Ritual practice offers order in psychic disorder in this space. The Tajweed class is a comfort to Nazwa: "This concentration on technique soothes me; it makes me forget everything around me" (Aboulela 127). The repetition of the recitation serves as a somatic anchor and makes her solid within the miscellany of the diaspora. According to Homi Bhabha, cultural boundaries are zones of anxiety and negotiation, although in this case, the boundary offers security and not opposition (Bhabha 2). The mosque is also a third space, whereby, at no point in her life is Najwa considered to be an individual of a demoted class, but rather based on her piety. The society there provides the appreciation that is not found in the secular workplace. Najwa observes during Eid, "We are pleased to see each other without our hijabs... It is not only the party clothes; some of us are transformed without our hijabs" (Aboulela 180). This change proposes liberation of the defensive stance necessary on the outside. According to Dori Laub, testimony entails the necessity of a listener to remake the fragmented narrative of self to provide a secure healing ambience (Laub 71). The listeners in this case are the sisters at the mosque who, in a judgment-free way, justify the experience of Najwa. According to Julia Kristeva, to endure abjection, the subject has to renegotiate the boundaries, and the mosque helped them to renegotiate through worshiping together (Kristeva 4). Finally, the mosque is not a religious place per se but a psychic home where ritual practice gives order to disorder and Najwa can survive the state of being labeled Other and find a community where she can be held and recognized.

Object Relations and Lacanian Frameworks in Reading Najwa's Subjectivity

According to object relations theory, the practice of religion is a transitional phenomenon of the Winnickian concept, in which Najwa balances the disjointed inner world and the aggressive external environment (Winnicott 115). The veil and the mosque are possible places where the ego can stabilize without total submission to external demands. Najwa notes, "Without the curls I looked tidy, tame; I looked dignified and gentle" (Aboulela 136). This revolution implies a reconstruction of the self-image, similar to the mirror stage of Lacan, in which the subject relates to an idealized image of the ego to overcome internal fragmentation (Lacan 83). The holy character provided is a logical reflection of the turmoil of exile, in which Najwa can claim, "I just think of myself as a Muslim" (Aboulela 127). This recognition is not only spiritual but also psychic, which means that it offers a unified opposition to the fragmentation of her secular past.



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The construction of Najwa's secular past and pious present functions as a Freudian ego defense system against traumatizing experiences that are too large to take (Freud 15). The fact that she separates her life before the coup from her life after the coup also helps her to shoulder the burden of her loss without falling into melancholy. Such a process can be explained by Julia Kristeva, whose idea of abjection presents the subject with the necessity to renegotiate the borders to live through the expulsion of the old self (Kristeva 4). Najwa admits, "I've come down in the world. I've slid to a place where the ceiling is low" (Aboulela 125). The space metaphor shows the psychic descent in which the former identity is discarded to save the central self. Judith Butler argues that such psychic lives of power entail subjecting norms to acquire existence, but Najwa's submission is agentic, and she does not have to submit but chooses to do so to survive (Butler 2).

Language and shame are important in rebuilding symbolic order. Sara Ahmed advances the view that feelings such as shame determine the surfaces of bodies, which is in line with the fact that Najwa uses prayer to deal with affective feelings of displacement (Ahmed 10). The Quranic Arabic chant replenishes a symbolic form of structure that has been lost during migration. According to Cathy Caruth, trauma is an unintegrated experience that returns to haunt the survivor and thus requires a defense mechanism against repeated shock (Caruth 4). Najwa's shield is the ritualized language. According to Homi Bhabha, cultural boundaries are places of anxiety; however, in this case, the boundary offers protection as opposed to hybridity or collision (Bhabha 2). The mosque community provides appreciation that is not present in the secular workplace. Dori Laub also underlines that testimony needs a listener to rewrite the fragmented history of the self, and it has to do so to make a safe place in which a person can heal (Laub 71). Lastly, Shoshana Felman considers literature as a means of witnessing to confirm that the story of Najwa is a witness to psychic survival (Felman 5). It is within the frames of these structures that *Minaret* brings out subjectivity as an ongoing process of reconstruction in which faith mediates the divide between trauma and recovery.

Interpersonal Alliances and the Repetition of Dependency

The relationship between Nazwa and Tamer is a dependent fantasy that reminds us of the idea of repetition compulsion described by Freud, in which trauma victims replay traumatic moments to gain control over them (Freud 15). Najwa is in an inferior position as a maid, but the fact that Tamer needs her emotionally to find her balance shows that both are vulnerable, as they were both displaced. He admits, "I can only talk to you, highlighting how religious self-fashioning intersects with deep emotional need" (Aboulela 230). This relationship makes agency more complex, as Najwa's piety provides form, yet it can be characterized by the repetition of servitude she belonged to in Khartoum before.

According to Saba Mahmood, religious agency does not necessarily pertain to resistance but may include the development of submissive virtues in patriarchal systems (Mahmood 24). This tension can be seen in Najwa's hesitation regarding Tamer's proposal. She notes, "I would rather be in the background of your life," suggesting a desire for security over autonomy (Aboulela 260). This overlaps with Judith Butler's theory of the psychic lives of power, which dictates that to obtain existence, one must submit to norms (Butler 2). Najwa is three-quarters of a century old, and her spiritual practice is a kind of holding environment, similar to the transitional phenomenon identified by Winnicott, that holds her fragmented ego together against the turmoil of exile (Winnicott 115).

But is it a challenge to commodified femininity? The money offered by Doctora Zeinab makes Najwa a lesser person: "You will take this money and stay away from my son!" (Aboulela 285). According to Sara Ahmed, emotions define the surfaces of bodies, which is also in accordance with how Najwa uses praying to cope with the shame of this exchange (Ahmed 10). The association turns into a repository of emotions in which trauma is coded in daily activities (Cvetkovich 7). However, the end, when Najwa turns down the money, claims a moral limit. Cathy Caruth claims that trauma is an event that has not been assimilated and haunts the survivor (Caruth 4). Najwa's visit to Hajj is an indication of the abandonment of interdependence between individuals and spiritual independence. Dori Laub stresses that testimony involves a person who needs to have a listener to rebuild the fragmented narrative of the self (Laub 71). This listener is not Tamer, but Najwa's faith. According to Jacques Lacan, the gaze disturbs the subject and therefore demands a screen to deal with anxiety (Lacan 83). Najwa is able to negotiate this by referring to departure





as a spiritual responsibility. Therefore, the alliance shows the way that spiritual practice deals with the weaknesses of displacement and provides a multifaceted bargaining of power and care.

Spirituality as Psychic Care: Grieving and Re-identification in Diaspora

Spirituality is critical psychic care in *the Minaret* that converts ritual into an important self-calming therapeutic mode of diasporic trauma. Structural containment is provided to the Tajweed class, with Najwa as a confession. "This concentration on technique soothes me; it makes me forget everything around me" (Aboulela, Part Two, Ch. 10). This is in line with the concept of repetition compulsion as postulated by Freud, in which ritualistic behavior is a way of coping with unbearable reality (Freud 15). Prayer establishes a Winnicottian holding environment that offers psychological containment against outside anarchy (Winnicott 115). Nazjwa writes about the veil, "Around me was a new gentleness... I was invisible" (Aboulela, Part Two, Ch. 32). The mosque community serves as a transitional space, which has recognition that is not given at the secular workplace. The mosque community serves as a transitional place, which has recognition that is not given at the secular workplace.

Mourning is an active psychic process, in contrast to passive loss. Najwa wants to purify her sins with ice on behalf of her mother as she tries to salvage the fractal narrative of self (Aboulela, Part Three, Ch. 19). This also resonates with Caruth's argument that the experience of trauma cannot be assimilated and returns to give the survivor a nightmare (Caruth 4). Najwa tells Omar, "Allah will forgive him... Then He will do wonderful things for you" (Aboulela, Part Four, Ch. 12), faith as a coping strategy of understanding guilt and seeing pain (Laub 71). The state of diaspora presupposes re-identification; Najwa states, "I just think of myself as a Muslim" (Aboulela, Part Two, Ch. 15). It enables her to build a consistent identity in the circumstances of exile fragmentation, where she keeps the trauma in her everyday practices (Cvetkovich 7). It enables her to build a consistent identity in the circumstances of exile and fragmentation, where she keeps the trauma in her everyday practices instead of in public history.

Finally, psychic reassembly is possible through spirituality. Najwa fantasizes about the bed of her parents, which she needs. "clean sheets, the privilege" (Aboulela, Part Six, Ch. 36). This desire is a call back to security using spiritual memory and abjection (Kristeva 4). Faith expands the gap that exists between the secular and sacred and reinstates agency in the diaspora (Al-Hassan 23). The novel implies that to heal, one must accept the fracture. As Najwa navigates the "antagonistic outside gaze" (Aboulela, Part Two, Ch. 10), faith is a barrier that she uses. Thus, *Minaret* depicts religious practice as a reinforcing strategy for a displaced, fractured psyche, which desperately requires a group response to individual crises (Herman 33).

The Ambivalence of Religious Practice: Resistance and Ethical Self-Restraint

The hijab in *Minaret* is also not used as a political statement but rather as a defense mechanism against trauma that is psychologically necessary to survive. When Najwa starts wearing a veil, she begins engaging in domestic labor, and this move to an invisibility of protection is in contrast to the kind of visibility that she previously had. According to Cathy Caruth, trauma is something that cannot be digested and returns to haunt the person who survived it; that is why a person needs defense against a repeat shock (Caruth 4). In the case of Najwa, the scarf is used as protection against the hostile metropolitan stare that labels her an "Other". She notes, "Around me was a new gentleness. The builders who had leered down at me from the scaffolding couldn't see me anymore. I was invisible, and they were quiet" (Aboulela 136). This invisibility is consistent with Sara Ahmed's theory of emotions as the surfaces of bodies, in which the veil alters the way other people encounter the body to minimize hostile affect (Ahmed 10). The veil is a mediating effect between the internal desire and the external gaze and is achieved through a Lacanian register. According to Jacques Lacan, the gaze disturbs the subject, and they have to deal with the anxiety of being observed through the use of a screen (Lacan 83). Nazawwa has felt this screening effect as a loss of pride in the face of extreme declassification. She reflects, "The hijab is a uniform, the official, outdoor version of us. Without it, our nature is exposed" (Aboulela 180). This isolation keeps the inner self out of social use and criticism. According to Saba Mahmood, the resistance of religious agency does not necessarily imply its lack of engagement with developing submissive virtues within patriarchal frameworks (Mahmood 24). The practice turns into a way of experiencing one's



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own survival in an unfriendly environment. In this way, negotiation is the veil as an intermediate between the inner world and the hostile outer gaze without either of the two extremes of condescension or emancipation.

Minaret and the Reconstruction of Subjectivity Post-Trauma

Finally, subjectivity (*Minaret*) is shown as a practice of mourning and re-identifying with the diaspora, making spirituality a mode of psychic treatment. This is illustrated in the way that Najwa comes out as having undergone a process of disintegration of self and reconstruction of self, but nonetheless, is not completely cured in a Western clinical sense. She asserts, "I just think of myself as a Muslim" (Aboulela 127), indicating the transition from national to spiritual subjectivity. According to Judith Butler, these psychic lives of power are about acquiescing to norms in order to acquire existence, but the submission of Najwa is agentic as it is a choice made to survive and not a matter of coercion (Butler 2). In her contribution, Judith Herman underlines that safety and connection are what victims need to recover after trauma (Herman 33). This is the safety that the mosque offers to Najwa as she is able to weaken her barriers against the disintegration of exile. Dori Laub points out that a witnessing person needs to rebuild the fractured history of self and provide a safe healing atmosphere (Laub 71). Najwa identifies this listener in religion, and not in secular relationships that recreate dependency. D. W. The idea of the holding environment by Winnicott describes how the mosque community offers the confinement that the fragmented ego of Najwa needs to balance the threats of the outside world (Winnicott 115). According to the novel, it is impossible to heal by denying the fracture. As Najwa navigates the "antagonistic outside gaze" (Aboulela 136), she uses faith as a delimitation. Thus, employing *Minaret* shows a religious practice as a reconstructive strategy to the psyche that is shattered by displacement and that there is an urgent necessity to have a collective reaction in relation to individual crisis.

CONCLUSION

This study argues that Leila Aboulela's *The Minaret* affects religious practice not only as ideological devotion but also as a crucial psychic survival strategy that emerged after traumatic displacement. The wearing of the hijab and the performance of ritual prayer, from a psychoanalytic perspective, are a rebuilding of the divide due to exile fragmentation in Najwa. Some of the key findings are that the mosque is a holding environment filled with Winnicottian recognition that is missing in the unfriendly metropolis, and interpersonal alliances demonstrate complicated aspects of dependency in trauma recovery. The analysis proves that spirituality can be interpreted as an active grieving work that helps Najwa restructure a fractured subjectivity with ethical self-restraint instead of secular emancipation (Aboulela). Hypothetically, the study fills the gap between psychoanalysis and trauma theory in the study of postcolonial literature, such as identity politics related to interior psychological healing. It implies that faith is like a mode of witnessing and self-comforting in the wake of migration, which is compatible with Caruth's idea of an unassimilated experience.

Nevertheless, the investigation is restricted to Najwa's interiority, and thus, further studies may explore other subjectivities of men or diasporic texts to enrich the literature on coping through religion. In addition, the overlapping of class demotion and spiritual agency outside the British context may be investigated further. In conclusion, *Minaret* remains highly relevant to the modern experiences of the diaspora, as it shows how spirituality can be used as a refuge for the psychic being in times of failure in external structures. The experiences of Najwa highlight that exile healing does not involve healing the past but negotiating a livable situation in the fractured present. The novel suggests that, in the case of the displaced subject, spiritual discipline is a required structure to sustain the state of being branded Other or to turn trauma into a place of reconstructed meaning and psychic nurturing.

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RESEARCH ARTICLE

English Language Learning Challenges of Tamil Medium Students: A Systemic Functional Linguistics Perspective

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ABSTRACT

English proficiency plays a critical role in India's educational and employment sectors, yet Tamil-medium learners often face significant disadvantages compared to their English-medium peers. This study explores the linguistic, pedagogical, psychological, and socio-cultural challenges encountered by Tamil-medium students in acquiring English. Using Systemic Functional Linguistics (SFL) as the analytical lens, the study examines how students' struggles and coping mechanisms can be understood in terms of three metafunctions of language namely ideational, interpersonal, and textual. Data was collected through interviews, classroom observations, and student writing samples. Then they were analysed using clause-level SFL tools. The findings revealed how differences phonology and syntax, limited communicative practice, lack of confidence and restricted access to resources hinder language acquisition, while strategies such as code-switching, media exposure, rote memorization, and peer collaboration provide partial support. Through SFL analysis, these challenges and strategies are reframed as meaning-making processes rather than isolated errors. The study also proposes that appropriate pedagogical interventions, including bilingual scaffolding, task-based learning, and explicit teaching of text organisation supports Tamil-medium learners in enhancing learning English language. By integrating grammar and meaning through SFL, this study contributes to more equitable and effective ESL pedagogy in multilingual contexts.

Keywords: Tamil-medium students, Systemic Functional Linguistics, language acquisition, writing skills and student strategies.



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INTRODUCTION

English is used all over the world and it has a great influence on many walks of life. It shapes how students learn in schools and universities, since many subjects and books are in English. Most software, websites and research are created or shared in English. This has made English as the main language for global conversation and connection. In Asian countries especially in India, knowing English is considered as the gate way to successful career. But there is a huge difference between English-medium and Tamil-medium students in learning and understanding English.

This study looks at how students at the college level from Tamil-medium background learn to write in English, the problems they face and provides suggestions to enhance their English language skills. Of the four language skills, only writing skills is analysed for the study. At the undergraduate level, majority of the students are from English medium. These students are exposed to English language from a young age. Hence they use English language to speak, read, write and think freely. On the other hand, there are a few students who have studied in Tamil medium schools and they often do not get the same level of exposure or opportunity to use English language. As a result they face challenges in comprehending and using English confidently. This study explores these challenges which are linguistic, teaching-related, psychological and culturally different based on SFL tools.

Systemic Functional Linguistics (SFL) has been used as the main framework for the study since it helps to understand language not just in the perspective of grammar or vocabulary but as a tool to explore language as a meaning-making resource in real life situation. Systemic Functional Linguistics (SFL) is a theory of language developed by M. A. K. Halliday the world-renowned linguist. It studies language based on the ways in which people use it in real-life situations to create meaning. According to M. A. K. Halliday (1978), language is not merely a set of grammatical rules but a resource for making meaning in social contexts. Systemic Functional Linguistics explains how learners use language to express ideas, maintain relationships, and organise information effectively. Therefore, SFL provides an appropriate framework to analyse the challenges faced by Tamil-medium students while learning English. SFL views language as a tool for communication and social interaction instead of looking at language only as grammar rules. Using SFL, the present study analyses the struggles of the students from Tamil medium not as “mistakes” but as part of a larger process of trying to make meaning in a new language.

In general, Tamil-medium students find it difficult to achieve enhanced English language skills and this becomes a barrier to succeed in higher education and also in finding jobs in top notch companies. Rod Ellis (1997) is of the opinion that second language learning is influenced by social, psychological, and educational factors. Their struggles usually come from limited exposure to English in daily life or a traditional language teaching method that focuses mainly on grammar and memorisation rather than real communication. Jack C. Richards and Rodgers (2014) emphasize that communicative language teaching encourages learners to use language in real-life situations instead of memorizing grammar rules alone. In several cases, the students at the undergraduate level also lack self-confidence and grow anxious of making mistakes while writing in English. Hence the study suggests that language teachers who teach English, must follow certain strategies that connect their mother tongue and English meaningfully, following SFL principles that focus largely on communication and meaning-making. The present study answers three main questions that are as follows:

- (i) What are the problems that the Tamil-medium students face while learning English?
- (ii) How can these problems be understood through the three SFL metafunctions?
- (iii) What kind teaching methods or interventions can help them learn more effectively?

This is a qualitative case study involving 25 undergraduate students who learn their B.E. programmes. At the school level, these students have not learnt their subjects in English. They have learnt in their mother tongue that is Tamil. The major challenges faced by Tamil-medium students can be classified under four areas. They are as follows:





- (i) Linguistic challenge
- (ii) Pedagogical challenge
- (iii) Psychological challenge
- (iv) Socio-cultural challenge

Tamil and English have different sound systems and grammar. This is a major linguistic challenge that leads to confusion in sentence structure and pronunciation. While teaching English, language teachers use grammar-translation methods instead of motivating conversation and activity-based methods. This is one of the pedagogical challenges involved. Psychological challenge arises when learners lack confidence and are afraid of being judged for mistakes. Socio-cultural challenge denotes the circumstance in which they rarely get chances to use English outside college. All these challenges together make writing or speaking in English difficult for students.

In order to examine the reasons for the difficulties faced by the experiment group, several learner-centric activities were conducted during the class over a period of 30 days. Data collection was done in three different ways. They are as follows:

- (i) Semi structured interviews
- (ii) Classroom observation
- (iii) Student writing samples

Semi structured interview was conducted in order to understand the students' thoughts and feelings about learning English. Classroom observations were made to watch how they use English in real classroom settings. Writing exercises were given so that the methods in which the students build meaning through sentences and paragraphs were analysed.

While examining the writing samples of the experiment group, it is observed that the errors are of several types. They often make inappropriate use of tense. For example, a student wrote "He go to school yesterday" instead of "He went to school yesterday". This is because Tamil verbs do not modulate for tense the same way as English. These students also omit articles. For example, a student wrote, "He is teacher" in the place of "He is a teacher". Prepositional errors were also found as it is seen, "We discussed about the topic" instead of "We discussed the topic". They also make errors in concord. For example, "Everyone are waiting" and not "Everyone is waiting". These students also use informal and wrong expressions such as "He only told me" and not "He is the one who told me". Most importantly they make spelling mistakes such as

"Receive" for "receive"

"Atten" for "attend"

"Replay" for "reply"

They also lack logical cohesion and present ideas without connection. For example, they write, "I woke up. Went school. Ate lunch. Coming home."

Overuse of direct translation for politeness or request, is also practiced by the experiment group. For example, "You coming or not?" (Tamil-style directness) instead of "Are you coming?" These are some of the major errors that students from Tamil-medium make while writing in English.

Interpretation through SFL framework

The writing samples were also examined based on the following SFL frame work in order to understand the problems faced by the Tamil-medium students:

Ideational interpretation: Limited vocabulary affects the ways in which learners describe experiences or ideas.

When learners do not have enough word power, they are not able to express their thoughts clearly. In one instance a student instead of writing "the book was informative and thought-provoking" they will just write "the book was good". Hence their message becomes less interesting and less detailed.



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Interpersonal interpretation: Avoiding complex sentences or modal verbs such as can, should, would, could, etc. reduces confidence in communication.

The interpersonal function of language is about interaction and relationship and the manner of expressing one's attitude, politeness or confidence when talking to others. If learners avoid using complex structures or modal verbs like can, could, should, might, they sound less sure or less expressive. The following usage of a student serves as an example:

"You come tomorrow" instead of "you should come tomorrow".

The necessity of coming the next day is not emphasized. Hence this sentence formation sounds less polite and less confidence.

Textual interpretation: Weak organisation of ideas makes writing look unclear or disconnected. If learners do not use linking words such as therefore, because, however, firstly, finally etc their writing sound disconnected.

Ex: I like music. I am learning it. My teacher helps me.

This could be improved as "I like music, but I find it hard because the notes are complex. However, my teacher helps me understand."

Hence the difficulties that the students from Tamil-medium face show gaps in making meaningful sentences across all three metafunctions of language.

The experiment group was also informed the ways to analyse the errors that they make. Three SFL tools are used to error analysis. The written scripts are examined using three SFL tools namely, transitivity, mood and theme rheme. Transitivity aims at analyzing how language represents an action, the doer of the action, the process of an action and its circumstance. For example, in the sentence, "The student read a book in the library," the student is the participant and the library is the circumstance. The way in which a language user describes his/her actions, feelings and experiences can be analysed through transitivity.

In language learning, mood explains how learners interact through questions, statements and requests. It focuses on clause types such as, declarative, interrogative and imperative. Studying the mood helps us understand how confidently or politely learners communicate and engage with others. Theme rheme is one of the most important tools to find out the ways in which learners organize ideas in writing. It analyses how a sentence is organized and it indicates that the information which is mentioned initially in a sentence is theme and the ideas that follow is rheme. In the sentence, "Gold is a costly metal" 'gold' is the theme and 'is a costly metal' is the rheme. This is helpful to check how the language user structures the sentences and whether their writing flows logically and clearly.

CONCLUSION

Thus, concepts such as transitivity, mood, theme-rheme structure and cohesion play an important role in understanding the manner in which learners use language meaningfully and effectively. These linguistic features not only help teachers analyse students' communication patterns but also guide them in designing appropriate teaching methodologies. Therefore, applying these concepts in English language classrooms will greatly support Tamil-medium learners in improving their writing skills in English.

To further motivate Tamil-medium students learn English effectively, language teachers can also use certain methods that include bilingual-scaffolding where Tamil language can be used where necessary to explain difficult ideas in English. According to Pauline Gibbons (2002), bilingual scaffolding greatly assists second language learners in understanding difficult concepts by connecting the mother tongue with the target language. Occasional use of Tamil in English classrooms will greatly reduce anxiety and help students participate more actively.



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Focusing on real-life communication tasks instead of just grammar rules will motivate the students too. Teaching text organisation will also help learners the ways to link sentences and build coherent paragraphs. Cohesion refers to the ways in which sentences and ideas are linked together using connectives like since, as a result, consequently, subsequently, etc., Each of the above-mentioned methods focus on a specific part of language learning and ensures learners develop complete communication skills. Stephen Krashen (1982) states that language acquisition becomes effective when learners are exposed to meaningful and understandable input. Tamil-medium students often receive limited exposure to English outside the classroom, which affects their confidence and fluency. Continuous exposure through reading, listening, and communication activities can improve their language skills gradually.

Thus, the difficulties faced by Tamil-medium students are not personal failures. They are the results of limited exposure and unequal access to English learning opportunities. They never get chances to use or hear English outside college and resources like availability of books in English, teachers or activities may not be available to everyone. They arise from unequal learning conditions, not from lack of ability. Therefore, proper guidance, supportive teaching methods, and adequate learning opportunities will definitely help Tamil-medium students improve their English communication skills effectively to a great extent. With encouragement and continuous practice, they will become confident users of English.

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RESEARCH ARTICLE

The Representation of Indian social Realities, Cultural Realities and Emotional Realities in Shashi Deshpande's Works: A Critical Analysis

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ABSTRACT

This paper explores the social, cultural, and emotional realities of people in India portrayed by Deshpande in her works. Shashi Deshpande is an authentic writer who meritoriously represents the authenticities of human difficulties and also about the ways in which they try to adapt the changes that they face in their lives. The objective of this paper is to bring the critical views of other writers about the writing style of Deshpande.

Keywords: tradition, cultural, emotional, authentic, religious.

INTRODUCTION

Deshpande's novels depict the manifestation of humans by bringing the joys and blues of daily life. The possibilities of improving human life are discovered and discussed at greater dimensions in her novels. Though the novels take a serious form initially, positive options are explored and the characters discover the divine qualities that are hidden in them as the story progresses. Thus, she is tagged as one of the leading, creative and humanitarian writers. Beena Agarwal, a reader in the department of English studies opines in *Mosaic of the Fictional World* like Wordsworth, creative writing is an inner compulsion with Shashi Deshpande.



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She conceptualizes the common problems in humans with no flaws like great authors as she has an internal urge to contribute to the society. She has found the art of writing as an effective tool to achieve her goal like P.G Woodhouse, an English comic novelist of twentieth century. He mentions in his novel *The Imitable Jeeves* that to write novels so true, so human, so moving, and so vital.

Deshpande has expressed in her work, *Writing from the Margin and Other Essay* that “It is through my imagination ...door into other world”. Though she is from a rich family, she comprehends and empathises with the complications and sufferings of lower-middle class people through her imagination.

Rashmi Sahi, a researcher advocates in her work *The Mother Daughter Relationship in the Novels of Shashi Deshpande* “The mother daughter relationship..... qualities to her. Deshpande strongly believes that every movement of a person is dependent with another in life, and so human values like reconciliation, reverence, love and compassion, and gratitude play a major role in all her novels.

Deshpande's style comprises brevity, concreteness, clarity, and richness. She eludes ambiguous words and she also avoids giving artificial shades to her works. She object in writing is to make the life of people happy like Wordsworth. B.K. Prasad mentions in *An Introduction to English Criticism* that “Wordsworth’s own object ... securely virtuous”. According to Wordsworth, writing makes a person feel more confident and joyful. She too expresses to Lakshmi Holmstrom, an Indian British -writer:

I learnt about language. ... I didn’t want to make melodramatic or overstatements, ever.

Deshpande’s language makes the readers comfortable and creates an urge in them to read more and more as it is simple and clear. Dieter Riemenschneider, the author of *The History and historiography of Commonwealth Literature* mentions in *The Story Must Be Told* says that Deshpande takes the readers to the life that women lead in the society which no author of the earlier age had dared to write in words as truthfully and Shashi Deshpande's excellently refined the sensibility infuses the subtle interplay of human relationships with a faithful mood which assists to clear our thoughts, and all at once we see in her a natural extension of our own intellectual parameters.

Deshpande takes an excessive effort to present not only the unity among relationships, but also the positive and negative roles of relationships in families. She articulates to Geetha Gangadharan in a meeting that human-associations are what an author deals with. The relationship from a person to person and person to society associations - these are the two key factors of a writer and, to me, the former is of colossal significance. Therefore she gives importance to families in her novels as it is believed that home sets the foundation for one’s interpersonal skills.

Deshpande mentions in an interview with Lakshmi Holmstrom that she is dissimilar from other Indian writers who write in English, she makes sure that her background is very strongly set in her work; she never had her studies in abroad. Thus she never follows any western style in her writing. Her writing is completely all about the simple Indian people and the complexities that they face in their lives.

Shashi Deshpande keeps learning about the pros and cons of Indian people and society every now and then and does her bit for the welfare of the society with her artistry. She also states in an interview: “My English is as we ... reader needs it” (Vol 2. 6 New Man International Journal 60). She is of the view that technique needs to worry only about the technique and she has to always go with the right one though it takes a long time to do so. She says that it is like setting a tampura.

She uses the stream of consciousness technique to depict the mind set of human beings candidly as the minds of humans are not always in the present; it swings to and fro among past, present and future. It is this technique that makes her stories more realistic and flawless. She is a great lover of classic authors like Shakespeare, Jane Austen, Charles Dickens and so on. Her writings are greatly influenced by these writers in terms of simplicity, language and



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technique. Deshpande like Jane Austen; “Reveals so frankly and with such sobriety, the economic basis of society” (Letter to Byron’, 1936).

Basavaraj Naikar says that Deshpande has been a very serious Indian English. She brings the problems of an Indian family set up as it is. In the novel *The Binding Vine* brings the emotions of mothers and the love that they have for their children. Urmi, the protagonist, loses her daughter in an accident and her fantasizing the deceased daughter gives her the greatest joy on earth.

Urmi discovers her mother-in-law’s writing skills through poems which were hidden in the trunk and she uses those poems to have a better understanding of her life. She empathizes with the problems of other women in the society and helps them to lead a balanced life. Thus, she works hard towards the upliftment of people by bringing the common problems that people face in their day-to-day lives.

R.K. Sharma, a researcher propounds in *That Long Silence: Long Night’s Journey into Day* that Deshpande’s heroines emerge from a traditional, middle-class, semi-urban milieu. While it gives them an innate strength to survive, it also handicaps them by burdening them with heavy inhibitions. The notion that women are basically low-grade to men is instilled into them from the start, giving them a mindset which they find difficult to discard subsequently.

Deshpande’s characters learn to understand the essence of their lives through their entire sufferings.

Dr. Amarnath Prasad, the editor of English literature books expresses in *Indian Writing in English Critical Explorations*: “Like Dorothy M. Richardson, Shashi Deshpande endeavors to render current existence as reflected in the consciousness of her heroine” (274).

J.P. Tripathi in *The Feminist Upsurge in Jaya’s Ego* in Shashi Deshpande’s *That Long Silence* expresses that like Virginia Woolf, Shashi Deshpande is a writer of feelings and emotions that crosses in human mind. The women characters that she portrays in her novel understand, dutiful and passive like the predecessors. Deshpande’s characters are silent and submissive, but they manage to go beyond their difficulties to find ecstasy in their lives.

Deshpande’s characters make the readers understand that egoism will end up in disharmony and chaos in the family. Bijay Kumar Das, a postmodern Indian English writer advocates that the traditional Indian wisdom stands strong in abolishing disharmony in Indian families in her novels. For instance, on an occasion in the novel *A Matter of Time*, Kalyani and Goda speak about Vithalroa’s and Manorama’s wedding as a miracle. At that instant, Sumi recollects the story of *Kumarasambhavam* (Hindu mythology) that speaks about the relationship of Lord Shiva and Goddess Parvathi. Kalyani speaks of the strong relationship between her parents. *Kumarasambhava* recounts the courtship of Lord Shiva and Parvati.

It also speaks about Goddess Parvati’s determination to win the love of Lord Shiva. The recollection of the story gives hope to Sumi to reunite with her husband and helps her in upholding the love that she has for her husband despite their separation for many years. Deshpande conveys to the readers that reading religious and classic books give hope for people to survive with self-confidence and the characters in the stories teach people to overcome struggles in life with forbearance.

Deshpande conveys to the readers in her novels, the significance of cultural rooting’s, and the value of preserving the landscape of ancestors and so on. She also emphasizes that culture, tradition and art offer knowledge that is necessary for physical and intellectual benefit of human beings. She also professes that the present generation can acquire knowledge through culture, art and tradition. Therefore, culture, art and tradition must be preserved by the present generation and transmitted to the future generation. The presence of human life with intuitive admiration for everything will create happiness in humanity. Thus, Deshpande’s characters impart to readers that art, tradition, music, nature and even poverty help people realize that there is optimism in life.





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RESEARCH ARTICLE

Designing an AI-Enabled Academic Vocabulary Assessment for Engineering ESP Students in HEIs: Pedagogical Implications

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ABSTRACT

This study presents an AI-driven Academic Vocabulary Proficiency Test designed for engineering undergraduates in English for Specific Purposes (ESP) within Higher Education Institutions (HEIs). The test uses Coxhead's Academic Word List (AWL) to address the need for productive vocabulary assessment. It aligns scoring with the Common European Framework of Reference for Languages (CEFR), moving beyond traditional receptive measures. Using AI technologies, the interactive open-ended cloze test provides first-syllable hints within real engineering contexts to evaluate learners' productive use of vocabulary. Features include adaptive item randomization, timed levels, and automated CEFR-aligned scoring, allowing efficient deployment and detailed diagnostic feedback. AI enables real-time data collection and advanced analysis, producing comprehensive learner profiles and institutional reports supporting targeted instructional interventions. The study highlights the tool's reliability and pedagogical importance in improving ESP vocabulary assessment. Although the platform mainly focuses on the AWL and has exact-match scoring limits, it represents an AI-enhanced assessment that tackles key educational challenges. This research advances ESP teaching and applied linguistics by combining AI capabilities with existing vocabulary frameworks, paving the way for new developments in academic language assessment for engineering students.

Keywords : Academic Vocabulary, AI-Enabled Assessment, CEFR Alignment, Educational Technology, English for Specific Purposes (ESP).



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INTRODUCTION

Academic vocabulary is pivotal in engineering undergraduates' academic and professional development. It enables them to engage with technical literature, compose research papers, and participate effectively in disciplinary discussions. In the context of English for Specific Purposes (ESP), however, vocabulary demands extend well beyond general English. Students must command abstract, technical, and field-specific terms that underpin disciplinary communication (Hyland & Tse, 2007). Despite its central importance, research indicates that many engineering students possess insufficient academic vocabulary, constraining their academic achievement and workplace readiness (Nation & Waring, 1997; Schmitt et al., 2011). Assessment of academic vocabulary knowledge presents additional challenges. While efficient multiple-choice recognition tasks provide only a partial picture, they do not capture productive knowledge or the ability to retrieve and use words accurately in context (Qian, 2002). In contrast, open-ended assessments offer greater validity but demand considerable resources regarding design and grading (Webb & Nation, 2017). Against this backdrop, the rapid integration of artificial intelligence (AI) into higher education creates new opportunities to address these limitations by enabling scalable, adaptive, and automated assessment approaches (Luo et al., 2025).

This study addresses these challenges by designing and implementing an AI-enabled Academic Vocabulary Proficiency Test for engineering undergraduates. The test is grounded in Coxhead's (2000) Academic Word List (AWL) and aligned with the Common European Framework of Reference for Languages (CEFR). It systematically assesses productive academic vocabulary knowledge in an automated manner. By integrating insights from the Productive Vocabulary Levels Test (Nation, 2001) with AI-driven analytics, the tool offers diagnostic precision and practical scalability, thereby addressing a significant gap in ESP-focused vocabulary assessment for engineering learners.

Accordingly, the following research questions guide the study:

1. To what extent can an AI-enabled Academic Vocabulary Proficiency Test be designed to reliably and validly assess the productive academic vocabulary of engineering undergraduates in ESP contexts?
2. How can AI-enabled automation and CEFR-aligned reporting enhance scalability, diagnostic accuracy, and educational relevance in academic vocabulary assessment?
3. What pedagogical and research implications emerge from integrating an AI-enabled vocabulary assessment tool into ESP programs for engineering undergraduates?

LITERATURE REVIEW

Challenges in Academic Vocabulary Assessment for Engineering ESP Learners

Engineering students frequently encounter difficulties with academic vocabulary, particularly discipline-specific and technical terms. As a result, these challenges affect their reading comprehension, writing abilities, and overall performance in English for Specific Purposes (ESP) contexts. Moreover, limited vocabulary knowledge has hindered academic achievement and career progression (Nation & Waring, 1997). In addition, studies of vocabulary size across engineering disciplines reveal substantial variation, with many students failing to reach levels considered necessary for academic success (Schmitt et al., 2011). Traditional multiple-choice formats are often used for assessment because they are efficient; however, they do not adequately measure how learners actively use vocabulary in practice (Qian, 2002). By contrast, open-ended and context-rich formats provide stronger predictive validity for academic performance (Webb & Nation, 2017). Nevertheless, these approaches face limitations, including complex scoring requirements and time constraints. More recently, meta-analyses of computer-assisted vocabulary assessment have confirmed such limitations while underscoring the potential of adaptive, technology-based approaches to address them (Aldukhayel, 2022).



**AnilKumar et al.,****The Role of Academic Vocabulary and the AWL in ESP**

Academic vocabulary enables students to communicate effectively and engage with academic content. For engineering students, this entails mastering both abstract academic terms and technical language tied to their field. However, general English courses seldom address these needs adequately (Hyland & Tse, 2007). To bridge this gap, Coxhead's (2000) Academic Word List (AWL), comprising 570 high-frequency word families, has become an essential resource for ESP instruction. Research consistently demonstrates that explicit instruction based on the AWL improves comprehension and writing performance in ESP contexts (Coxhead, 2000; Hyland & Tse, 2007). Furthermore, studies employing corpus-based tools to support AWL instruction show that ESP learners retain vocabulary more effectively and readily transfer it into academic tasks (Boulton, 2022).

Receptive versus Productive Vocabulary Knowledge

Another strand of research highlights the distinction between receptive vocabulary knowledge, which involves recognition, and productive vocabulary knowledge, which requires active use (Nation, 2001). For engineering students, productive vocabulary is crucial since they must communicate clearly in technical reports, research papers, and professional discourse. Despite this importance, many assessments prioritize receptive knowledge because such formats are easier to design and grade. However, reliance on receptive measures alone risks underestimating learners' actual communicative competence (Nation, 2001).

AI and ESP: Innovative Frontiers**AI-Driven Vocabulary Learning in ESP**

Recent developments show increasing interest in leveraging AI to support vocabulary learning in ESP contexts. For instance, Silitonga et al. (2024) reported that integrating AI chatbots into ESP classes significantly enhanced vocabulary retention among engineering students. Similarly, Zamanpour and Etemadzadeh (2024) demonstrated that AI-driven corpora improved financial engineering students' acquisition of academic idioms and lexical bundles. Beyond retention, broader investigations highlight AI's role in fostering engagement, reflection, and behavioural change in ESP learning (Shadiev et al., 2023; Patty, 2024; Rahimi & Fathi, 2022; Utami et al., 2023). In addition, digital collaboration platforms and flipped classroom models have further strengthened vocabulary acquisition, with studies showing measurable gains in ESP learners' outcomes (Kohnke & Moorhouse, 2022; Zou & Xie, 2019).

AI-Enhanced Assessment in Higher Education

Parallel to learning, AI has also begun reshaping assessment practices in higher education. Luo et al. (2025) noted the growing use of AI-based systems for personalized feedback, tutoring, and cognitive and affective outcomes evaluation. Complementing this, Ilieva et al. (2024) proposed a multi-stakeholder framework for assessment design, while Vargas et al. (2024) outlined strategies for developing assessments that are resilient to AI misuse. Pilot implementations have provided encouraging evidence. For example, the AI Assessment Scale (Furze et al., 2024) produced measurable improvements in student learning outcomes, and Impey et al. (2024) found that ChatGPT-4's grading accuracy closely matched human instructors. Furthermore, mobile-assisted flipped classrooms and AI-enabled analytics have shown potential to enhance assessments by supporting active learning and timely feedback (Tseng & Yeh, 2019).

AI in Engineering Education

Several studies in engineering education illustrate AI's potential beyond language learning. Pursnani et al. (2023) revealed that carefully refined prompting strategies improved ChatGPT's performance on the Fundamentals of Engineering examination. At a broader scale, Chamberland et al. (2025) applied AI to analyze student feedback and visualize engagement trends, illustrating its promise for institutional decision-making. Moreover, longitudinal research suggests that embedding data-driven approaches within ESP courses contributes to gradual but sustained improvements in academic vocabulary (Wu & Miller, 2020; Lin & Warschauer, 2015).



**AnilKumar et al.,****Pedagogical Implications and Institutional Response**

The rapid adoption of generative AI, reportedly by 92% of university students in the UK (Higher Education Policy Institute & Kortext, 2025), has compelled institutions to reconsider their assessment practices. In response, several strategies have emerged. For example, some universities have reinstated oral viva examinations to authenticate students' understanding (University of South Australia, 2022). Others have adopted policies requiring disclosure of AI use and provided training in ethical and responsible application (Indian Institute of Technology Delhi, 2024). Collectively, these measures reflect an effort to balance the opportunities presented by AI with the need to maintain academic integrity.

Research Gaps and the Way Forward

Although AI-assisted assessment has gained traction, most studies emphasize general English or receptive vocabulary measures. Only a limited number of validated instruments are available for assessing productive academic vocabulary in engineering ESP contexts. Furthermore, automating the evaluation of open-ended responses remains technically challenging. These gaps underscore the need for new approaches.

Synthesis and Rationale for the Study

The literature highlights the central role of academic vocabulary in engineering ESP contexts and the persistent difficulties students face in mastering it. While the Academic Word List provides a valuable foundation for instruction, assessments remain limited by their reliance on receptive formats, which fail to capture the productive use of vocabulary essential for academic and professional communication. At the same time, recent advances in AI have opened promising avenues for both learning and assessment, offering scalability, adaptability, and enhanced diagnostic precision. However, despite this potential, there remains an apparent lack of validated tools that leverage AI to evaluate productive academic vocabulary among engineering undergraduates. This gap points directly to the need for the present study, which proposes an AI-enabled, CEFR-aligned assessment designed to address the shortcomings of existing methods while responding to the pedagogical and institutional demands of contemporary ESP education.

Development of the AI-Driven Academic Vocabulary Assessment Test

Building on the research gaps identified in the literature review, particularly the absence of validated tools for assessing productive academic vocabulary in engineering ESP contexts, this study developed and implemented an AI-enabled Academic Vocabulary Proficiency Test. The design uses Paul Nation's Productive Vocabulary Levels Test (PVLTL) framework, modifies it to incorporate Coxhead's Academic Word List (AWL, 2000), and delivers it through an interactive, automated platform. By emphasizing productive recall, CEFR alignment, and scalable deployment, the methodology directly addresses the call for more precise diagnostic tools and pedagogical relevance in academic vocabulary assessment.

Test Design and Structure

To ensure systematic coverage of the AWL, the researchers structured it into ten sequential levels, each corresponding to one AWL Sublist. The progression moves from high-frequency to lower-frequency academic word families, reflecting the natural gradient of lexical difficulty. Each level contains 20 fill-in-the-blank items presented in sentence contexts. The tasks provide the first syllable of the target word as a cue, requiring participants to type the complete form. The researchers selected this open-ended, context-rich design because prior research demonstrates that productive formats are stronger predictors of academic performance than recognition-based tasks (Qian, 2002; Webb & Nation, 2017). For instance, in the item "*The team needed to co_____ their efforts for better results,*" the correct answer "*coordinate*" evaluates knowledge of meaning, form, and contextual usage simultaneously.

Timing and Progression Rules

Each level is time-limited to five minutes to promote focus and ensure standardized conditions. While learners can view all levels from the outset, progression is contingent upon completing the preceding level. This sequencing balances autonomy, valued in ESP pedagogy, with comprehensive lexical coverage.



**AnilKumar et al.,****Randomization for Validity**

The platform incorporates randomization at the item-selection stage to safeguard validity and minimize practice effects. The system generates unique sets of items drawn from the relevant AWL Sublist for every test attempt. This mechanism reduces item overlap across participants and retakes while preserving the intended progression of difficulty within the AWL.

Data Capture and Analytics

The AI-driven architecture enables detailed tracking of learner performance. Data collected include the number of items attempted and correctly answered per level, time spent, and estimates of known academic words and mastered word families. The system displays these outputs on an administrative dashboard and allows users to export them into spreadsheets for further analysis. In addition, the dashboard provides visual analytics such as score distributions, progression trends, and pass/fail rates. Such analytics enhance institutional monitoring and align with the broader shift toward data-driven feedback in AI-supported ESP instruction (Kohnke & Moorhouse, 2022; Luo et al., 2025).

CEFR Alignment

Upon completing all ten levels, the system evaluates learner performance by mapping it to CEFR bands, using accuracy, lexical range, and mastery of word families as key indicators. A 90–100 percent score corresponds to the C1–C2 range, signifying advanced proficiency, while 75–89 percent places learners within the B2–C1 upper-intermediate band. Those achieving between 60–74 percent are classified as B1–B2, reflecting intermediate ability, and scores ranging from 40–59 percent map to the A2–B1 level, representing elementary to lower-intermediate competence. Learners below 40 percent are in the A1–A2 range, indicating beginner to elementary proficiency. By providing CEFR-aligned results, the system gives learners a clear and internationally recognized benchmark of their progress and allows instructors to interpret outcomes within globally accepted standards (Hyland & Tse, 2007).

Pedagogical Integration

Overall, the test design integrates productive vocabulary measurement, adaptive item randomization, and CEFR-referenced reporting to tackle longstanding challenges in academic vocabulary assessment. The combination of scalable automation and detailed diagnostic feedback makes the tool suitable for institutional deployment while equipping instructors with actionable insights for targeted interventions in engineering-focused ESP programs.

Technical Implementation of the AI-Enabled Academic Vocabulary Assessment Test System

This study developed an AI-enabled Academic Vocabulary Assessment Test as a web-based platform for evaluating English for Specific Purposes (ESP) vocabulary proficiency among engineering undergraduates. The researchers used the Canva AI Code environment to implement the system and applied Tailwind CSS to create a responsive and accessible interface design. Conceptually, researchers organized the platform into five modular layers: the user interface layer, AI integration layer, assessment logic layer, data management layer, and security layer. The System Integration Tree Diagram (Figure 1) depicts this architecture, highlighting the hierarchical relationships and functional segregation of components.

The integration of these layers produces a cohesive and scalable platform. At the front end, the user interface layer combines HTML5 and Tailwind CSS to deliver a mobile-optimized, user-friendly environment conducive to diverse learner contexts. Underpinning this, the AI integration layer utilizes GPT-based large language models (LLMs) to dynamically generate contextually relevant test items and furnish adaptive, immediate feedback, thus enhancing responsiveness and instructional adaptability (Hurix, 2025; CTLT UBC, 2023). The assessment logic layer orchestrates the flow of test items, timing, and CEFR-based proficiency estimation, ensuring rigour and standardization aligned with internationally recognized frameworks (ETS, 2023; Pearson, 2018). Data management employs local browser storage with export capabilities in CSV format to facilitate formative learner feedback and summative research analytics. The security layer enforces real-time user behaviour monitoring to safeguard academic integrity, preventing malpractice through full-screen enforcement and tab-switch tracking (HackerOne, 2025). Collectively, this

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layered design supports a robust, secure, and efficient AI-driven assessment environment suitable for large-scale ESP vocabulary testing. The workflow diagram (Figure 2) further explicates the user journey and system logic. Upon login, learners select a proficiency level corresponding to one of ten Academic Word List (AWL) sublists (Coxhead, 2000; Shabani, 2014). They engage with randomized cloze test items featuring first-syllable hints within a five-minute session to promote rapid vocabulary recall and reduce guesswork. AI algorithms automatically score submissions, monitor timing adherence, and determine learner eligibility for progression. Concurrently, the system collects accuracy and time metrics for ongoing performance tracking and research. The workflow culminates with an administrative dashboard enabling data visualization and export, thus bridging learner assessment with educational research initiatives.

Data Pipeline and Vocabulary Selection

The assessment's lexical database is built considering Coxhead's (2000) AWL, widely recognized as a comprehensive resource for academic vocabulary acquisition in ESP contexts (Shimray & Wangdi, 2022). This list is organized into ten sublists increasing in lexical difficulty, promoting a structured and scaffolded learning trajectory. The system encodes vocabulary items as structured JSON objects containing the target word, an engineering-context sentence with a missing lexical item, and a first-letter hint to scaffold learner recall (Ijaz, 2024). A random shuffling algorithm governs item selection per session to optimize exposure variability and minimize memorization bias. The cloze format combined with initial-letter hints facilitates effective retrieval practice, a strategy supported by cognitive principles of vocabulary retention (AI IJISAE, 2024). Levels are unlocked sequentially to uphold assessment fairness, and within-level randomization further diversifies learner experience.

AI Model Integration and Prompt Engineering

The Canva AI environment integrates with GPT-based LLMs, employing few-shot prompting methodologies to generate domain-specific cloze items that align with ESP objectives (PromptingGuide.ai, 2025). Few-shot prompting improves task accuracy by providing contextual exemplars, calibrating model output to maintain consistent difficulty and contextual relevance (Min et al., 2022). A typical prompt instructs the model to: "Create a cloze test question using the academic word '{word}' in an engineering context. Provide: (a) a sentence with the word partially omitted, (b) a hint indicating the initial letters."

This technique controls the generative capacity of LLMs to produce high-quality, contextually authentic test items while reducing manual item-writing workload (Hurix, 2025). The system also generates automated feedback instantaneously, enhancing formative learning by reinforcing correct lexical use and supporting self-regulated learner engagement (CTLT UBC, 2023). This AI-driven item generation supports scale and adaptability, consistent with emerging practices in AI-enabled language assessment design (QASource, 2025).

Assessment Workflow and Adaptive Scoring

Consistent with best practices in timed vocabulary assessment, each level imposes a five-minute limit to maximize rapid lexical retrieval (Pearson, 2018). The system computes learners' scores via:

$$\text{Score} = \left(\frac{\text{Correct Answers}}{\text{Total Questions}} \right) \times 100$$

Scores are then mapped onto CEFR bands to ensure interpretability and standardization internationally. The bands applied are: C1–C2 (≥90%), B2–C1 (≥75%), B1–B2 (60–74%), A2–B1 (40–59%), and A1–A2 (<40%) (ETS, 2023; Pearson, 2018). The flowchart (Figure 4) illustrates this workflow: timed completion followed by automated scoring and CEFR alignment. Learners are then either advanced via adaptive pathways or redirected to conclude the assessment, enabling personalized learning pathways while aligning with recognized proficiency frameworks (ETS, 2023).

UI/UX Design for Engagement and Accessibility

The platform's design emphasizes learner engagement and universal accessibility. Tailwind CSS breakpoints ensure responsive adaptation across diverse devices (mobile, tablet, desktop), essential for ubiquitous learning environments (Lexi AI UX Award, 2024). Onboarding forms capturing informed consent and participant data



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support ethical research protocols. Engagement features such as progress bars and countdown timers are implemented to promote sustained motivation during assessment (Hurix, 2025). Accessibility considerations include high-contrast colour schemes, semantic HTML markup, and full keyboard navigation support, thus accommodating users with diverse needs (W3C Accessibility Guidelines, 2024). Usability testing and iterative development were key to refining user experience and ensuring the platform meets contemporary standards for inclusive educational technology (CTLT UBC, 2023).

Security and Data Privacy

Security protocols are rigorously embedded, reflecting essential safeguards in web-based assessment environments. JavaScript functions enforce full-screen test mode, turn off copy/paste/print functionality, and continuously monitor tab switching to mitigate cheating risks (HackerOne, 2025). Attempts to access developer tools trigger immediate test suspension, reinforcing academic integrity. Concurrently, the system ensures data privacy through anonymized, locally encrypted learner data storage. Only aggregated, de-identified data is exportable for research analysis, adhering to data protection principles (GDPR, 2025). This dual-layer approach aligns with ethical standards in educational research and secure online assessment frameworks (National Centre for AI, 2023).

Scalability and Research Analytics

The platform's stateless architecture and lightweight front end enhance scalability by minimizing server load and facilitating deployment across distributed contexts (QASource, 2025; testRigor, 2024). Batch data export ensures compatibility with statistical packages (SPSS, R, Python), supporting advanced quantitative research (Hurix, 2025). The administrative dashboard, developed using Chart.js, provides real-time visualization of learner metrics such as CEFR band distributions and level completion rates. Such analytics empower educators and researchers to track performance longitudinally and explore vocabulary acquisition trends, thus bridging assessment with applied linguistics research (Kabudi, 2021).

Pedagogical Alignment for ESP Learners

The platform's pedagogical design reflects current models of ESP vocabulary acquisition, embedding lexical items within authentic engineering contexts to maximize relevance and transferability (Shimray & Wangdi, 2022). Material sequencing avoids cognitive overload by scaffolding complexity gradually (Nation, 2007). Automated, AI-generated immediate feedback fosters active learning and self-regulation, crucial for vocabulary mastery (Ijaz, 2024). Furthermore, the modular framework facilitates adaptation to other ESP domains, ensuring broader applicability. Combined with integrated analytics, these features contribute valuable insights to educational technology and applied linguistics scholarship (Kabudi, 2021; CTLT UBC, 2023).

Pedagogical and Research Implications

The AI-enabled Academic Vocabulary Assessment Test provides several teaching benefits. First, instructors can assess students' productive vocabulary knowledge more accurately than recognition-based formats, which gives a clearer view of learners' readiness for academic and professional communication. The CEFR-aligned scoring helps educators interpret results against an internationally recognized standard, supporting curriculum alignment and comparison. From a teaching perspective, the detailed analytics produced by the platform, including item-level performance, time-on-task data, and level-wise mastery, enable targeted vocabulary instruction. Educators can identify specific academic word families that need reinforcement, creating different learning paths. Using AWL-based tasks keeps instruction relevant to the academic needs of engineering students, linking classroom learning to real-world applications. The test provides researchers with a repeatable framework for studying vocabulary development in ESP contexts. Its automated scoring and data capture features eliminate logistical barriers to large-scale, open-ended vocabulary assessment. Additionally, by enabling repeated measures with randomized item selection, the tool supports long-term studies on vocabulary growth and the effectiveness of specific interventions.

The study's findings address the three guiding research questions mentioned in the introduction. First, regarding the design of a valid and reliable AI-enabled Academic Vocabulary Assessment Test for engineering undergraduates in ESP contexts, the results confirm that basing the assessment on the Academic Word List (AWL) and the Productive



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Vocabulary Levels Test (PVLТ) framework ensures both theoretical soundness and practical usefulness. Open-ended cloze tasks with partial-word prompts, placed in realistic engineering contexts, measure productive vocabulary use instead of passive recognition. Standardized task formats, fixed time limits, and randomized item selection support reliability, reducing practice effects and improving consistency across test administrations. Second, AI-driven automation combined with CEFR-aligned reporting has shown straight forwards calability, diagnostic accuracy, and benefits in teaching relevance. Automated item generation, sequencing, and scoring enable the system to deliver the assessment efficiently to large groups without lowering task complexity. Integrating CEFR-based performance bands translates raw scores into internationally recognized proficiency levels, which helps educators, learners, and institutions interpret results meaningfully. This scoring framework improves diagnostic accuracy by identifying specific academic word families needing reinforcement. It also allows instructors to align targeted interventions with global language proficiency standards.

Finally, the teaching and research implications of incorporating this tool into engineering-focused ESP programs are significant. Instructors access detailed, item-level analytics to guide personalized instruction, while learners receive immediate and relevant feedback. From a research standpoint, the tool offers a repeatable model for studying vocabulary growth over time, facilitating both cross-institution studies and comparisons within specific disciplines. Additionally, the system's modular design and AI integration enable adaptive learning applications, where assessment results directly inform personalized learning modules, connecting testing and targeted instruction.

Limitations

While the test addresses several issues in current vocabulary assessment practices, it has limitations. First, the assessment focuses only on the AWL and does not include highly technical or discipline-specific engineering terms outside this list. Therefore, it shows a strong indicator of general academic vocabulary, but not the complete range of an engineering student's vocabulary. Second, although the open-ended format better reflects how students use vocabulary, automated scoring still depends on exact matches to target words. Without further improvements in natural language processing, this method may miss partially correct answers, synonyms, or contextually appropriate alternatives. Third, the researchers conducted the study in a single academic and cultural context, which may limit how well the findings apply to other educational systems, language backgrounds, or disciplines. Finally, while the AI-driven format improves scalability, it assumes access to reliable internet and digital devices, which may limit its use in areas with fewer resources.

Directions for Future Research

Future studies could expand the test to include discipline-specific engineering vocabulary and the AWL, providing a clearer view of students' lexical skills. Adjustments to the scoring algorithm using natural language processing allow for partial credit, recognition of synonyms, and more detailed feedback. Long-term research could examine how repeated tool use affects vocabulary growth, especially when paired with targeted teaching methods. Studies across different institutions in and beyond engineering would strengthen the applicability of the findings and show how academic vocabulary needs vary in different contexts. Finally, combining the test with adaptive learning platforms could create a closed feedback loop. In this setup, assessment results would directly shape personalized learning modules. This integration could monitor and actively speed up academic vocabulary development, making the tool a key part of improved ESP teaching.

CONCLUSION

This study has presented the design and implementation of an AI-enabled Academic Vocabulary Assessment Test specifically developed for engineering undergraduates within English for Specific Purposes (ESP) contexts. To begin with, it integrates several foundational frameworks, including the Academic Word List (AWL), the Productive Vocabulary Levels Test (PVLТ), and CEFR-aligned reporting, thereby creating a comprehensive AI-driven assessment platform. Consequently, this system addresses a persistent gap in measuring productive academic





vocabulary on a large scale. Unlike traditional recognition-based formats, the test incorporates open-ended tasks, context-rich assignments, randomized item selection, and real-time analytics, providing a robust alternative with precise diagnostics and practical scalability. From a pedagogical perspective, the tool significantly aids instructors by pinpointing vocabulary gaps at the word-family level. Moreover, it aligns instructional efforts with recognized proficiency standards, thus enabling targeted interventions tailored to learners' needs. In addition, its automated data capture and CEFR mapping facilitate large-scale research on vocabulary development, allowing researchers to track learner progress longitudinally and evaluate instructional strategies more effectively. Technically speaking, the system's modular design and AI integration offer considerable adaptability, enabling straightforward customization for other ESP domains beyond engineering. Significantly, including engineering-relevant contexts enhances the disciplinary specificity of the assessment, increasing its relevance and applicability.

Nevertheless, the current system presents some limitations. Specifically, it focuses primarily on the AWL rather than incorporating specialized technical terminology, and it relies on exact-match scoring, which may not fully capture nuanced learner responses. However, these limitations also present opportunities for future enhancement through expanding the word lists and incorporating advanced natural language processing techniques to improve scoring accuracy. Overall, this study provides a replicable and scalable model of AI-enhanced vocabulary assessment suitable for higher education contexts. Ultimately, by bridging the gap between emerging technology and instructional needs, the platform lays a solid foundation for future innovations in ESP testing. It holds promise for improving curriculum alignment and enabling adaptive learning designs that respond to learner performance in real-time. Therefore, this work contributes to advancing the theory and practice of vocabulary assessment in ESP, offering new avenues for research and pedagogical development.

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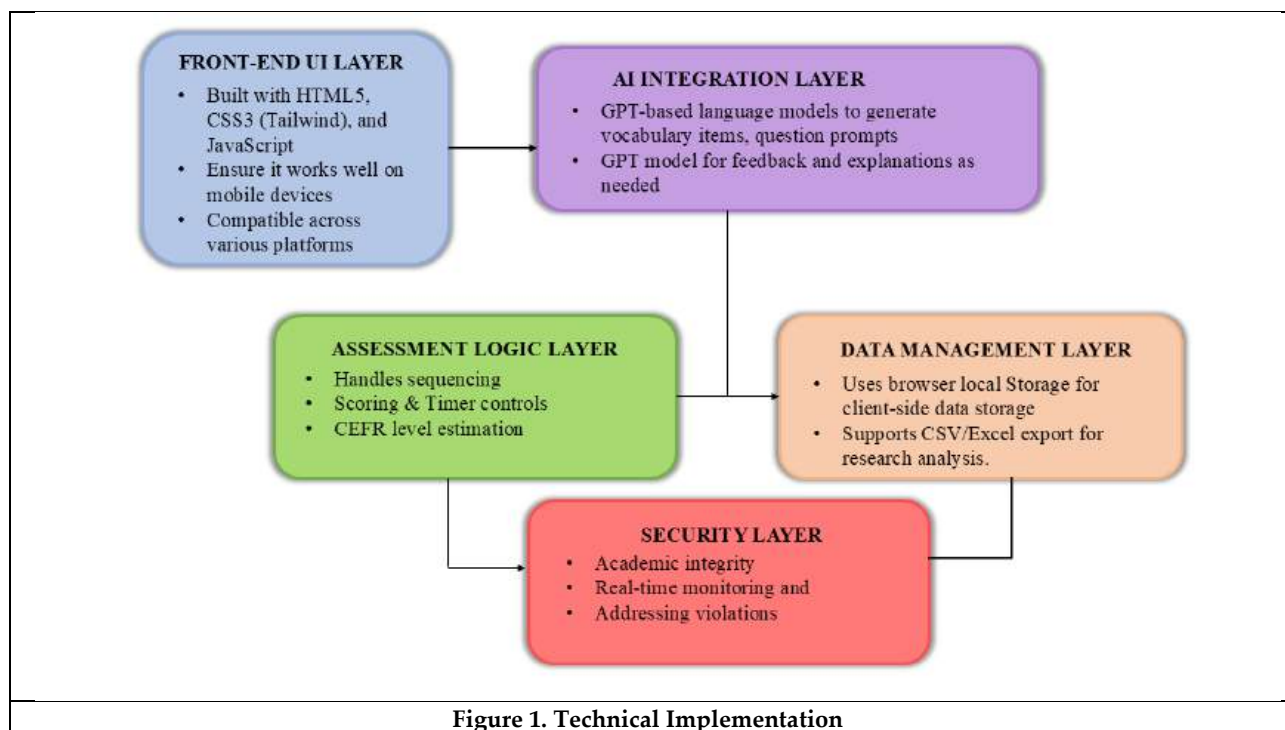
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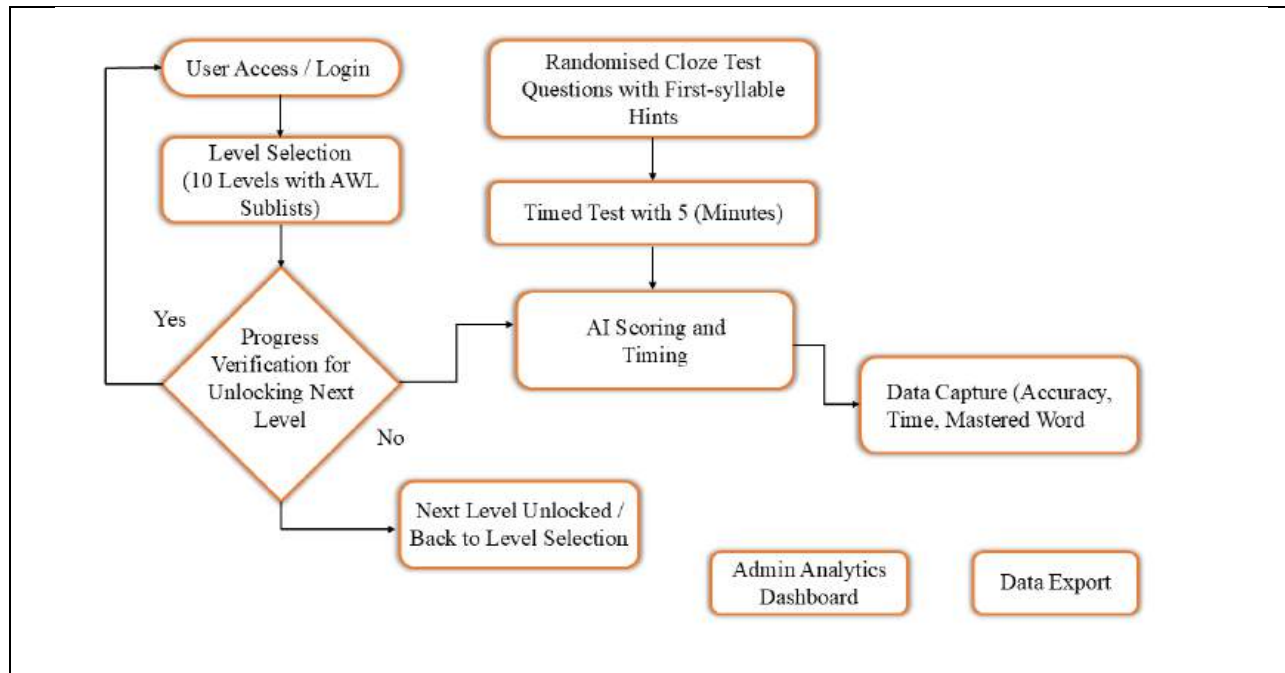


Figure 2. Functional Workflow of the AI-enabled Academic Vocabulary Assessment Test

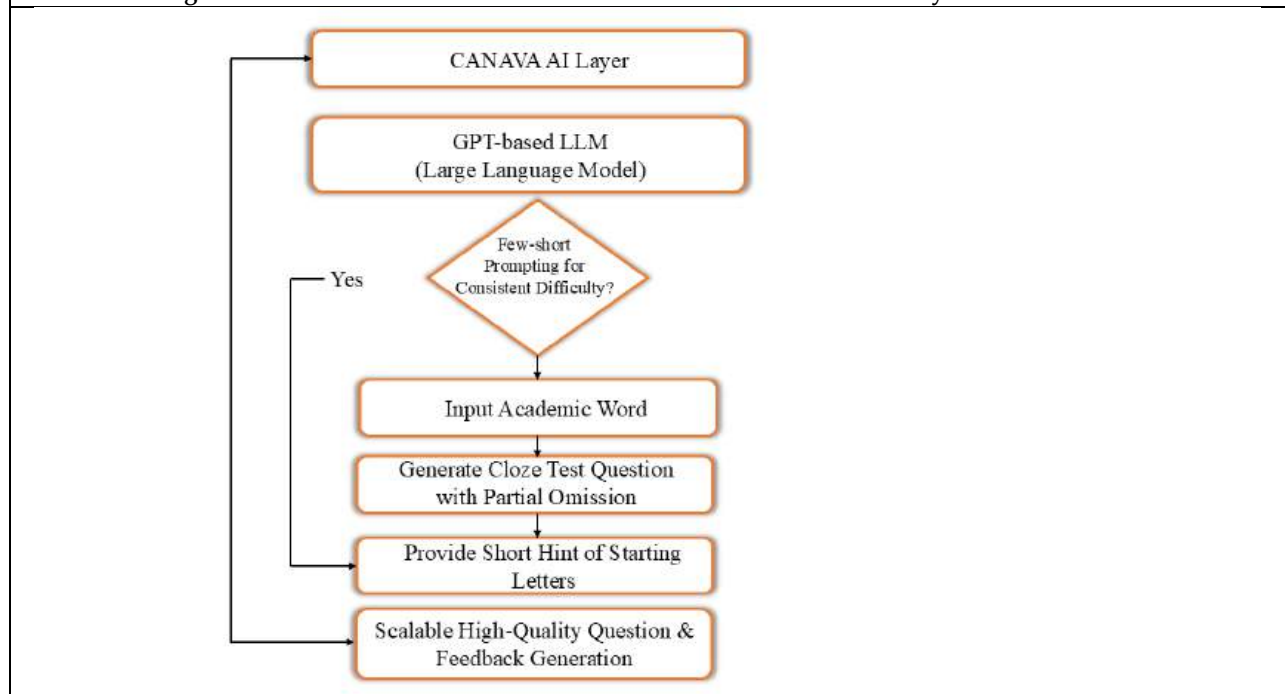


Figure 3. AI Model integration





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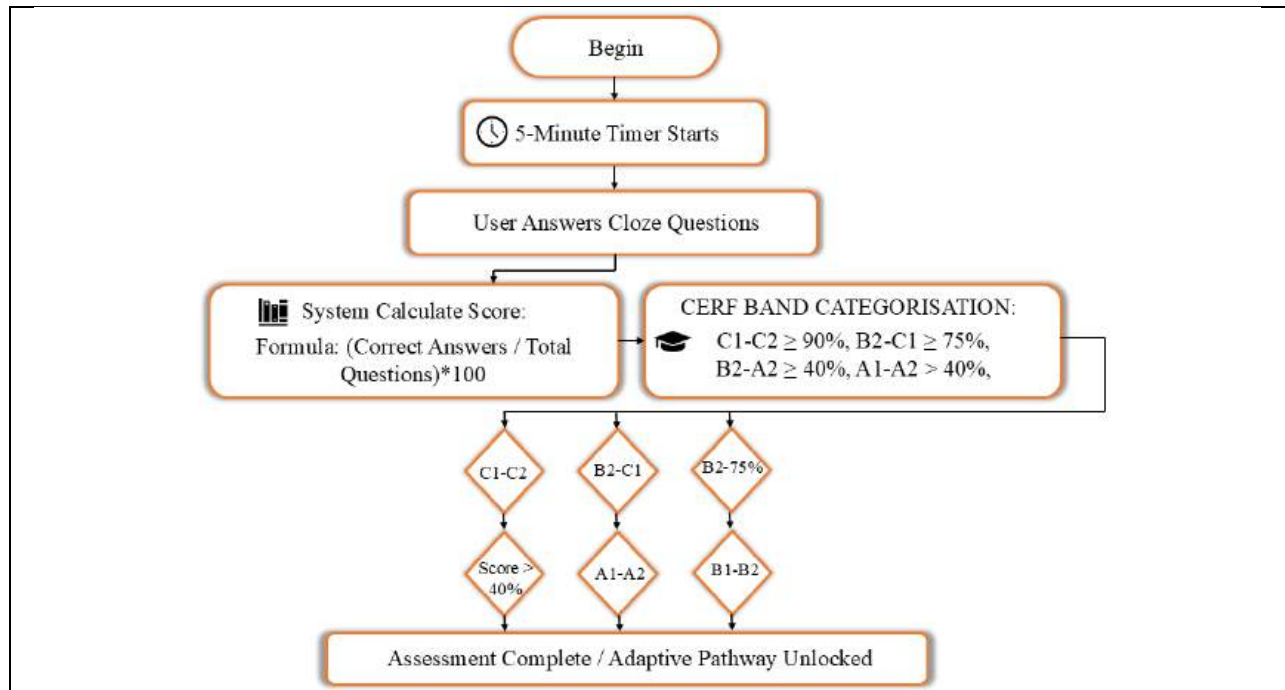


Figure 4. Assessment Workflow

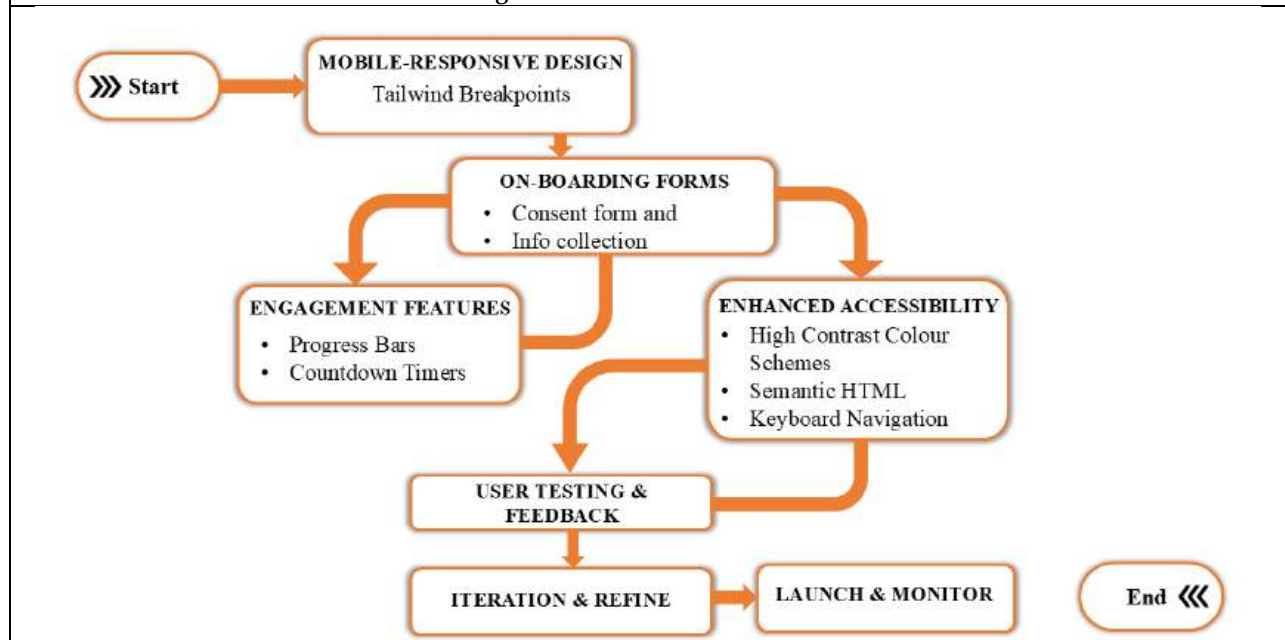


Figure 5. UI-UX Design





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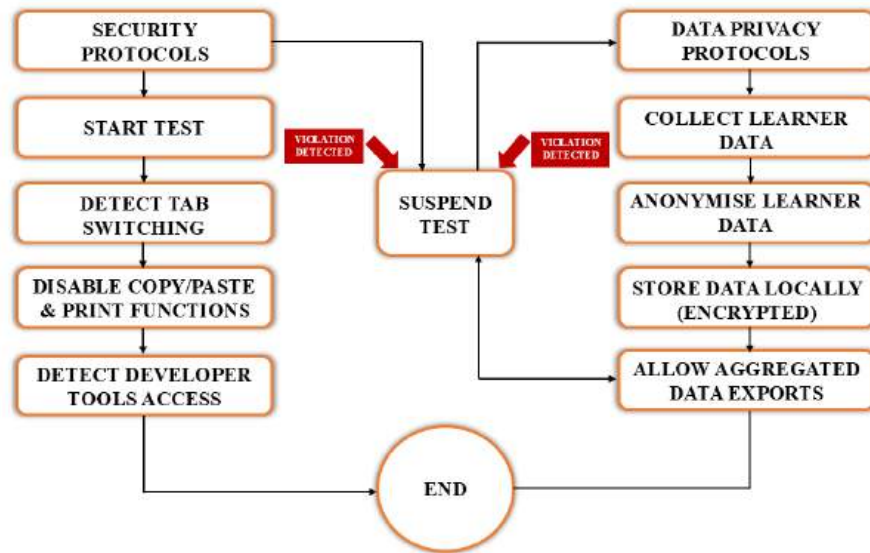


Figure 6. Security and Data Privacy

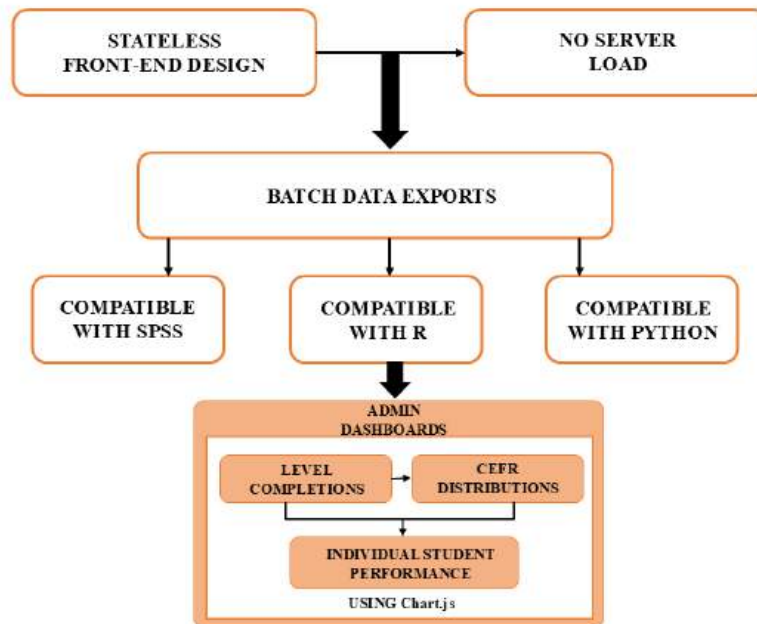
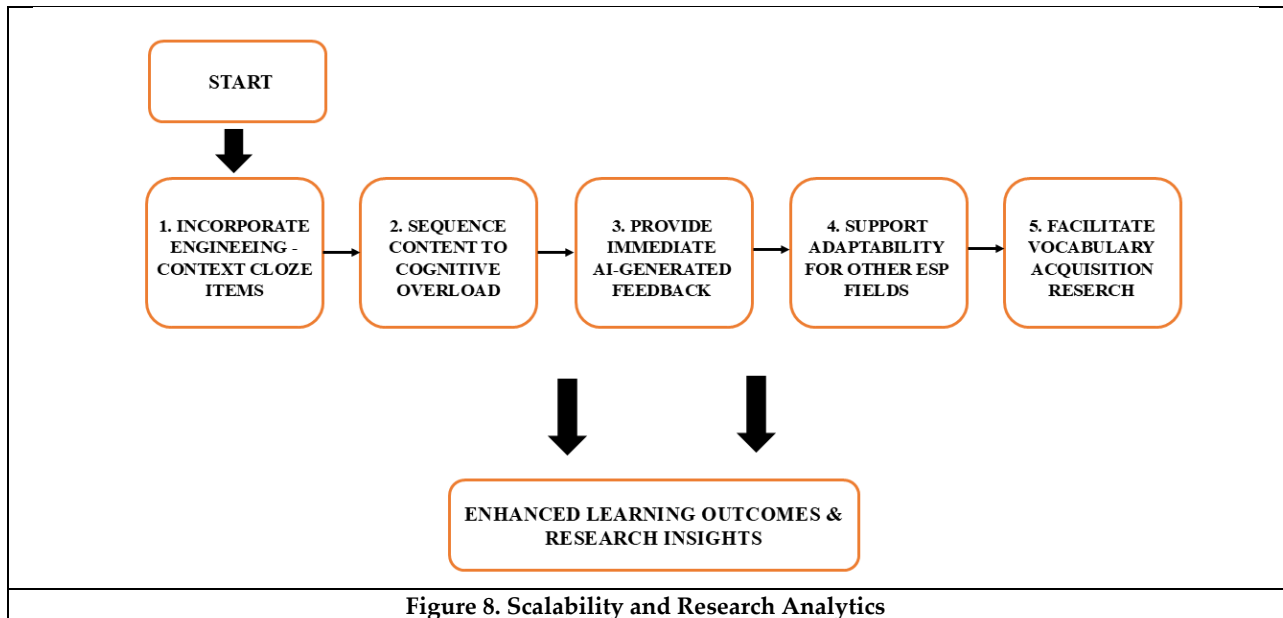


Figure 7. Scalability and Research Analytics



**AnilKumar et al.,****Figure 8. Scalability and Research Analytics**

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RESEARCH ARTICLE

Indian History through Indian English Non-Fiction in Writings of William Dalrymple

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ABSTRACT

The abstract explores the theme of Indian History through Indian English Non-Fiction as reflected in the writings of William Dalrymple, particularly in his seminal works *Nine Lives: In Search of the Sacred in Modern India* and *The Age of Kali*. Dalrymple's observations offer profound insights into the multifaceted tapestry of Indian history, culture, and spirituality through narratives of individuals from diverse religious backgrounds. In *Nine Lives*, Dalrymple examines the sacred dimensions of modern India through the lives of Jain nuns, temple dancers, matriarchs, and hijras. The intertwining of religion and gender is explored, revealing traditions that shape social and cultural dynamics. Jain nuns provide insight into the disruption of traditional gender roles through religious ideologies. Temple dancers illuminate the historical exploitation and resilience of women in religious contexts. Matriarchs challenge conventional gender norms, demonstrating the evolution of women's roles in family leadership. Hijra communities reveal the historical context of non-binary gender identities in India and their continuing struggles within society. *The Age of Kali* further enriches the understanding of Indian history through non-fiction by examining the social and cultural transformations of contemporary India. Dalrymple portrays the matriarchs of Kerala as emblematic of women who challenge conventional gender norms, offering historical insights into the changing landscape of gender roles in India. His exploration of hijra communities in Kolkata highlights their historical significance in religious contexts and showcases their role as agents of social and cultural change throughout history. In Dalrymple's non-fiction works, *Nine Lives* and *The Age of Kali*, the author offers a historical perspective on religion, gender, and society in India. Through vivid storytelling, he traces the roots of Indian traditions and highlights the evolving roles





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of women, from Jain nuns to the matriarchs of Kerala. These narratives deepen the understanding of Indian history and culture, making these works essential readings for exploring India's diverse heritage.

Keywords: Religion, gender, spirituality, tradition, cultural transformation.

INTRODUCTION

In the vast landscape of Indian literature, the genre of Indian English non-fiction stands as a significant conduit for exploring the complexities of Indian history, culture, and society. This study endeavors to examine the rich tapestry of Indian heritage through the lens of one of its eminent voices, William Dalrymple. With meticulous research, empathetic storytelling, and keen observation, Dalrymple has emerged as a prominent figure in the realm of Indian English non-fiction, offering profound insights into the multifaceted dimensions of India's heritage. William Dalrymple, a renowned Scottish historian, writer, and broadcaster, has made indelible contributions to the understanding of Indian history and culture through his engaging narratives. His works not only serve as historical documents but also as captivating stories that illuminate the diverse experiences and perspectives within Indian society. Dalrymple's unique approach blends scholarly rigor with literary flair, making his writings accessible to a wide audience while maintaining academic integrity.

Central to this study are two seminal works by William Dalrymple: *Nine Lives: In Search of the Sacred in Modern India* and *The Age of Kali*. These books serve as windows into the soul of India, offering readers a nuanced exploration of its spiritual, cultural, and social landscapes. In *Nine Lives*, Dalrymple embarks on a journey across India, chronicling the lives of individuals from diverse religious backgrounds—Jain nuns, temple dancers, matriarchs, and hijras—to unravel the intricate tapestry of spirituality in modern India. Through empathetic storytelling, he delves into the sacred dimensions of their lives, shedding light on the historical roots and evolution of religious traditions. Similarly, in *The Age of Kali*, Dalrymple turns his gaze to contemporary India, examining the social and cultural transformations shaping the nation. Through vivid narratives and insightful analysis, he explores themes of tradition, change, and continuity, offering readers a panoramic view of India's complex reality (Kochuthresia 154). From the matriarchs of Kerala challenging conventional gender norms to the hijra communities of Kolkata asserting their historical significance, Dalrymple's exploration captures the essence of India's dynamic ethos (Thomas 262).

The study aims to unravel the layers of Indian history, culture, and society as depicted in William Dalrymple's works. By examining the themes, narratives, and methodologies employed by Dalrymple, the study explores the multifaceted dimensions of India's rich heritage and the enduring relevance of Indian English non-fiction in shaping contemporary discourse.

LITERATURE REVIEW

In the fields of Indian literature and historical scholarship, William Dalrymple's non-fiction works have garnered significant attention and acclaim for their insightful exploration of Indian history, culture, and society. Existing scholarship on Indian history, Indian English literature, and Dalrymple's works provides a rich foundation for understanding the themes and methodologies employed in his narratives. By reviewing existing literature, researchers gain a nuanced understanding of the thematic threads interwoven throughout Dalrymple's works. Themes such as religion, gender, spirituality, tradition, and cultural transformation emerge as focal points, inviting scholars to explore their significance within the broader context of Indian society. Anu Kochuthresia's review in the research paper, "**Gazing at the East: A Critical Evaluation of William Dalrymple's *Nine Lives: In Search of the Sacred in Modern India***" (2023), succinctly summarizes the impact of travelers' expeditions and their portrayal of India, particularly through the lens of William Dalrymple's work. In her review, Kochuthresia highlights Dalrymple's





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exploration of India in *Nine Lives: In Search of the Sacred in Modern India* and his encounters with a diverse array of individuals. She underscores Dalrymple's extensive travels throughout India and his focus on the country's contemporary Hinduism and occult practices, portraying India's spiritual landscape through the narratives of its inhabitants. Kochuthresia's review examines how popular Western travelogues often emphasize the mystical aspects of Indian culture, thereby fostering misconceptions about the prevalence of superstition and faith among its people. This critical evaluation sheds light on the tendency of tourists to exoticize and romanticize India while overlooking its complexities and diversity (Kochuthresia 153).

In Thomas's analysis, "**Play of Perceptions: The South Indian Identity in *The Age of Kali: Indian Travels and Encounters* and *Nine Lives: In Search of the Sacred in Modern India***", he discusses how the depiction of South Indian identity in works such as William Dalrymple's *Nine Lives* and *The Age of Kali* often accentuates mystical qualities, perpetuating negative stereotypes of superstition and blind faith among local communities. Thomas explores various hypotheses and caricatures of South Indians emerging from identity-mapping projects, noting that while some individuals maintain their cultural authenticity amid globalization, others are subjected to ridicule for their perceived antiquated beliefs. Thomas contends that writers like Dalrymple, through their narrative styles, inadvertently contribute to the reinforcement of biases against Indian culture. Although Dalrymple aimed for objectivity, Thomas suggests that certain passages in his works reveal underlying biases. By examining Dalrymple's interpretations, Thomas seeks to uncover implicit prejudices and encourage readers to reflect on societal assumptions. In essence, Thomas's analysis critiques the portrayal of South Indian identity in Western travelogues and non-fiction narratives, particularly through the lens of Dalrymple's works. By highlighting the intersection of language, worldview, and individual experiences, Thomas underscores the need for a more nuanced understanding of cultural representation and the implications of biased narratives in shaping perceptions of Indian society (Thomas 260).

In Vijesh's article, "**William Dalrymple's *Nine Lives: In Search of the Sacred in Modern India: A Semiotic Analysis of Culture and Language***," the author explores the intricate relationship between language and culture, emphasizing how language serves as a vehicle for expressing and shaping ethnic, regional, national, and global identities. Vijesh contends that language and culture are inseparable, like two sides of the same coin, with each influencing and reflecting the other. Through a semiotic analysis of William Dalrymple's *Nine Lives: In Search of the Sacred in Modern India*, Vijesh examines the intersection of language and culture. Using Dalrymple's work as a case study, he analyzes how language is employed to delineate the cultural identities of each character portrayed in the book. For instance, he highlights a Buddhist monk dedicating his life to crafting prayer flags after assisting Tibetans against Chinese invaders, and a Jain nun maintaining emotional detachment while witnessing her friend's self-imposed starvation. Vijesh underscores the diversity and richness of Indian culture through the varied stories of the nine individuals depicted in Dalrymple's work. By analyzing the linguistic and cultural nuances embedded within these narratives, Vijesh offers readers a deeper understanding of the intricate interplay between language and culture in shaping individual and collective identities (Vijesh 462–468).

Research Objectives for the Study

The research objectives for the study include:

- To analyze the portrayal of religion and gender in William Dalrymple's works by examining how these themes are depicted in *Nine Lives: In Search of the Sacred in Modern India* and *The Age of Kali*, with particular focus on the narratives of Jain nuns, temple dancers, matriarchs, and hijras.
- To explore the intersectionality of religion and gender by investigating the complex interplay between religious beliefs and gender identities, including how religious practices influence traditional gender roles and the challenges faced by individuals at this intersection.
- To evaluate the narratives' portrayal of opportunities for change and empowerment within religious and gender dynamics, including instances where individuals challenge societal norms and advocate for reform.



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- To contribute to a deeper understanding of religion and gender in contemporary India by synthesizing the findings to provide insights into the multifaceted nature of Indian identity and culture, as well as the complex relationship between religion and gender in the context of modern India.

Overall, these research objectives aim to provide a comprehensive analysis of the themes of religion and gender as depicted in Dalrymple's works, offering valuable insights into the intersection of these themes and their implications for individuals and society.

Identification of Gaps in the Literature

- Although diverse scholarly reviews have explored various aspects of Indian history and literature, there remains a need for in-depth analyses of the historical influences on the themes and motifs in Dalrymple's works.
- Gaps also exist in the examination of Dalrymple's portrayal of marginalized communities, the role of narrative voice and perspective in shaping historical interpretations, and the implications of his works for contemporary discourses on identity, representation, and power dynamics.

This study aims to address these gaps by providing a focused analysis of Dalrymple's exploration of religion, gender, spirituality, tradition, and cultural transformation in his non-fiction narratives. By identifying key themes and gaps in the existing literature, the study seeks to lay the groundwork for a deeper understanding of the significance and implications of Dalrymple's works for contemporary scholarship and discourse.

Themes in Dalrymple's Works

Dalrymple's portrayal of gender dynamics in religion and the historical evolution of gender roles in Indian society offers a rich tapestry of narratives that reflect the complexities, contradictions, and resilience of individuals navigating diverse socio-cultural landscapes.

Religion and Spirituality

In *Nine Lives*, William Dalrymple intricately weaves the themes of religion and spirituality throughout the narratives of Jain nuns, temple dancers, matriarchs, and hijras, offering profound insights into the diverse spiritual landscape of modern India. Through empathetic storytelling and meticulous research, Dalrymple explores the sacred dimensions of these individuals' lives, illuminating the intersection of faith, tradition, and personal devotion (Vijesh 462). The narratives of Jain nuns reveal the transformative power of religious ideology, highlighting the historical evolution of gender roles within Jainism and the ascetic practices that shape their spiritual journeys. The stories of temple dancers provide a historical context for the exploitation and resilience of women within religious spaces, shedding light on the enduring spiritual significance of dance in Indian culture. Matriarchs challenge traditional gender norms, offering glimpses into the historical transformation of women's roles as leaders and decision-makers within their families, rooted in spiritual beliefs and cultural practices (Thomas 260). The exploration of hijra communities unveils the historical context of non-binary gender identities in India, emphasizing their roles in religious contexts and the enduring challenges they face in society. Through these narratives, Dalrymple presents a vivid portrait of the intricate interplay among religion, spirituality, and individual experience, inviting readers to contemplate the diverse expressions of faith within the tapestry of Indian society.

Gender Dynamics and the Historical Evolution of Gender Roles in Indian Society

William Dalrymple's portrayal of gender dynamics and the historical evolution of gender roles in Indian society, particularly in *Nine Lives* and his other works, offers a nuanced exploration of the complexities inherent in the Indian social fabric. Through meticulous research and empathetic storytelling, Dalrymple provides historical context for understanding how historical events, cultural practices, and religious beliefs have shaped gender dynamics over time. His narratives highlight the intersectionality of gender and religion in India. Religious ideologies and traditions have influenced perceptions of gender roles, often reinforcing patriarchal norms while simultaneously providing avenues for resistance and transformation. Through the stories of temple dancers and matriarchs, Dalrymple



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illustrates instances in which women challenge traditional gender norms and assert their agency within their respective social and cultural contexts. Dalrymple also traces the evolution of gender roles in Indian society by highlighting shifts in attitudes, practices, and power structures over time. In his exploration of hijra communities, he sheds light on the historical significance of non-binary gender identities in India. By challenging binary notions of gender and sexuality, Dalrymple offers a nuanced understanding of the diverse expressions of gender identity within Indian culture. Throughout his works, Dalrymple employs empathetic storytelling to humanize individuals and their lived experiences, transcending stereotypes and fostering a deeper understanding of gender dynamics within Indian society.

Findings from the Analysis

The analysis of William Dalrymple's *Nine Lives: In Search of the Sacred in Modern India* and *The Age of Kali* reveals a rich array of themes centered on religion and gender. Through intricate narratives featuring characters such as Jain nuns, temple dancers, matriarchs, and hijras, Dalrymple explores the complex intersection of religious beliefs and gender dynamics within Indian society. These narratives emphasize how religious ideologies shape traditional gender roles, often challenging societal norms while simultaneously reinforcing them. Dalrymple's writings also reflect the broader cultural transformations occurring in India, depicting the evolving nature of gender dynamics, religious practices, and societal norms in the face of urbanization and globalization. While the narratives highlight challenges such as discrimination and marginalization, they also present opportunities for change and empowerment, showcasing moments of resistance, advocacy, and transformation.

DISCUSSION

William Dalrymple's empathetic storytelling serves as a powerful lens through which readers can gain a deeper understanding of Indian history and culture. Through his meticulous research, keen observations, and compassionate portrayal of individuals from diverse backgrounds, Dalrymple brings to life the multifaceted complexities of Indian society. By humanizing historical figures and contemporary individuals alike, he bridges the gap between the past and the present, inviting readers to empathize with the triumphs, struggles, and aspirations of those whose stories he narrates. Whether chronicling the lives of Jain nuns, temple dancers, matriarchs, or hijras, Dalrymple delves beneath surface narratives to uncover the underlying nuances of Indian culture and spirituality (Shingal 107–123). Dalrymple's narratives also serve as a valuable lens through which to understand the intricate relationship between religion and gender in India. They illustrate how religious beliefs and practices can both challenge and reinforce established gender norms, shedding light on the complex dynamics of faith and identity. Through the stories of these individuals, readers gain insight into the resilience and agency of those who strive to create spaces of autonomy, transformation, and empowerment within the complex fabric of their identities. His empathetic approach enables readers to connect personally with the individuals he portrays, fostering a deeper appreciation of the rich tapestry of traditions, beliefs, and lived experiences that shape Indian history. Through his storytelling, Dalrymple not only educates but also inspires empathy, compassion, and a nuanced understanding of the complexities inherent in India's cultural heritage.

CONCLUSION

This study has explored the rich tapestry of Indian heritage through the lens of William Dalrymple's seminal works, *Nine Lives: In Search of the Sacred in Modern India* and *The Age of Kali*. Dalrymple's empathetic storytelling, meticulous research, and keen observations offer profound insights into the multifaceted dimensions of India's history, culture, and society. Through his narratives, Dalrymple illuminates the themes of religion, gender, spirituality, tradition, and cultural transformation, inviting readers to reflect upon the diverse expressions of faith and identity within the Indian context. By addressing the gaps identified in existing scholarship and contextualizing Dalrymple's



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contributions within the broader landscape of Indian literature and historical studies, this research contributes to a deeper understanding of India's rich cultural heritage and the enduring relevance of Indian English non-fiction in shaping contemporary academic discourse. Dalrymple's empathetic storytelling encourages readers to engage with the lives of the individuals whose stories he recounts, fostering a greater appreciation of the complexities, diversity, and resilience that characterize Indian society.

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RESEARCH ARTICLE

Emoji and Interpersonal Meaning: Extending Halliday's Framework to Digital Communication

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ABSTRACT

The widespread use of emoji expands the digital communication which has transformed interpersonal meaning-making practices. Fewer analyses have systematically integrated them into the framework of Systemic Functional Linguistics (SFL). While emoji has been examined in pragmatics, sociolinguistics, and multimodal studies. This study argues that emoji function as structured interpersonal semiotic resources that realize affect, modality, engagement, and mood in computer-mediated communication by drawing on M.A.K. Halliday's interpersonal metafunction and appraisal theory (Martin & White, 2005). The study demonstrates that emoji operates as interpersonal adjuncts, intensifiers, and minor clauses within digital discourse, by using a qualitative–quantitative analysis of 500 social media posts from Twitter and WhatsApp. Findings of this analysis suggest that emojis are not peripheral decorative elements but increasingly grammaticalized resources that extend Halliday's interpersonal system into multimodal environments. The study contributes to the theoretical expansion of SFL into digital discourse and proposes refinements for analyzing interpersonal meaning in 21st-century communication.

Keywords: Interpersonal Metafunction, Systemic Functional Linguistics, emoji, digital discourse, Appraisal theory, Modality, multimodality.





INTRODUCTION

Digital communication has basically reshaped how interpersonal meaning is enacted. The environments of Computer-mediated communication (CMC) reduce access to prosody, gesture, and facial expression, thereby requiring alternative semiotic strategies (Crystal, 2011; Herring, 2007). Emojis have become globally conventionalized resources for expressing affect, stance, irony, alignment, and intensity, among these strategies. (Danesi, 2016; Evans, 2017). Halliday's (1978, 1994) Systemic Functional Linguistics (SFL), conceptualizes language as a social semiotic system organized around three metafunctions: ideational, interpersonal, and textual. The interpersonal metafunction mainly concerns social relations enacted through mood, modality, and evaluative resources. SFL's application to multimodal digital contexts remains underdeveloped, while SFL has been widely applied to spoken and written discourse. This study also extends Halliday's interpersonal framework to emoji use in digital discourse. Specifically, it analyses and addresses the following research questions: How do emoji realize interpersonal meanings in digital communication?, Can emoji be systematically mapped onto mood, modality, and appraisal systems?, and Do emojis demonstrate patterns consistent with grammaticalization?.

This study advances the multimodal development of systemic theory, by integrating quantitative frequency analysis with qualitative SFL-based discourse analysis. By functioning as visual interpersonal adjuncts that encode affect, adjust modality, signal engagement, scale evaluative force, and occasionally substitute for clause-level mood structures. Emojis operate as multimodal realizations of interpersonal systems traditionally encoded through grammar and prosody and realize interpersonal meaning in digital communication. Their patterned distribution across clause types and communicative contexts suggests that emojis are not peripheral embellishments but emergent semiotic resources integrated into the interpersonal system network of digital discourse, within a systemic functional framework.

Halliday (1978) conceptualized language as a resource for making meaning in social contexts. The clause functions as exchange, structured through mood (declarative, interrogative, imperative) and modality (probability, obligation, usuality, inclination) (Halliday & Matthiessen, 2004) within the interpersonal metafunction. While modality is encoded via modal operators and adjuncts (Eggins, 2004), mood is realized through the Subject–Finite configuration. The interpersonal system enables speakers to negotiate roles, alignments, and degrees of commitment. Martin & White's Appraisal theory (2005) expands interpersonal meaning into three subsystems: Attitude (affect, judgment, appreciation), Engagement (dialogic positioning) and Graduation (force and focus). Digital discourse studies have increasingly applied appraisal analysis to social media (Zappavigna, 2018). However, emoji have not been fully integrated into appraisal system networks.

In the late 1990s, Emojis evolved from Japanese mobile communication systems and were standardized via Unicode (Evans, 2017). Research shows that emojis that are used to highlight a primary human desire to add emotional and nonverbal communication to text-based interactions and improve the constraints of plain text. (Riordan, 2017). Signal irony (Dresner & Herring, 2010) theory was proposed by Eli Dresner and Susan C. Herring which displays graphic symbols function as illocutionary force indicators (IFIs) rather than just emotional displays in a seminal paper on computer-mediated communication. Tone of voice, facial expressions, and body language signal that a statement should not be taken literally in spoken conversation. In text-based communication, this paralinguistic context is missing.

A corpus of 500 publicly available posts were collected from Twitter (300) and from WhatsApp (200) with consent and anonymization, over three months time duration. English-language posts containing at least one emoji were included. The emoji was coded for Position in clause (initial, medial, final, stand-alone), Interpersonal function (affect, engagement, graduation, modality, mood substitution) and Co-occurring clause type (declarative, interrogative, imperative) for each instance emojis. Two rounds of coding were conducted to ensure consistency.





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The findings depicts that affect realization is the dominant function, but graduation and engagement also represent substantial categories.

The interpersonal meaning involves how speakers express feelings, judgments, and evaluations in SFL. This is called **Attitude**, which includes: Affect (emotion), Judgment (ethics/behavior) and Appreciation (evaluation of things) in appraisal theory (Martin & White, 2005). Often, Emoji functions as **compressed affect markers**. For example, “I got placement ☹️”. The crying emoji does not literally mean sadness; it encodes **high-intensity joy/relief**. It realizes, Affect (positive emotion) and Graduation (intensification). Instead of writing, “I am extremely happy.” Visually, the emoji performs that interpersonal work so emoji act as **interpersonal adjuncts encoding affect**.

Modality expresses degrees of certainty, obligation, or inclination in Halliday’s system. For example, “Can you send the report? 😊” The smiling emoji softens the request. It decreases imposition that corresponds to, Modulation (softened obligation), and Interpersonal mitigation. The clause may appear direct or demanding without the emoji and the interpersonal force changes with the emoji. Therefore, emoji, adjust interpersonal distance, modify perceived authority and re-calibrate power relations. They function similarly to modal adjuncts like, “just”, “maybe” and “please”.

Engagement concerns how speakers position themselves toward other voices (Martin & White, 2005). For example, “Sure, that’s ‘fair’ 😏” The laughing emoji indicates irony. It creates distance of the speaker from literal meaning, signals heteroglossia (other perspectives exist), and invites shared alignment. Emoji directs interpretation and prevent misreading. They perform as **interpersonal stance markers**.

Graduation makes adjustments in the strength of evaluation. For example, “That performance was amazing 🌟🌟🌟”. Repetition increases intensity. Emoji amplifies force, replace prosodic emphasis and function like typographical emphasis (!!!) we use, Stress, Pitch, and Facial expression. In digital writing, emoji perform this prosodic role in spoken language. Emoji shows speakers mood support and substitution while using mood structures enact speech roles like statement, question, and command. They operate as **multimodal interpersonal resources** within a written medium.

In digital communication, Emoji realize interpersonal meaning by functioning as visual interpersonal adjuncts that encode affect, adjust modality, signal engagement, scale evaluative force, and occasionally substitute for clause-level mood structures. Emoji operate as multimodal realizations of interpersonal systems traditionally encoded through grammar and prosody within a systemic functional framework. Their patterned distribution across clause types and communicative contexts suggests that emoji are not peripheral embellishments but emergent semiotic resources integrated into the interpersonal system network of digital discourse. Halliday (1978) described language as an adaptive semiotic resource. Emoji explains this adaptability in multimodal environments. Emoji display integrated into interpersonal system networks rather than existing outside grammar.

CONCLUSION

Emojis are not decorative but systemic interpersonal resources. They realize affect, modulate modality, manage engagement, and occasionally substitute for clause structure. Extending Halliday’s framework to digital communication demonstrates the continued vitality of systemic theory in evolving semiotic landscapes. Future research should examine cross-linguistic emoji use and longitudinal grammaticalization patterns.

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Table 1 : Distribution of Emoji by Interpersonal Function

Interpersonal Function	Frequency (n)	Percentage (%)
Affect (Attitude)	297	40.8%
Graduation (Intensification)	175	23.5%
Engagement (Alignment/Irony)	131	17.7%
Modality (Mitigation/Strengthening)	93	12.7%
Mood Substitution (Minor Clause)	41	5.3%
Total	737	100%

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RESEARCH ARTICLE

Imagining Planetary Futures: Ecocritical Analysis of Climate Crisis and Propositive Narratives in Kim Stanley Robinson's *The Ministry for the Future*

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ABSTRACT

Writing in the modern era has become increasingly significant as a means of linking moral and emotional issues to scientific realities as the climate crisis worsens. This article uses Kim Stanley Robinson's *The Ministry for the Future*, published in 2020, as an illustration of constructive climate fiction. This type of fiction goes beyond end-of-the-world scenarios, envisioning institutional solutions and collective action. The purpose of this study is to illustrate, via the application of ecocritical analysis, how the multiphonic structure of Robinson's novel, the composition of documentary and fictional elements, and the emotional journey all contribute to the development of critical hope and thought on a global scale. The article claims that a well-written piece of science fiction has the potential to assist one in understanding and teaching about the difficulties people have while depicting the Anthropocene.

Keywords: climate fiction, ecocriticism, Anthropocene, propositive narratives, Kim Stanley Robinson, environmental humanities.



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INTRODUCTION

The Intergovernmental Panel on Climate Change's Sixth Assessment Report says that temperatures around the world are likely to rise above 1.5°C above pre-industrial levels in twenty years. Environmental and social issues will start to happen one after the other (IPCC 2021). But climate change is hard for people to understand in the normal ways because it affects a lot of places at once and takes a long time to happen in geological time. Climate change is a "hyperobject," which means that it is so spread out in time and space that it cannot be normally seen or understood (Morton 135). Literature has become an important way to connect vague climate data with personal experiences, moral reflection, and political debate as mental and emotional stress grows. Stories about climate change can help people learn more about science. This is carried out by telling tales. Most news stories about climate change were about how it caused terrible natural disasters and people to fight over resources. There is a new type of climate fiction called "propositive." Not many bad things happen in this type of climax fantasy. To fix things, one has to understand how groups work, and make small changes that are more important. Kim Stanley Robinson's *The Ministry for the Future* (2020) is a great example of this good trend. The book has a made-up UN group whose job is to keep the kids safe and make sure everyone around the world does what they can to stop climate change. The story takes place between 2025 and 2050. Robinson's writing shows how strong emotions, a new story style, and a range of policy ideas can be used in literature to help with the important work of stopping and dealing with climate change. This study looks at *The Ministry for the Future* from a number of ecocritical points of view to answer some significant questions: What does the book do to make the story of climate change clear and make one feel about it? The second question is, which ecocritical theories best explain the text's formal and subject structures? Last but not least, what makes Robinson's "propositive" method different from the "catastrophic sci-fi" method? In real life, what does this difference mean? How could stories like these change what people think and what the government wants? What types of jobs can people get at school or with the government? To answer these questions, this article reads them carefully and thinks about them in a general way. Literature can give people the tools they need to deal with climate change in the long term, make hard science more interesting, and help people work together better.

Literature Review: Ecocriticism and Climate Fiction

The Anthropocene and Literary Representation

Human action has become the most important thing that changes Earth's systems, and people are now living in the Anthropocene. Adam Trexler, in his *Anthropocene Fictions*, talks about how stories can show the vastness of space and time. It says that fiction makes clear what scientific words often make unclear. This is tough to show in a picture because time moves slowly, the reasons are spread out, and what impacts people does not always match what impacts the world. They make it impossible to use normal story structures. This kind of damage to the land is called "slow violence" by Rob Nixon (Nixon 2). It takes a long time and cannot be seen. Literature answers by using new writing styles like multi-temporality, polyphonic narrative, and documentary-fictional hybrids that turn scientific facts about climate change into emotional experiences (Trexler 8–12). These techniques help readers understand things that are hard for them to grasp and also make them feel threatened by things that are not real.

Econarratology and Formal Innovation

Econarratology, the study of how story structure expresses ecological themes, has become an important framework for examining the formal strategies used in climate fiction. The author Xiaowen Xiao is of the opinion that contemporary climate fiction makes use of "narrative instability" in order to emphasise how unpredictable the weather may be. It accomplishes this by demonstrating to readers that the world is in a state of instability by presenting them with a number of different possible futures, timelines that are broken, and stories that are impossible to trust (Xiao 540). These stories do not provide readers with a sense of closure; rather, they teach them what Xiao refers to as "narrative endurance," which is the ability to deal with ambiguity and remain free even when there is no end. Because it is difficult to forecast climate change due to feedback loops, tipping points, and



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compounding repercussions, this formal approach was developed. Ulrike Krause investigates the ways in which science fiction draws on experience and metaphor in order to establish a connection between scientific ideas and human feelings (Krause 72). The most effective approach for people to learn is through the telling of stories in these ways, which not only keeps their attention but also demonstrates how ecosystems are connected and how to comprehend the comprehensive picture.

Propositive versus Catastrophic Cli-Fi

Martin Ryle makes a distinction between catastrophic sci-fi, which imagines the end of the world, and propositive sci-fi, which imagines changes to institutions and group answers (Ryle 265). Most of the stories in this genre are catastrophic, showing worlds after society has fallen apart. Even though these kinds of stories do a good job of explaining what is at stake, critics are starting to question how useful they are for politics. Some researchers say that catastrophic climate fiction could lead to “climate fatigue,” which is when people become less sensitive to disasters after seeing them too many times (Ismail 895).

Propositive sci-fi does not focus on how people stay alive in destroyed worlds; instead, it imagines changes to institutions, technological answers, and group action. Adeline Johns-Putra says that care-oriented climate fiction teaches readers to care about future generations and vulnerable groups. It does this by teaching them ways to be responsible that are not just in their own best interests (Johns-Putra 170). Robinson’s writing is a great example of techno-optimistic positive science fiction because it shows in great detail how policies work, how environmental technologies change the economy, and how policies work. It is possible to doubt if these types of stories do not consider the political issues that exist, mainly the fact that capitalism is structurally resistant to decarbonisation, or if they give the creative tools people need to change the whole system (Estok 295). When people talk about climate change, there are bigger differences between being serious about the problems and seeing hope as a strategic necessity.

Narrative Form and Planetary Scale**Polyphonic Structure and Collective Agency**

The Ministry for the Future uses radical polyphony, weaving together dozens of different voices: survivors, governmental players, collective entities, and nonhuman points of view. The book starts with Frank May’s terrifying first-person account of escaping a terrible heat wave in India that kills twenty million people. This creates emotional stakes through direct experience. The story then turns to Mary Murphy, who is in charge of the Ministry. Her third-person chapters describe how the institutions respond, including committee meetings, diplomatic talks, and problems with getting money. “You are in the future now, and it is a strange place” (Robinson 45), which is a straight address to the reader in a different chapter. This piece of speech blurs the line between the fictional world and the reader’s own life, making the climate crisis seem like a shared problem instead of something far away to think about. In other chapters, nonhuman entities like photons, carbon molecules, and market forces are talked about. These entities decentre human uniqueness and show how the environment is connected. Carbon says in one chapter, “We are you and you are us, and we are all in this together, the whole planet” (1899). This approach of using multiple narrators is very important for environmental reasons. First, it shows that the climate disaster cannot be stopped by a single person or group. Instead, problems on a global scale need collective action from many people and groups. Second, it shows how different levels of reality are linked, from personal trauma to institutional policy to the biogeochemical cycles of the planet. This shows how both crisis and reaction are part of a larger system. Third, it breaks the rules of anthropocentric storytelling by giving nonhuman characters a voice and recognising that they have power over the futures of the world. So, the polyphonic form works on the ecological principle of interdependence, turning the complexity of the system into the structure of a story. Readers do not experience climate change as a single storyline, but as a property that arises from many processes interacting with each other. This is a formal innovation that mirrors the reality it describes.



**Aswathy and Karthik Kumar****Documentary-Speculative Hybridity**

A term that might be used to define Robinson's work is "documentary futurism." He combines actual documentary film with extrapolations based on imaginary situations. Minutes from meetings, reports on the economy, scientific data, proposals for public policy, and ideas for technology of the future are all included in this book. For instance, it discusses the creation of artificial snow in order to melt glaciers, the fertilisation of oceans in order to assist them in absorbing more carbon, the development of a carbon currency that is based on blockchain technology, and the regulation of solar radiation by the introduction of particles into the stratosphere. By establishing a connection between what will occur in the future and the institutions, scientific knowledge, and political boundaries that are now in place, this combination of genres makes the stories more plausible. Robinson does not show a complete breakdown; instead, he extrapolates from current technologies and trends, making societal change seem possible rather than impossible.

Lakshmi Krishnan says that this "plausibilization" lets sci-fi work as a thought experiment, trying social arrangements and technological changes in story space before they happen in real life (Krishnan 4). As a way to teach, the documentary mode also teaches readers about economics, geography, and climate science with great accuracy. In chapters, carbon budgets, central banking, international law frameworks, and geoengineering science are all explained in clear but detailed language. But this teaching serves a narrative purpose: by explaining how things change, Robinson makes systemic reform real instead of abstract. People do not just learn that things need to change; they also see how it might actually happen, like what committees would meet, what laws would pass, and what technologies would be used.

The hypothetical parts, especially geoengineering, start moral discussions about how people should interact with Earth's processes. Robinson says that these technologies are needed to deal with the climate emergency, but they come with a lot of risks, such as changing weather patterns, increasing global tensions, and the moral hazard of lowering the pressure to reduce climate change. Characters fight about who should be in charge: who decides to use geoengineering? Who is at risk when bad things happen? How does one strike a balance between short-term danger and long-term uncertainty? By putting these debates in a dramatic rather than an abstract setting, the book encourages readers to think deeply about them and shows them how to use collective reasoning to solve problems in the Anthropocene.

Temporal Structure and Incremental Change

The book *The Ministry for the Future* is set between 2025 and 2050, and it follows small steps toward growth instead of a catastrophic break. This framework of time goes against what most people expect from a story. Instead of building up to a big event, the book is made up of small wins, losses, and slow changes. Chapters are short and often broken up, just like climate change is spread out and does not happen in a straight line. What Xiao calls "narrative endurance" is built up through the pace; readers learn to deal with slow, uncertain progress (Xiao 545). Robinson gets readers ready for the real time of climate action, which is slow, frustrating, not enough, but important, by not giving readers the usual story satisfaction. "The work was never finished, would never be finished" (Robinson 563) is how the book ends, but it does not give a clear answer. This kind of open-endedness makes readers feel like they can take part instead of just watching, which helps them develop the attitudes they will need for long-term involvement.

Institutional Imagination and Political Futures**The Ministry as Collective Protagonist**

In contrast to most novels, which are about individual heroes, *The Ministry for the Future* is about an organisation. The Paris Agreement created a made-up UN agency called *The Ministry for the Future*. As part of its mission, it is responsible for ensuring that all individuals are aware of how to cope with climate change, handle carbon currency, and advocate for future generations on international forums. People alter the way that they think about agency by shifting the focus away from individuals and towards organisations and groups. It is not the case that the protagonist of the story is the attorney Mary Murphy. A greater number of people than anything else congregate around her, including scientists, bankers, activists, politicians, terrorists, and nonhuman forces. Whenever she makes a decision,



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she is forced to contend with a multitude of institutions, political happenings, and a large number of other individuals who have an effect on the outcome.

This book discusses a great deal about the functioning of institutions, including how organisations are formed, where money comes from, the law, and how to behave in a civilised manner. Readers can understand how the Ministry obtains funding, how it collaborates with the governments of other nations, and how it manages the bureaucratic processes of the United Nations by reading this article. Because of these particulars, it is feasible to alter the structure, which is in direct opposition to the neoliberal individualist concept that individuals can only take responsibility for their own decisions. In addition to this, it discusses the challenges that groups encounter, such as the challenges of slow bureaucracy, political differences, and moral issues. However, despite the fact that it is not a techno-utopian vision, the Ministry's victories are extremely uncommon, controversial, and ethically confusing. This will allow everyone to collaborate in order to answer.

Geoengineering and Technological Complexity

The book has a lot of arguments about geoengineering technologies, showing them as important ways to deal with the climate disaster, but also dangerous and morally questionable. Robinson talks about different types of geoengineering, such as pumping seawater onto Antarctic glaciers to make fake snow and slow the loss of ice, adding iron to the oceans to help phytoplankton grow and take in more carbon, removing carbon directly from the air, and putting aerosols into the stratosphere to reflect sunlight. There is a lot of technical information about each technology, and it is based on real scientific studies. However, each technology is also shown as experimental and not yet proven.

Characters fight about ethics and government: who decides to use geoengineering? What if one country moves on its own? When unforeseen events occur, such as monsoons that alter, floods in some areas, and damage to ecosystems, who is responsible for the risks that are associated with these occurrences? What distinguishes the risk that is present in the short term from the uncertainty that is present in the long run? The issues that are being discussed in these discussions are genuine scientific and political issues. It is irrelevant to Robinson's plan whether people are terrified of technology or if they are enthusiastic about it. The belief held by technophobic individuals is that the way the Earth functions should not be altered by humans. On the other hand, techophilia refers to the view that technology has the potential to improve things without enacting any changes in the way people live their lives. Geoengineering, on the other hand, keeps temperatures the same, but it also brings about new concerns, like changes in weather patterns, political disputes over who controls the climate, and the likelihood that emissions will not be decreased as much as they need to be. A variety of perspectives exist regarding the question of whether or not individuals ought to be active in the Anthropocene. In spite of the fact that this dialectical method acknowledges that "natural" baselines no longer exist due to the fact that the systems of Earth are so diverse, it continues to investigate recent changes with a great deal of attention and analysis. As stated in the book, geoengineering is neither a miracle nor a calamity. This is according to the literature. On the contrary, it is a region in which political ideologies are in conflict with one another, and in which nations are required to collaborate and maintain democratic governments at all times.

Economic Transformation and Political Violence

People in the book believe that there will be significant shifts in the way that businesses and new technologies operate. Using blockchain technology, Robinson proposes the creation of a carbon currency that would contribute to the reduction of carbon pollution. Due to the fact that there would be monetary compensation involved, individuals, corporations, and even entire nations would be compensated for storing carbon. Restoration would become more feasible as a result of this. When one reads this book, one will learn how to convince wealthy nations to pay higher taxes, how to convince less fortunate nations to forgive their debts, and how to convince central banks to prioritise climatic stability over economic growth. According to these points of view, capitalism is to fault for the climate calamity because it claims that it must continue to expand, that it forces other people to pay for the damage that it causes to the environment, and that it is solely interested in gaining more power and earning more money. In



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addition to this, they consider what will occur to the company in the event that capitalism is abolished. Robinson also shows political violence as a reaction to climate change, which is an unusual choice for a story. There is eco-terrorism in the book, such as sabotaging fossil fuel infrastructure, shooting down planes carrying climate deniers, and killing corporate leaders who are blocking progress. Some characters defend violence as the only way to stop what they see as genocidal inactivity, while others say it is useless and morally wrong. Robinson does not want an easy moral answer. Instead, he creates moral complexity. Frank, who lived through the heat wave, joins a secret network that is carrying out attacks. Mary, who is in charge of the Ministry, has to deal with the political fallout while also understanding people's intentions, if not their means. This lack of clarity is meant to teach by getting readers to think about tough issues like means and ends, legality and authority, violence and justice in times of existential crisis. The book does not support terrorism, but it does admit that when legal channels fail, and millions of people die, some people will think that chaos is okay. Robinson's propositional fiction is different from more idealised versions of smooth institutional change because it is realistic about political conflict.

Affective and Ethical Dimensions**From Trauma to Critical Hope**

The emotional journey of the book goes from trauma to grief to hard-won, cautious growth. The first heat wave sets up the emotional stakes: Frank's guilt over surviving, mass death, and institutional failure. In later parts, one can see how the characters deal with eco-grief, anxiety, and anger. Mary goes through burnout and hopelessness; Frank has PTSD; and other characters talk about feeling lost. Still, the story slowly builds up a list of small wins, such as successful geoengineering tests, economic changes, international cooperation, and ecosystem restoration. This path encourages what researchers call "critical hope" — not naive positivity, but recognising the difficulties while affirming the possibilities (Krause 85).

The book's language of hope is not emotional; it is calculated. A lot of times, characters stress that growth is only partial, fragile, and not enough. At the end of the book, Mary thinks, "They had done some good. Not enough, but some" (Robinson 541). This limited hope is meant to teach by showing how to be emotionally strong, which is needed for long-term climate action. Pure catastrophism can paralyse people; if things are going to fall apart anyway, why do anything? If people are sure that science will save them, why make any changes? Critical hope finds a middle ground between these two extremes, letting people have choices while also recognising their limits.

Ethical Complexity and Moral Education

The book has moral problems with no clear answers. It can be used to teach morals and practise being moral. When legal routes fail, and millions of people die, is ecoterrorism okay? Should one take a chance on geoengineering's unexpected effects or be ready for disaster? Who pays for adaptation? The people who caused the problem, or the people who are affected by it? How does one balance the needs of today with the needs of tomorrow? Characters think about these issues and show readers how to think morally.

Johns-Putra says that reading climate fiction helps kids learn care ethics, which means paying attention to how vulnerable people are, how they depend on each other, and their duty across time and space (Johns-Putra 175). By following characters as they make tough decisions, readers build the moral imagination they need to deal with the unprecedented ethical challenges of the climate crisis. The novel's polyphonic framework makes this moral work stronger by showing different points of view from the Global North and the Global South, from present and future generations, from human and nonhuman, and from institutions and individuals.

Reader Positioning and Civic Engagement

The novel's second-person chapters talk directly to readers, putting them in the middle of both the problem and the solution: "You know what you need to do" (Robinson 478). This type of rhetoric makes readers think of themselves as possible agents instead of passive viewers. The ending of the book supports this stance by implying ongoing work rather than completion. Such choices in stories may encourage people to get involved in politics, support policies, or organise, but there is not a lot of real-world study on cli-fi's effects yet (Milner 8).





Critical Evaluation: Strengths and Limitations

Strengths of Robinson's Approach

The Ministry for the Future has a lot of value for learning and teaching. It helps individuals grasp hard topics like economics, geopolitics, climate science, and more by thinking deeply about policy. Changes to systems are now real, not simply thoughts. It goes against the premise that each person is responsible for their own actions because it has more than one voice. Emotional pathways get away from both the paralysis of absolute dystopia and the ease of easy positivism. They establish a balance between calamity and hope. Using both real video and guesses makes the story appear more authentic. It also makes one think about how technology could be used to muck up elections and affect the way things work in politics. Many read and talked about the book, which shows that science fiction can have a big impact on society as a whole (Rani et al. 95). Most people who read academic climate discussions are experts. But popular fiction can reach millions of people and change the way they think about politics and the world.

CONCLUSION

Through formal innovation and institutional fantasy, *The Ministry for the Future* is a good example of climate fiction that makes one feel good. Its complex structure turns the global scale into a story form, showing how people can work together and how ecosystems are connected. The mix of documentary and speculation makes the story more believable and sets up moral arguments about how technology should be used. The institutional approach changes the way people think about agency so that it is structural instead of personal and explains how systems can change. The emotional path from grief to critical hope builds the emotional strength that is needed for long-term climate action. Robinson shows how literature can make the climate problem easier to understand, more interesting to feel, and more possible in politics through these methods. This study adds to ecocriticism by showing how propositive cli-fi can help us learn more about how literature's climate works. It shows how the form of a story can reflect ecological principles like interconnection, complexity, and emergence while also being used to test social arrangements. The book has important educational implications: teaching sci-fi in literature and environmental studies classes can help students think about the world on a larger scale, think about right and wrong, and imagine how politics might work. *The Ministry for the Future* shows that literature has an impact on climate discourse that goes beyond scientific papers and government records. The fact that policymakers, activists, and journalists liked the book shows that fictional imaginations can have an effect on policy discussions. Building "climate cultures" through literature is possible. These are shared ways of understanding and dealing with crises that combine scientific knowledge, morals, and political goals. In the future, researchers should compare authors of positive climate fiction, look at how readers actually react to it, and pay more attention to non-Western climate fiction, do intersectional analyses of climate justice issues, and look into how different media affect climate imagination. As the climate disaster gets worse, the emotional, moral, and creative aspects of literature help science and policy by providing important tools for dealing with the most important problem of our time. Robinson's book shows that positive stories can show how people can work together to make things better, make complicated systems easier to understand, and encourage critical hope—all of which are needed to imagine and create better possibilities for the whole world.

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RESEARCH ARTICLE

Mirrored Burdens: Emotional Parentification, Neglect and Traumatic Selfhood in *The Silent Patient*

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ABSTRACT

Parentification is a term used to refer to a child taking on adult responsibilities, providing care, emotional support and comfort for their dysfunctional parents at the cost of the child's own innocence, happiness and mental health. *The Silent Patient* by Alex Michaelides is a psychological thriller novel, and it explores the trauma caused by the long-term impact of emotional parentification on children through two main characters of the story, Alicia Berenson and Theo Faber. This book offers a rare literary exploration of emotional parentification and the devastating consequences it has on children. In this case, both protagonists as children inherit their parents' emotional and psychological burden and exhibit symptoms related to PTSD, anxiety, and unspoken trauma due to childhood role reversal, parentification and emotional imbalance. This paper relates this condition to foundational psychological theories of Miller and Boszormenyi-Nagy and recent empirical research to analyse how parentification creates depression, OCD and impulsive disorders. Through close textual analysis, it is found that Alicia Berenson's silence can also be read as a sign of emotional parentification, the silencing of needs and feelings to avoid trauma and abuse. Meanwhile, Theo's intellectual control, boundary violation, and obsessive behaviours can be read as a symptom of unprocessed childhood trauma. The analysis proves that Michaelides has used fragmented narrative structure, unreliable narration, and dual perspectives that mirror the effects of trauma on consciousness and memory, building the novel as a serious trauma narrative. This study bridges literary criticism and clinical psychology to bring out the importance of a psychological literary narrative. This paper argues that parentification should be recognised as a form of childhood ill treatment that creates trauma and causes crucial developmental issues that require therapeutic intervention and social policy.

Keywords: Parentification, Childhood trauma, PTSD, OCD, DTS, Neglect, Role reversal.





OBJECTIVE

To identify and analyse how Alex Michaelides has depicted the trauma of parentification through the characters of Alicia Berenson and Theo Faber in the primary text, mainly focusing on emotional parentification, role reversal, abusive childhood, and its disastrous impact on children.

INTRODUCTION

“Parentification robs children of their right to be children. They grow up fast, carrying loads far too heavy for their small shoulders, while their own needs are silenced, unseen and unmet.” (Chase, 1999) Do you ever feel that you have grown up too fast, especially when you are the eldest child of the family? If you ever felt the need to constantly take care of your siblings, manage household chores, and sometimes provide emotional support to either of your parents, all while being a child yourself (Stanić & Ajduković, 2025), you were not mature or grown up for your age; you were not appreciated, but parentified. You could have received compliments for being the obedient and responsible child you were, but while trying to step up and take responsibility, you lost your childhood (Trak et al., 2025). There is no problem in helping one’s parents with household chores or babysitting once in a while, but if it becomes a constant habit, then it is toxic for the child who is exposed to parentification. The term “parentification” was first coined by Ivan Boszormenyi-Nagy and Gerald Spark through the concept “Dialectical Relational Theory” in their book *Invisible Loyalties: Reciprocity in Intergenerational Family Therapy* (Parad, 1976) to describe how a child is expected by their parents to assume parental responsibilities. This happens in both healthy and dysfunctional families, but it becomes pathological when the child is burdened with excessive or inappropriate responsibilities for their developmental age. There are two significant types of parentification: emotional parentification, (Chase, 1999) in which the child is expected to provide emotional support, mediate a conflict, or provide caregiving to the parent, and instrumental parentification, in which the child takes on adult-like responsibilities like cooking, taking care of siblings, etc (Schorr & Goldner, 2023). Of these two types, instrumental parentification helps the child learn a few life-saving skills that will be helpful in the future and shapes them to be responsible and accountable, (Pretsch et al., 2025) but emotional parentification burdens them with unnecessary scars, and as a result, they are afraid to socialize and they also have a constant need to provide care and emotional support to whoever they think resembles the parent they once took care of. When the child is exposed to emotional parentification at an early age, (Monaco & Heesacker, 2025) he/she becomes internally vulnerable (Schier et al., 2015). It spoils the child’s mental development and pushes them to become mentally unstable adults who, when left unattended and rightfully cared for, are a risk to themselves and society (Rennison, 2015). This paper analyses how emotional parentification ruined the lives of both the characters Alicia Berenson and Theo Faber in the novel *The Silent Patient* (2019) by Alex Michaelides (Michaelides, 2019).

LITERATURE REVIEW: PERSPECTIVES ON PARENTIFICATION

The concept was first studied in the book *Invisible Loyalties* (1973) (Parad, 1976), through a revolutionary work on intergenerational family therapy by Nagy and Spark. The term ‘Invisible Loyalties’ describes how families have invisible ‘debts’ and ‘loyalties’ that get transmitted from one generation to another like a secret inheritance (Monaco & Heesacker, 2025). Children may feel that they owe their parents something in return for bringing them into the world, even when the parents are unstable and harmful (Miller, 1990). This feeling of needing to fulfil a void or gap that they were not responsible for is always unconscious (Parad, 1976). They don’t even realise that they feel this way. The child thinks it has to do anything and everything it requires to pay back their parents, and it sacrifices its own innocence and childhood in the process. The children feel the need to heal their parents’ emotional wounds, often ignoring their own developmental needs (Monaco & Heesacker, 2025). This framework brought forward parentification as an intergenerational phenomenon, where dysfunctional family structures ruin the emotional growth and maturity of the children through invisible emotional debts (Masiran et al., 2023). They also stated that



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only a parent who is damaged internally can create damaged children. It is all a cycle of events happening between generations (Parad, 1976). If the parents are hurt by their own parents and carry the emotional wounds from the past, they pass them on to their children, who take care of them instead of enjoying their childhood (Masiran et al., 2023). The children become trapped while trying to heal their parents' emotional wounds, and as a result, they are forced to sacrifice their own childhood. They also feel guilty if they cannot take care of their parents, even if they get hurt in the process (Iakab, 2025).

Following this theory, Nancy Chase, in her book *Burdened Children* (1999) (Chase, 1999), talks about parentification in a more comprehensive way. She draws a distinguishing pattern between two primary types of parentification (Huczewska & Mynarska, 2025). She says that while trying to take care of their parents, kids often become the 'parent' in the family, while parents act like children (Chase, 1999). She divides parentification into two types: instrumental parentification and emotional parentification. While the former can be beneficial for children when they grow up, the latter, on the other hand, burdens them with emotional stress, secrets and unnecessary responsibility (Iakab, 2025). She differentiated between adaptive parentification (age-appropriate responsibilities) and destructive parentification (overwhelming emotional responsibilities) to highlight both the benefits and disasters of parentification (Chase, 1999).

Alice Miller, a Swiss Psychologist, coined the term "Poisonous Pedagogy" to explain the mental control parents have over their children (Miller, 1990). She defines the term as a set of toxic child-rearing beliefs and practices disguised as "proper education" that are imposed on children to control their behaviour. These beliefs justify parental control, emotional manipulation, and the systematic breaking of a child's will, all under the guise of "doing what's best for the child" (Miller, 1990). It is a mental control technique that families use to have certain power and control over their children and normalise dysfunction in the family. She brought together a set of doctrines that are being passed on from one generation to another to maintain discipline and impose family order (Hooper, 2007). Few of them are listed here, "it says that parents deserve respect simply because they are parents, strong feelings are always harmful, the way you behave with your parent is always important than the way you really feel, god and parents should never be offended, obedience makes the child strong, pretending to have gratitude is always better than showing honest ingratitude, duty produces love, and so on" (Miller, 1990). These doctrines transmit psychological trauma and guilt-trip children into becoming the adults the parents want as they grow up (Hawthorne, 2025).

Imi Lo, an independent consultant and children's counsellor, emphasises that "sensitive, gifted, and empathic children" are more prone to being parentified because they feel the intensity of their parents' failed emotions and feel the urge to be a parent to them (Tolmacz et al., 2025). They can sense the emotional instability and unsafe conditions, and they take it as their responsibility to provide the care that they were neglected (Fatima & Bashir, 2025). This leads to anxiety and premature maturity (Tiwari & Woodward, 2025). She also states that all the suppressed emotions, anger and neglected needs stay within the child as it grows up and creates a psychic split, where one part of the affected child will go on as an 'apparently normal self' leading an everyday normal life, but the suppressed emotion creates a traumatised self, and it haunts them subconsciously (Tolmacz et al., 2025). As a result, they never feel safe or secure in any sort of relationship. They dissociate themselves from their inner experiences to survive, and constantly feel that their life is always incomplete, and it is partial (Dial, 2014). Lo also specifies a few adult patterns that parentified children exhibit, based on different parentification experiences. If parents praise their child only for his/her achievements, then he/she becomes a "human doing" (Earley & Cushway, 2002) rather than a human being and constantly feels the need to perform exceptionally to gain parents' love. If the parents are depressed and emotionally dependent on the child for their needs, then the child loses their own self, needs and identity and seeks parental love and care (Masiran et al., 2023). If a child is overburdened with responsibilities, then it develops a harsh inner critic that urges them to exceed all expectations and shine. If a child is emotionally abandoned, it feels spiritually orphaned and compares itself with others, making it impossible to fit in society (Dial, 2014). In case the parents turn out to be bullies, the environment that the child grows up in becomes toxic, and as a result, the child becomes allergic to soft emotions and always feels lonely (Monaco & Heesacker, 2025). In such cases, silence becomes the parentified child's defence mechanism as the child realises early on in life that showing emotion and being



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vulnerable in front of parents will only cause disappointment and trauma (Caruth, 2016). This forces the child to learn 'Silent scream' for survival. Lo also suggests that, despite the horrors faced in childhood, healing is definitely possible for parentified children because, as adults, they are highly sensitive, emphatic, kind and intuitive (Dial, 2014).

A recent study on parentification by E Trak et al in 2025, examining the relationship and difference between both parent-focused parentification and sibling-focused parentification, states that adults who have undergone both these conditions are most likely to be associated with symptoms of obsessive-compulsive disorder (OCD) and relationship obsessive-compulsive disorder (ROCD) (Trak et al., 2025). This study critically analyses how parentification creates maladaptive cognitive patterns that serve as a mediating path for obsessive beliefs, which are then manifested as obsessive-compulsive symptoms in adulthood (Baştan, 2025). This study also sheds light on how parents' role reversal in childhood and neglect affect not only emotionally but also psychologically, restructuring cognitive processing patterns, causing people to develop recurring, controlling behaviours in their adult lives and relationships (Trak et al., 2025). This study has surpassed Chase's distinction between the types of parentification (Chase, 1999). Both the parent-focused type and sibling-focused type of parentification nurture obsessive-compulsive symptoms in adulthood that force them to follow repeated controlling patterns of behaviour to survive mentally (Chua, 2025). The psychological damage of parentification does not grow out of specific relationship malfunctions but from the initial violation of rights, emotions, generational boundaries and the premature responsibilities that burden the child, regardless of whether it is focused on parents or siblings (Dariotis et al., 2023). This creates in them a need for control, perfection and reassurance, as they are mediating between childhood parentification and adult psychopathology (Trak et al., 2025).

Perspectives on Childhood Trauma and Psychopathy in *The Silent Patient*:

A recent study by Muhammad Zia-Ul-Haq has analysed *The Silent Patient* by Alex Michaleides from the angle of post-traumatic stress disorder. It has examined and identified PTSD symptoms in both the protagonists, Alicia and Theo, including hypertension, insomnia, hallucinations, nightmares and hyper-arousal emerging from their exposure to ill treatment at a very young age from their dysfunctional parents (Zia-Ul-Haq, 2023). This study applies Judith Herman's PTSD model (Herman, 2011) to analyse the behaviour of both Alicia Berenson and Theo Faber and associates it with the post-traumatic stress disorder paradigm (Zia-Ul-Haq, 2023). The people who are suffering from PTSD are known to have shame, guilt, drug addiction, social anxiety, suicidal behaviour, sleeplessness, etc (Viswanath, 2023), all these are seen in both the main characters in the novel. Theo, who was subjected to physical abuse as a child, fears his father and describes that his childhood was filled with anxiety, fear and suppressed anger (Manoranjani & Sripadmadevi, 2024). As a result, after growing up, he became afraid of society and started avoiding social gatherings and had difficulty making friends. He also suffers from sleeplessness and tries to take his life by consuming pills. He also starts smoking marijuana to reduce his anxiety and feel happy (Larik et al., 2025; Manoranjani & Sripadmadevi, 2024). He visits a psychotherapist to overcome his childhood trauma, which later on encourages him to become one himself to help others (Zia-Ul-Haq, 2023). While Alicia, on the other hand, suffers from childhood trauma all her life and becomes mentally affected, as she does not get any appropriate help when needed. She considers her husband, Gabriel, (Larik et al., 2025) to be her saviour and invests her feelings in praising him and loving him beyond measure, which, in turn, hurts her when she comes to know of his betrayal. On the whole, this paper talks about how childhood trauma brings PTSD through the characters in the novel (Tolmacz et al., 2025).

A recent study by Dr Viswanath scrutinises the text through the lens of psychopathy and examines how childhood trauma and repressions can become the major factor in turning a normal human into a psychopath (Viswanath, 2023). Psychopathy is described to be a personality disorder that affects the human psyche and affects a human's social behavioural system and nurturing traits like aggressive narcissism. This study also explains that psychopaths have no emotional connection (Earley & Cushway, 2002) with the outside world and humanity in general, and how they are selfish enough to do what they please without any guilt for violating societal norms. Children basically yearn for love and affection; when those needs are not met by their parents or caretakers, they develop a sense of



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anger and hostility towards their parents and start attacking society to avenge their wounded ego and self (Viswanath, 2023). Likewise, Theo Faber, who suffered from childhood physical abuse, turns to his wife, Kathy, for comfort and love, but when she betrays him with Gabriel, Alicia's Husband, he becomes jealous and stalks and attacks him in his own house (Sherin, 2024). He unknowingly triggers Alicia's childhood trauma by asking her husband to choose between his own life and her life. He chooses his own life, and Alicia, who was deeply hurt by a similar incident in her childhood, (Zia-Ul-Haq, 2023) becomes triggered and takes out her anger on Gabriel by shooting him. Alex Michaelides' portrayal of Theo Faber in the book helps the readers understand the depth of psychopathic behaviour in adults and serves as a major factor in understanding how childhood bad experiences and social factors affect a person's psychological development as they grow up (Sherin, 2024).

Another study by Banu Priya talks about Parental Alienation Syndrome (PAS) (Banupriya & Aravind, 2024) and how it affects children as they grow up. The study primarily states that the inability to be a good parent always arises from not getting good parenting while they were children. This study also applies PART theory (parental acceptance and rejection theory) by Rohner to explain how a parent's acceptance or rejection is reflected in the child's psychological development, shaping their mental health in the process (Banupriya & Aravind, 2024). It applies the PART theory to analyse how poor parenting in their childhood becomes a major cause for the pathological dependence of both main characters in the novel. Alicia, who was neglected and verbally abused by her father as a child, sees her husband, Gabriel, as a father figure in her life (Pratiwi, 2022). When he gives her the same emotional wound that her father once gave her, it triggers all the old, buried emotions of anger and rage, and she kills him (Banupriya & Aravind, 2024). Theo, on the other hand, suffering from the verbal and mental abuse from his father and unsupportive mother, decided to end his life by consuming paracetamol, but he got a psychotherapist's help and realised that he could be of help to others who also suffered as a child like him. But his father's abusive words and curses never left him (Nurjayanti, 2021). It was always with him in his memories and kept taunting him as he tried to become a better human being. In both their cases, it is the cause of their father's abusive nature that caused them to develop psychological adjustment issues as they grew up (Banupriya & Aravind, 2024).

Another recent study by Ashraf uses Sandor Ferenczi's trauma theory and the personality theory of Freud to study the main protagonist of the novel, Alicia Berenson, to examine how childhood abuse affects adult personalities (Ashraf et al., 2022). It analyses how Alicia's trust was abused by the people around her, as her friend Jean-Felix warns her not to trust the people around her blindly, especially Gabriel. This is one of the reasons why she remains silent after killing her husband (Arvira, 2021). It also talks about the subconscious rage that Alicia harboured early on from childhood, which she expresses on various occasions, even when she was with Gabriel. Alicia had distanced herself from society and her own relatives as a result of the abuse she faced as a child (Ashraf et al., 2022). It is because of the pain of not being loved when she was a child. Her brother-in-law, as well as her aunt, refused to support her after she murdered her husband. This was because Alicia was always aloof and kept her distance from the people around her (Mustafa 2021). Thus, Alicia's trust issues, her rage, depression, social exclusion, phobia, non-verbal expression and inappropriate behaviour are always the outcome of the verbal and mental abuse she faced as a child in the hands of her very own father (Ashraf et al., 2022).

A research study by S Amuthavalli has compared *The Silent Patient* with *Sharp Objects* by Gillian Flynn and brought out that parental influence plays a large part in developing a child's psyche (Amuthavalli & Rajkumar, 2022). It focuses on how childhood development is influenced by trauma he/she faced in childhood and how it contributes to mental growth. It also analyses how a person's id, ego and superego, as formulated by Freud (Rennison, 2015), are affected due to abusive parenting and later on reflect on how they behave as an adult.

Content Analysis:

This paper explores the theme of parentification and how it affects the psychological development of young adults through two of the main characters in the novel taken for study. *The Silent Patient* is a mind-bending debut thriller novel written by British-Cypriot writer Alex Michaelides (Sherin, 2024). It received universal praise, awards and accolades for its uniqueness and construction. The main protagonist of the novel, Alicia, is admitted to The Grove,



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which is a fictional psychiatric unit, after she is accused of murdering her husband, Gabriel (Celestina, 2021). She does not even utter a single word after the murder. She becomes silent, and all she gives as a testimony is a painting of a naked self-portrait and titles it ALCESTIS, based on an ancient Greek tragedy by Euripides (Larik et al., 2025; Michaelides, 2019). The beginning of the story starts with Alicia writing in her journal and ends with it. Theo Faber, the speaker of the novel, who joins 'The Grove' to treat Alicia for her muteness, tells the reader how Alicia was found by the police officers with a gun in her hand and slit wrists, after she allegedly murdered her husband (D Angreni, 2023). Her silence is a form of affective resistance, which is a bodily response to parentification and inherited guilt (Michaelides, 2019). Theo finds her in a heavily sedated state when he first meets her in the unit and immediately works on reducing her medication to make her sober enough to respond to therapy (Salsabila, 2025). Slowly, he tries to break the wall she has built around herself and starts penetrating her mind. He is seen as a persistent and patient therapist by Diomedes, who is the clinical director of the unit. Deep down, he tries to help Alicia so that he can reduce his guilt (Michaelides, 2019). It is only revealed almost at the end of the story that he is the reason for Alicia's condition, as he unknowingly triggers a past trauma when he tries to make her see the real face of her lovable husband, Gabriel, who was secretly in a relationship with his wife, Kathy, while pretending to be loyal to Alicia (Michaelides, 2019). This paper helps to analyse how both Alicia and Theo were subjected to emotional parentification and how their trauma is not only seen as a psychological wound but also as emotional inheritance. Alicia's silence and Theo's urge to provide care are both the result of parentification. Both Theo and Alicia, failing to get their parents' love and care, became their own parents (Akram & Muhammad Akbar Khan, 2024).

Parentification and Emotional Burden:

Previous scholarship on *The Silent Patient* has talked about the psychological impact of parental influence on the main characters, Alicia and Theo and how they suffered from PTSD (Trak et al., 2025). They have all failed to acknowledge how they were parentified as children. They were both subjected to emotional parentification by their dysfunctional parents (Chase, 1999). This paper analyses their characteristics and psychological development from the perspective of parentification; to help the reader understand the major impacts emotional parentification could have on young children (Chase, 1999). The prologue of the novel starts with Alicia Berenson's diary. In the diary, she mentions that she has been depressed lately, and to help her, her husband Gabriel gets her a new notebook to write about her feelings, so she can clear her head and start concentrating on the upcoming painting exhibition (*Ek Abullah*, 2025). She mentions that she only started writing for the sake of Gabriel, so he would stop worrying about her (Sherin, 2024). Later on in the novel, readers come to know she has done many similar things to console and reassure him, like agreeing to see a therapist, so he would not worry about her. This shows that she has the habit of putting others before herself. This habit is one of the signs of emotional parentification (Bekkai s, 2025). When the child is neglected by parents and yearns for love and care, it starts treating love as a privilege it could never have, and when someone cares for the child, it starts treating them as a superior being and puts others' needs before its own welfare (Trak et al., 2025).

When she is trying to paint a portrait of Jesus for her art exhibition, she wants Gabriel to be her model. Such is the admiration she has for her husband. She fails to see all the human flaws that Gabriel seems to possess due to her unconditional love and admiration for him. This is because she is afraid of hurting his feelings and earning his wrath or disappointment (Tolmacz et al., 2025). She cannot afford to lose his love and care, as she feels that she is too crazy and undeserving of it. It is the lack of her father's love for her when she was a little girl that makes her yearn for Gabriel's love and cherish him more than anything in her life (Stolarek, 2014). There is one instance when Gabriel's big brother, Max, tries to misbehave with her. Alicia does not want to tell Gabriel about Max's behaviour as she fears it may upset or anger him and jeopardise his love for his brother. Alicia has ROCD (Relationship Obsessive Compulsive Disorder) (Trak et al., 2025); she is obsessed with Gabriel and his love for her.

This yearning for love and care started growing in her after her mother's death. It was one of the crucial moments that broke her childhood and reshaped it, turning her into an emotionally unstable person. Her mother killed herself by driving her car into a wall with her young daughter in the back seat, to escape her father's torture and toxic love (DO MUSTAFA, 2021). It deeply shook Alicia. She even mentions that her mother tried to murder her, as she



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willingly let her daughter ride with her when she was going to commit suicide (Faheem & Fayyaz, 2025). She does not remember what a mother's love is like; all she remembers when she thinks of her mother is the cruel act she performed that almost killed her. Her mother, Eva, was riding in a yellow car when she committed suicide. From then on, whenever she thinks of the colour yellow, she feels the wrath and disappointment she has had for her mother for years (SARAH, 2022). This is also the reason she does not want to have kids. She fears she might turn into her own mother and harm her kids. She does not want to put her kids through the same torture and parentification she went through as a little girl (Akram & Muhammad Akbar Khan, 2024). While her mother tried to murder her physically, her father emotionally murdered her. "...my poor girl, my Eva... Why did she have to die? *Why did it have to be her? Why didn't Alicia die instead?*" (Michaelides, 2019) After his wife's death, Alicia's father, Vernon Rose, due to the love he had for his wife, did something even more terrible than the act his wife attempted on their daughter. In his drunken state, he wished that Alicia had died instead of Eva, and Alicia happened to hear it. She feels her heart breaking and states that her father has emotionally killed her (Salsabila, 2025). Theo comes to know of it when he inquires about Alicia to her cousin Paul. Thus, Alicia lost both her mother and father on the same night; she never got love from her parents (Hossain, 2021). It was always her and her lonely thoughts in her world, until she met Gabriel. The trauma she experienced as a child kept recurring in her life even after she met the love of her life. By applying Caruth's trauma theory, it can be seen that trauma returns through silence and repetition later on in life (Faheem & Fayyaz, 2025).

Theo Faber is a psychotherapist, and he is trying to help Alicia, but he has also suffered from emotional parentification when he was a child. He was also brought up in an abusive household, where his father often verbally abused him, hit him, and demeaned him (SARAH, 2022). Theo and his mother were so afraid of their father that they celebrated the days he was away on business like a festival. They would make an ice statue of their tyrant, his father, on the snow outside and pelt it to vent their anger. He describes that the house was always either silent or filled with his father's shouting (Penih, 2022). His mother did nothing to support him; (Abullah & Mohammed, 2025) she was weak and subdued, having been parentified as a child herself and relying on her child for emotional support (Akram & Muhammad Akbar Khan, 2024). This characteristic of his mother made him yearn for a motherly figure who would rescue him from his father, and he found that in Ruth, his therapist. Later, when he met his wife, Kathryn, for the first time, he felt an unexplainable connection. This was because he had been searching for his mother in every woman he met (Anggraeni & Bowo, 2023). When he found Kathy, he saw similarities between her and his mother. That's why he fell in love with her instantly. Theo describes his wife as the person responsible for his happiness and the light in his life. He says she helps him drive away the demons that haunt him (Viswanath, 2023). But when she betrays him, he seeks revenge. He feels that his father's taunts and demeaning words never left him. Applying Hirsch's postmemory theory, it is analysed that he has carried his father's trauma with him as he grew up (Hirsch, 1997). He feels that the trace of his abusive father still resides within him and urges him to teach Kathy a lesson (Larik et al., 2025). "I didn't know it then, but it was too late – I had internalised my father, introjected him, buried him deep in my unconscious" (Michaelides, 2019). However, he does not act on this urge. Instead, he decides to expose the person who is wooing his wife, Gabriel. So, he breaks into Gabriel's home, ties both him and his wife, Alicia, to chairs, and exposes his secret love affair (Faheem & Fayyaz, 2025).

Silence as an Archive of Trauma:

Silence is seen as an enigmatic plot device, but it is actually an exposure of trauma when one cannot express their emotions. Alicia uses her silence as a survival strategy when she was abused as a child by her own father and Aunt Lydia (Bekkai & Amirouche, 2025). Her cousin Paul describes her to Theo as a child who did not speak much. She was always silent and in her own world (Zia-Ul-Haq, 2023). It was a way of protecting herself from the emotional wounds that were inflicted on her. Later, in the story, after she had killed Gabriel, she became totally silent and refused to speak, even when she was facing the trial (Arvira Pramesty Cahyani, 2021). It is because she was emotionally deeply hurt by Gabriel's betrayal, and his act of emotionally condemning her to death had caused such a deep wound that she could not speak (Tiwari & Woodward, 2025). She writes in her diary that Gabriel murdered her when he willingly let her die instead of him. It was just like how her father hurt her with his words (Stolarek, 2014). That is why she says that while he emotionally murdered her, she just pulled the trigger. "I saw it now. I would



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never be safe. Never be loved... I didn't kill Gabriel. He killed me. All I did was pull the trigger" (Michaelides, 2019). Her father must have also suffered from some sort of trauma and parentification as a child. Otherwise, how would a father wish his own daughter's death? Alicia is unconsciously carrying her father's trauma, relating her state to Marianne Hirsch's postmemory theory (Hirsch, 1997). Theo also used silence as a survival strategy when he was living with his parents to safeguard himself from his father's wrath. He was always silent as a child, so when he moved out of the house, he had no friends (Stanić & Ajduković, 2025). He struggled so much because of this when he was in university and decided to end his life. Such is the impact of emotional parentification on children. They use silence as a survival technique to shield themselves from the abuse and trauma inflicted upon them (Schorr & Goldner, 2023).

Loneliness and parentification:

When children are parentified, they often tend to lean towards loneliness as they have no one to express their emotions to. They get hurt by their parents' behaviour and feel that they don't have anyone to rely on, as their parents are emotionally abusing them (Penih, 2022). For a child, his/her parents are the first friends. They look up to their parents for everything and confide in them in times of despair. When they don't receive that kind of love from parents, they think that they have no one in the world who loves them and start distancing themselves from the outer world (Stanić & Ajduković, 2025). There is also another reason why emotionally parentified children prefer loneliness. When they see children who grow up with love and care from parents, they feel they are not deserving of parents' love and distance themselves from those children (Nurjayanti, 2021). This behaviour is reflected in *The Silent Patient* (Michaelides, 2019), in both Alicia and Theo. Alicia prefers loneliness because she does not trust the outside world. She only trusts Gabriel completely. He is perfect in her vision, and for him, she would do anything (Schier et al., 2015). When such a person breaks her trust, she loses her sense and kills him. Theo practised loneliness as he had no one in his life with whom he could share his past and wounds. He suffered from severe anxiety and loneliness when he was in college and tried to commit suicide (Penih, 2022). It is only after this incident that he considered visiting a therapist and met Ruth, who mended his wounds and made him feel worthy again (Schorr & Goldner, 2023). Kathy became the true companion that he yearned for in his life. But when she betrayed him, he lost complete trust in the relationship. Even then, he tried to win her back by silently removing her lover from her life, but all in vain (SARAH, 2022).

Art as Testimony: Alcestis and Parentification

Alicia's art stands as a testimony when she cannot speak for herself. She expresses all her emotions only through her art. For instance, she portrays her aunt Lydia as a comical, gigantic figure that provokes laughter (Abbas et al., 2025). This symbolises how she saw her as a child. Even though Lydia tried to boss around the house and take control of Alicia, she never saw her aunt that way (Pretsch et al., 2025). Meanwhile, Lydia failed to be a motherly figure to her. She also paints a self-portrait after killing Gabriel and names it Alcestis, an ancient figure from Greek mythology (Ahmed & Mohamad, 2025). Alcestis sacrifices her life so that her husband can live (Pratiwi & Pramesti, 2022). She is later brought back to life by the Greek demigod Heracles, but after coming back, she does not utter a single word, much like Alicia (Akram & Muhammad Akbar Khan, 2024). In the self-portrait, she is standing naked in front of a canvas and looking straight behind her, with blood dripping from her slashed wrists (Ahmed & Mohamad, 2025). Her eyes look blank, and nobody could read what she was going through when she painted it. Upon closer inspection, it becomes apparent that, in the shadows of the painting, a black figure lurks in the corridor (W. J. Celestina, 2022). This denotes the mysterious guy who broke into her house (Akhter, 2025). Her psychiatrist, Theo, gives her a chance to paint again, to see if that would make her express herself. She paints a portrait where The Grove is completely engulfed by fire, and Theo is seen carrying Alicia in his arms. It is indefinite whether he is trying to rescue her or throw her into the fire. By this, she expresses the suspicion she has of Theo (Ahmed & Mohamad, 2025).

Mothers and Their Role in Emotional Parentification:

Mothers play an important role in raising their kids. They are the primary caregivers, and they directly shape the child's sense of responsibility (Banupriya & Aravind, 2024). When the mother is emotionally weak or depressed, it often affects the child. The child tries to emotionally care for his/her mother (Abbas et al., 2025). This is the case of



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Theo. His mother is weak and depressed, and subdued by her father. He tries to care for her emotionally, and in the process, loses his childhood (Akhter, 2025). He has always yearned for a mother who would shield him from his father's abuse and who would tend to him and support him when he was hurt, but it was always the other way around. She might have felt guilty, but she is emotionally dependent on her child (Al Areqih, 2026). If we look at the relationship between Alicia and her mother, we can see the lack of motherhood she faced as a child (Baştan, 2025). When she needed her mother the most, she left her to suffer alone at the hands of her father and committed suicide (Ashraf et al., 2022; Aurel, 2025). Alicia carried this hollowness with her throughout her life. This created a terrible fear in Alicia that she never wants to have children, as she is afraid that she will turn out like her mother and abandon her child. She does not want her child to face the hardships she faced as a child (Aurel, 2025).

Climatic Imagery as Psychological Mirror:

In the novel, both Alicia and Theo mention the weather while describing their feelings and surroundings. Theo talks about winter, and Alicia about summer. Theo says that he feels the cold of the winter weather when he is working in The Grove (Baştan, 2025). He also mentions winter when he recalls his early life. "Somehow, grasping at vanishing snowflakes is like grasping at happiness; an act of possession which instantly gives way to nothing" (Michaelides, 2019). Alicia describes that the summer heat makes her feel drained and overwhelmed when she is painting. It is also mentioned that it was in summer that her mother killed herself. "It reminded me of another summer, hot like this one – the summer mum died" (Michaelides, 2019). Both express their emotions in the form of the weather. The characteristic of the particular climate mirrors their inner turmoil and psychological state. Winter is associated with coldness and a lack of warmth. Likewise, Theo feels coldness, violence, lack of warmth and neglect when he remembers his abusive childhood. He always feels emotionally drained (Akhter, 2025). Winter also resembles numbness. Theo becomes numb and suppresses his feelings to survive in his childhood house as well as the world (Baştan, 2025). Alicia describes that the heat of the summer is unbearable. It is symbolic of her longing for warmth, love, and being scorched by the lack of it. Summer also suggests overwhelming intensity, heat, vulnerability and burning trauma (Caruth, 2016). It denotes her anger because of her father's rejection and her inner rage. Her silence can also be read as the aftermath of that overwhelming heat. Both are deprived of parental warmth and love. Winter and summer imagery symbolise how they both internalised that deprivation differently: Theo by freezing his emotions and Alicia by burning inside. Here, seasons are the metaphors of memory (Chua, 2025).

CONCLUSION

Alex Michaelides' *The Silent Patient* offers a very deep interpretation of emotional parentification and how it psychologically affects children with long-term consequences that affect their behaviour, social circle, intimate life and mental health (Chua, 2025; Dariotis et al., 2023). This novel is full of truths that are too painful to articulate. Through the two major characters of the text, Alicia Berenson and Theo Faber, we can see that childhood ill treatment, parental abuse, and emotional detachment are signs of emotional parentification, and how it affected both of them in different ways (Chua, 2025). Even though they both lead different lives, they both grew up in an emotionally deprived environment, making them vulnerable to emotions like love, care and security. Alicia coped with emotional parentification through her silence and art, while Theo coped with intellectual control (Earley & Cushway, 2002). Theo chose psychopathy to help others who had a childhood similar to his, but in reality, he became a psychotherapist, so he could find people like him and find some similarities that could make him one with them, as he was so lonely as a child and adult (Fatima & Bashir, 2025). That is the main reason he chose to help Alicia. He saw something in her that drew him in, and his inner self found something similar to his own condition. He had Ruth to help him overcome his demons; he wanted Alicia to have someone to overcome her demons with, too (Earley & Cushway, 2002). On closer inspection of the text, they both are emotionally parentified and have carried the burden throughout their lives, but they have acted differently upon it (Faheem & Fayyaz, 2025). Alicia has suppressed her rage and bubbling emotions for a very long time, refusing to see a therapist or take medication, resulting in her acting out on that rage in the most vulnerable of times, when she shot Gabriel straight in the face. On the other hand, Theo suffered from loneliness and social anxiety throughout his adulthood, and at one time, he tried committing





suicide, but he realised that it was wrong and decided to see a therapist and try to become a better person who could help others like him (Hawthorne, 2025). Alicia was always unstable and had no control over her emotions. She even tried to commit suicide after her father's death and was known to have illusions and emotional breakdowns (Tolmacz et al., 2025). Even though Theo tried to become a better person, in the end, he did something terrible that speaks volumes about why he is his father's son (Hawthorne, 2025). He gave Alicia an overdose to silence her forever, to stop her from exposing him, failing years of therapy with Ruth. He was the one who broke into her house on the night of Gabriel's death to get his revenge (Stolarek, 2014). He wanted to punish Gabriel for having a secret affair with his wife, Kathy. He unknowingly triggered the suppressed rage within Alicia, resulting in her killing her husband in cold blood (Herman, 2011). All this is the cause of both their childhood trauma. As Sigmund Freud wisely said, "Unexpressed emotions never die. They are buried alive, and will come forth later, in uglier ways." (Rennison, 2015) As Alice Miller warned, "The more we deny our own childhood wounds, the more we inflict them on our children." (Miller, 1990) The novel's tragic ending suggests that recognising emotional parentification early on in life is necessary, but it is insufficient. Healing from parentification requires therapy, but neither character in the novel seems to have achieved it (Chase, 1999). 159.

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RESEARCH ARTICLE

Innovative Approaches in English Language Teaching for bridging the Skill Gap between Academic Education and Workplace Requirements

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ABSTRACT

The question of graduate employability has increasingly drawn attention in recent years, particularly in contexts where academic achievement does not automatically lead to successful job placement. One area that continues to influence this transition is the learner's ability to use English language effectively in professional situations. However, it is often observed that students, despite years of formal instruction, struggle to communicate with clarity and confidence during campus recruitment processes. This paper reflects on the role of English language training in addressing this concern, with a specific focus on the use of innovative teaching practices. Rather than treating language as a set of rules to be mastered, the study considers how classroom practices can create opportunities for meaningful use of English. Methods such as simulation exercises, task-based activities, role-based interaction, and the use of digital tools are discussed as ways of bringing real-world communication into the learning space.

Keywords: Bridging the Gap, Employability, English Language Teaching, Campus Placements, Communication Skills, Innovative Pedagogy, Experiential Learning, Professional Competence, Skill Development, Placement Readiness.



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INTRODUCTION

In recent days many companies started using communication skills assessment test as the basic yardstick which comprises exercises based on listening, speaking, reading and writing. Instead of traditional language teaching process which emphasizes on memorisation, grammar exercises and exams oriented questions and answers we are in a need to teach practical communication. There is huge skill gap between the expectations of the recruiters and the level of student's communication skills. Main reason for this skill gap is lack of practice. Though our students score good marks in English examinations the language proficiency is lacking due to lack of practice which is comfortable and useful to them. Innovative teaching approaches are the need of the hour to bridge the gap between skill set of students and the company's expectations. The four language skills LSRW are the major requirement for the successful career.

Innovative exercises for improving listening skills

Listening skill is important in attending meetings and comprehending, understanding information, and client communication. Listening effectively allows you to understand the speaker's message, emotions, and intentions. Effective listening is essential for building trust, empathy, and strong relationships in personal and professional settings. Listening and repeating: We can make one student in the classroom read sentences from the newspaper and ask all the other students to repeat with proper pronunciation and intonation in chorus for the first time and individually for the next time. At first this activity helps the learners to overcome their shy ness and in other way can improve concentration, comprehension and vocabulary.

Listening to audio clip and taking notes: In this activity all the students made to listen to an audio clip and take down important words and phrases .This helps the learner to improve concentration and note making skills which will be useful in the professional environment. Listening for specific information : In this activity students listen to an audio clip of a conversation and they have to answer the questions like form filling, gap filling, re-ordering sentences, and information transfer. Another listening exercise in this category is dictogloss. In this exercise, a group of students listens to a short passage at moderate speed and take notes after which they will be asked to restructure the original text. The students work in a group share ideas and restructure the sentence. This activity helps the learners to improve collaborative listening and accurate restructuring of factual information.

Innovative exercise for improving speaking skills:

Role play activity: Here students assume different roles in real life and respond to each other according to the roles given to them. This is an interactive teaching and learning technique which helps the students to improve fluency, confidence, communication skills and professional behaviour. This activity hypothesises a realistic atmosphere and the students get drilled to use English language effectively, naturally and meaningfully. Just a minute talk challenge: This is another innovative speaking activity used in the process of language teaching. Students are asked to talk on a particular topic for a minute and they should talk without hesitation, repetition or a long pause. This is a influential method which encourages students to think and react swiftly and express concepts unmistakably. This activity is broadly used in classrooms, recruitment process, placement training sessions and communication workshops. Picture description prompt speaking: In this activity the students observes a picture and describe it verbally with all the nuances like emotions, expressions, back ground details, people ,action and possible story or situations. This activity improves public speaking skills, communication confidence, presentation skills and creative thinking.

Innovative exercises for improving speaking skills:

Reading skills play an important role in the process of language learning, and it helps the students to develop communication skills, academic achievement and professional development. Students can improve intellectual capacity, vocabulary, critical thinking, and knowledge acquirement through proper training in reading activities. Reading activities enhance students' ability to interpret information, comprehend ideas, and respond profoundly.



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News buzz: In this activity the teacher can enhance the students to improve pronunciation, public speaking skills and confident elocution. The teacher selects the articles from the newspaper on the suggested areas like social issues, education, technology, sports and business. Students read the selected articles carefully and note the key facts, locate the main idea and highlight unfamiliar words. After this they involve in a group discussion, debate, interviews and news reader presentation. Students can get feedback from the teacher and peers based on fluency, content clarity, pronunciation and clarity presentation skills. **Story sequencing:** Story sequencing is an interesting activity where the teacher selects a story and shuffles the sentences and content and the students have to arrange sentences, events, and paragraphs of the story in the exact sequential order. This activity transforms monotonous reading process into an enjoyable and interactive one. Since this is a learner oriented activity student's gain interactive analytical thinking and multiple language skills. This activity also enhances the employability skills like logical reasoning tasks, professional problem solving, and creativity.

Innovative activities for improving writing skills:

Writing exercises enhances the students to express creative ideas, thoughts, and information effectively in written format which helps them to improve vocabulary, spelling clarity, grammar and organisation of ideas. These activities also help students to develop their employability skills like professional communication, analytical thinking, and creativity. **Scaffold guided writing practice:** Guided Writing is an ELT technique which encourages the students to write with the assistance of clues, outlines, prompts, images, sentence starters. The teacher selects and explains the topic at first and gives hints such as sentence starters, keywords, and outlines. And the students brainstorm the ideas and organise the thoughts in sequential order and write paragraph or essay with the guidance provided. This activity focusses on proper language use, vocabulary appropriate words, and coherent flow of ideas. It helps the students to improve communication competence, workplace documentation skills and professional success.

Dialogue writing practice: This is ingenious activity in which students create conversation with imaginary characters which helps them to improve their skills in functional English and conversational language skills. This activity encourages creativity and improves natural flow of dialogue, appropriate word usage, and originality of conversation. Dialogue writing exercises make the students get ready for customer service communication, team collaboration and professional interactions. And Companies always prefer applicants who can converse clearly and politely.

The students, language proficiency and employability skills can be improved by these pioneering activities based on LSRW skills. The training activities like JAM sessions, News Buzz, story sequencing, role play, guided writing, and dialogue writing generate collaborative and student centred classrooms. Through assimilating realistic situations, technology, and integrated learning methods in the process of English Language Teaching, teachers can bridge the skill gap between academic education and workplace requirements. Hence, for developing competent, confident, and employable students, progressive and innovative ELT practices are essential in the contemporary international environs.

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RESEARCH ARTICLE

Embodied Ecologies: Somatic and Environmental Resistance in the Fiction of Meena Kandasamy and Avni Doshi

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ABSTRACT

The environmental resistance in the contemporary Indian women's literature has been characterized as an intimate form of resistance that is also political in nature. This article proposes that Meena Kandasamy's *When I Hit You* (2017) and *The Gypsy Goddess* (2014), as well as Avni Doshi's *Burnt Sugar* (2020), form a part of the ecofeminist tradition of environmental resistance literature wherein the despoliation of the natural world is equated with the despoliation of the female body. Further, the resistance against patriarchal and caste-based violence is also a form of environmental resistance against the despoliation of the natural world. The theoretical frameworks utilized in the analysis of the two texts are ecofeminism, postcolonial ecocriticism, the logic of mastery as proposed by Val Plumwood, the notion of slow violence as proposed by Rob Nixon, as well as the notion of neuro-ecological fiction. The article proposes that the two texts under analysis portray a form of environmental resistance that is unique to the contemporary Indian women's literary tradition. The form of environmental resistance that is portrayed in the two texts is quiet in nature, cumulative in nature, bodily in nature, as well as radical in nature.

Keywords: ecofeminism, environmental resistance, Meena Kandasamy, Avni Doshi, *When I Hit You*, *The Gypsy Goddess*, *Burnt Sugar*, slow violence, postcolonial ecocriticism, body-land nexus, urban entropy, neuro-ecological fiction, Indian women's writing



**Gandhimathi and Sangeetha****Introduction: The Body, the Land, and the Logic of Mastery**

Val Plumwood's seminal eco-feminist work *Feminism and the Mastery of Nature* (1993) establishes the "logic of mastery" that underpins both women's oppression and nature's exploitation. This logic of domination is based on a series of interlocking dualisms of reason/nature, culture/body, male/female, human/non-human, where each pair is seen in opposition, with the first term of each pair being privileged, and the second devalued, in a relationship of domination and exploitation, not of mutual interrelation and coexistence. This logic of domination has resulted in a world where women and nature are simultaneously idealized and exploited, loved and destroyed, where women and nature are sources and waste products..

Contemporary women's fiction in India has engaged critically with this logic of domination in ways that are remarkable for their power and accuracy. Meena Kandasamy, a poet, novelist, translator, and Dalit feminist activist based in Tamil Nadu, and Avni Doshi, a Desi-American writer whose debut novel *Burnt Sugar* was shortlisted for the 2020 Booker Prize, are two women writers who have each written novels where the relationship between women's bodies and nature is not merely figurative but also substantive. Thus, the Tamil Nadu landscape of Kandasamy's *When I Hit You* and *The Gypsy Goddess* is at once the site of Dalit subjugation and environmental degradation, as well as the site of resistance. In Doshi's *Burnt Sugar*, the arid urban landscape of Pune is not merely the background but the mirror that reflects and enhances the psychological and intellectual decay that is the central theme of the novel.

This article is a comparative ecocritical analysis of the three novels with the argument that they form a cohesive and important tradition of environmental resistance writing that is part of the larger corpus of environmental writing in the context of contemporary Indian women's writing. There are seven sections to this article: the theoretical section, close readings of Kandasamy's two major works, close reading of Doshi's *Burnt Sugar*, the comparative analysis of the environmental resistance strategies used in the three works, the role of the female body as a site of ecology, the comparative table of the environmental aspects of the works, and the conclusion that places the works in the context of the broader tradition of environmental writing that is part of the ecofeminist writing tradition in India.

Theoretical Framework: Ecofeminism, Slow Violence, and Neuro-Ecological Fiction

Ecofeminism, as a theoretical framework developed by thinkers such as Vandana Shiva, Val Plumwood, Karen J. Warren, and Maria Mies, forms the principal theoretical framework for this analysis. The basic tenets of ecofeminism, which assert that the subordination of women and the subordination of nature are not merely analogous but are structurally linked, rooted in a common logic of hierarchy, are particularly relevant to the analysis of Indian women's fiction because of the complex interplay between caste, gender, and ecology.

Vandana Shiva's idea of the 'maldevelopment' paradigm is particularly relevant with respect to Kandasamy's work. Vandana Shiva's argument, as she outlines it in *Staying Alive* (1988), is that the imposition of Western models of development on rural communities in India has had the effect of dispossessing women of their traditional ecological role and destroying the biodiversity that is essential to the sustainable rural way of life. In Kandasamy's *The Gypsy Goddess*, the Dalit farming community of Kilvenmani is subjected to this process of maldevelopment: their farming labour is exploited, their access to the productive capacity of the land is controlled by the upper-caste landlord class, and their attempt to resist this process of exploitation is met with the violence that resulted in the massacre of 1968. The environmental aspects of this social disaster are as important as the political aspects.

Another dimension is provided by the theory of slow violence as formulated by Rob Nixon. According to this theory, the most devastating environmental damage is the damage that is not immediately visible, such as the gradual accumulation of pollutants, the gradual degradation of biodiversity, the slow poisoning of water and earth, and so forth. This theory is directly applicable to the formal techniques of both Kandasamy and Doshi, as neither of the novels depicts environmental crisis in terms of spectacular events, but rather in terms of accumulation, repetition, and the gradual degradation of landscapes and bodies.





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The idea of neuro-ecological fiction, which has been proposed in recent ecocriticism to define those texts in which the conditions of the environment are seen to have a direct impact upon psychological states, is perhaps the most interesting idea to apply to Doshi's **Burnt Sugar**. The narrative of cognitive decline in the mother figure, Tara, who suffers from Alzheimer's disease, is constantly correlated with the environmental decline of the urban landscape in Pune, implying that there may be a direct relationship between ecological decline and cognitive disintegration. The dying plants on Antara's balcony, the parched trees, the smell of rust and overripe fruit – they are all signs of an environment in distress, an environment that reflects the psychological distress of the damaged characters.

Meena Kandasamy's *The Gypsy Goddess*: Dalit Land, Caste Violence, and the Burnt Field

The Historical Context: Kilvenmani and the Ecology of Caste

The Gypsy Goddess (2014) is a fictionalised account of the Kilvenmani massacre that took place on Christmas Day, 1968, in which 44 Dalit agricultural labourers, mainly women and children, were burned alive in their huts by upper-caste landlords and their hired agents in retaliation for the demands of agricultural labourers for better pay. This is set in a small village in the Nagapattinam district of Tamil Nadu, in the fertile delta region of the Kaveri River. Kandasamy's novel is a kaleidoscopic narrative that eschews as much as possible the genre of the realist novel as much as it eschews the ideology that led to the massacre.

The environmental aspects of the novel are inextricably linked to its social and political aspects. The setting of the novel in the delta region of Tamil Nadu—paddy fields, irrigation channels, coconut groves, and the distributaries of the river Kaveri—is not only the backdrop of the story of Kilvenmani; it is also very much its object. The Dalit agricultural labourers in this novel are not only labourers; they are also the custodians of the land, its fertility, its ecosystem. The removal of the Dalits from the land—through economic mechanisms of bonded labour, social mechanisms of caste hierarchy, and finally physical mechanisms of arson and murder—is also an environmental removal. The burning of the Dalit huts is also the burning of the community's relation to its land.

The Burnt Field as Ecological Symbol

The most potent environmental image in Kandasamy's work is fire, the fire that burns the Dalit settlement, as well as the broader metaphor of burning that is woven throughout the imagery of the novel. The fire in *The Gypsy Goddess* is not transformative or purifying; it is an annihilating force. It burns the bodies of the women and the children, it burns the community in terms of its physical place in the land, and it is the ultimate expression of the logic of mastery, the burning of the dispossessed from the land they have worked so hard to build. The form that environmental resistance takes in the novel is the insistence of the Dalit people on staying on the land, their refusal to work for the wages and conditions that the dominant class landlords are offering, their insistence on being paid adequately for their labour, without which the fertility of the delta would not be realized. This, Vandana Shiva would call ecological labour resistance, and it is what the dominant class responds to so violently in the form of the massacre that is the subject of Kandasamy's novel.

Language, Landscape, and Dalit Ecopoetics

Kandasamy's use of the natural landscape is directly influenced by the ancient Tamil poetic tradition of Sangam literature, which uses a very formal codification of the natural world, such as the use of specific flowers, birds, seasons, and landscapes as metaphors or similes for specific emotional and social conditions. As the ecopoetic scholar Balaev has pointed out, Kandasamy's novel challenges the pre-existing conflicted landscapes and narratives of her native Tamil Nadu through a re-engagement with the ecological symbolism of the Sangam tradition. In this way, the Kaveri delta, whose ecology is encoded in the Sangam tradition's 'Mullai' landscape of pastoral forest, and whose fertility is the product of Dalit labor, is reclaimed as the site of Dalit ecological memory and Dalit political aspiration.

The experimental nature of the novel, the fusion of documentation and lyric, the direct address to the reader, and the metafictional elements of writing itself, are all part of the resistance. Refusing the traditional realism of literature, Kandasamy refuses the ideological stances that the dominant culture has employed in its literature of the Tamil land





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and its people. The form of the novel is itself an act of resistance that matches the resistance described in the novel. It is an assertion of the right to represent the land and the people as they would represent themselves.

Meena Kandasamy's *When I Hit You: The Confined Body, the Colonised Landscape* Domestic Space as Ecological Prison

When I Hit You (2017) is Kandasamy's autofictional retelling of her experience of being in an abusive relationship with a Communist Party functionary in a short marriage in Mangalore. The environmental aspects in *When I Hit You* are less obvious than in *The Gypsy Goddess*, although they are also structurally integral to the argument of the book. The apartment in which the protagonist is kept, an environment of total surveillance and control of movement, and the gradual dissolution of identity, can be seen, in ecocritical terms, as an ecological prison, an environment constructed to separate the protagonist from the natural world, the social world, and the world of relationships that have constructed her identity and agency.

The way in which the narrator becomes increasingly disconnected from the outside world—she cannot leave the apartment unaccompanied; she cannot access the internet, books, or other people without restriction; she cannot even access her own body without the husband's permission—is conveyed through imagery that explicitly uses the language of ecological deprivation. She is an image of wilt, of thirst, of a lack of access to light. The apartment itself, with its closed windows and its controlled atmosphere, is a space of atmospheric toxicity—an environment hostile to life. This is the logic of mastery on a domestic scale. The same logic that underlies the exploitation of ecological systems underlies the exploitation of the female body within the context of the institution of marriage.

Writing as Ecological Recovery

The narrator's resistance to her husband's domination is, centrally, a resistance enacted through language — through the writing that she continues to do in secret, the poems she hides, the narratives she constructs in the margins of permissible existence. In ecocritical terms, this linguistic resistance is also an ecological one: language, in Kandasamy's framework, is not separate from the natural world but continuous with it. The Sangam tradition that Kandasamy draws on throughout her work encodes the natural world in language, makes the landscape the medium of human emotional and political experience. To write is, in this tradition, to reclaim one's relationship with the natural world — to resist the ecological as well as the personal dimensions of confinement.

The novel emphasizes the need for resistance that is both bodily and ecological in nature. Memory, language, and creative practice are seen as the means of reclaiming both personal and ecological wholeness. The auto fictional hybridity of the novel brings forth a new form of literary resistance in the genre of Indian English writing. The act of writing the novel is an act of environmental recovery in the sense that the act of the protagonist leaving the apartment is the act of the land leaving the colonizers.

The Body as Ecological Site

The most radical argument that this novel makes along ecofeminist lines is that the body of the protagonist itself is an ecological site, a landscape which has been colonized, exploited, and damaged by the logic of patriarchal mastery, and which needs to be reclaimed through the same logic by which other colonized natural landscapes are being reclaimed. This argument is being made through the novel's use of the nature/culture nexus, the repeated imagery of growth and suppression, seasons and confinement, water and thirst that connects the protagonist's bodily experience with the ecological conditions of the world outside her apartment.

The similarities Kandasamy draws between the exploitation of women and the exploitation of nature are not simply metaphorical, but rather structural. The same logic of mastery that allows the husband to dominate the narrator's body is the logic of mastery that allows the agricultural land to be dominated by the upper caste landlords. The same logic of inferiority that allows the husband to dominate the woman is the logic of inferiority that allows the ecological environment to be dominated. Therefore, in this sense, *When I Hit You* is not simply the story of one woman's experience of domestic violence, but rather an exploration of the ways in which domestic violence is made possible,



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and an argument that the fight against domestic violence cannot be separated from the fight against ecological violence.

**Avni Doshi's *Burnt Sugar*: Urban Entropy, Ecological Memory, and the Slow Violence of the City
Pune as Ecological Character**

Avni Doshi's *Burnt Sugar* (2020), published in India as *Girl in White Cotton* and shortlisted for the 2020 Booker Prize, is located in Pune, the fast-expanding metropolitan city in the state of Maharashtra in western India. While the main concerns of the novel are related to the intergenerational themes between the protagonist Antara and her mother Tara, whose Alzheimer's disease forces the protagonist to confront their shared traumatic past, the ecological dimensions of the novel are both pervasive and significant. The city of Pune is not merely the location of the novel, but it is also the ecological character of the city, its ecological witness, and the medium through which the main arguments of the novel are being conveyed.

The opening description of the environment, "dust settled on rooftops, trees turned grey. Everything was thirsty," establishes the tone for the entire novel. This is not an atmospheric opening, but an argument. The drying up of the cityscape and the gradual disappearance of Tara's memory are described as similar phenomena, subject to the same laws. The dusty environment is a metaphor for Antara's emotional exhaustion and Tara's disconnection from reality. The novel links emotional exhaustion with environmental degradation, drawing upon the principles of eco-psychology, where the mental health of humans is inextricably linked to the health of the environment.

Ecological Imagery and Psychological Deterioration

However, as the narrative progresses, Doshi develops this ecological theme further with imagery that includes rot, decay, and heat. These sensory details, which include the sun beating down on the characters as if it is a punishment, as well as the smell of rust and fruit gone sour, echo the souring of Antara's emotional state. Antara's emotional collapse is paralleled with the polluted urban ecology. However, this polluted urban ecology is not coincidental but is rather a product of the modern Indian cityscape that is affected by the challenges of climate change, pollution, and disconnection from the natural world. Doshi's narrative is part of a subtle form of climate fiction that is characterized as not necessarily focusing on natural disasters but rather the entropy of the urban world.

The domestic space of Antara's apartment is also noteworthy. The plants on the balcony that wilt within days of being brought home, the scarcity of furniture, the dead plants – all are physical manifestations of a life stripped of natural connection. The apartment, like the psychological state of the narrator herself, is a space of ecological deprivation – a space in which life cannot be sustained because it has been severed from natural cycles of life. This is the urban dimension of the ecological crisis that Kandasamy's narrator undergoes in her domestic prison of her abusive marriage – in Doshi's novel, it is the prison that is the city itself, a space that has organized itself around a denial of ecological connection.

The Ashram as Ecological Alternative and its Failure

The most developed treatment of an alternative ecological vision can be found in the sections of the novel that describe the ashram of Baba, to which Tara flees in her youth. The ashram, with its garden, its communal practices, its rejection of the consumerism of the city, appears at first to be an ecological alternative, a place of sustainable communal living, far removed from the entropy of the urban environment. But Doshi does not allow this alternative to be romanticized; it is revealed to be just as much a place of exploitation and patriarchal domination as the family and the urban environment it seeks to escape. Baba's exploitation of Tara, his use of the communal practices and ecological resources of the ashram to assert his own power, is the same logic of mastery, only in 'green' packaging, patriarchal domination dressed up in the rhetoric of spiritual and ecological community.

This is one of Doshi's most astute political observations: that ecological alternatives which do not fundamentally challenge the patriarchal logic of mastery are not alternatives. The garden cannot redeem the exploitation of women. The community agriculture cannot make up for the hierarchy of spiritual authority. Doshi's argument suggests that



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true ecological resistance involves not just a new kind of relationship to plants and to the earth, but a fundamental rethinking of the social relations that shape access to both human and non-human resources.

Memory, Dementia, and Ecological Loss

The most original contribution of this novel to environmental resistance literature is its exploration of the link between cognitive decline and environmental decline. The Alzheimer's disease of Tara, her disconnection from her own memories, relations, and identities that define her selfhood, is always depicted in terms of environmental decline: her mind is depicted as a landscape losing its features, a river losing its channels, a garden losing its plants. This model of neuro-ecology implies that environmental memory decline—loss of community memory about nature, passed on from previous generations—may be a form of environmental violence. In the context of urbanising India, where the ecological knowledge of rural and semi-urban communities is under threat from the same forces of urbanisation that have destroyed the ecosystems those communities once lived with, the use of dementia as a metaphor for ecology has special relevance. The forgetting that Alzheimer's disease instils in the individual mind is reminiscent of the forgetting that modernising society instils in itself, as a way of forgetting the ecological knowledge that is necessary for the survival of the species: the knowledge of where plants grow, when the rivers will flood, and so on.

Strategies of Environmental Resistance: A Comparative Analysis**The Body-Land Nexus**

The most fundamental strategy shared by Kandasamy and Doshi is the construction of what ecocritics have called the body-land nexus: the systematic identification of the female body with the natural landscape, such that violence against one is rendered as violence against the other, and resistance by one is rendered as resistance by the other. In Kandasamy's *The Gypsy Goddess*, the bodies of the Dalit women burned at Kilvenmani are identified with the delta landscape that their labour has sustained; in *When I Hit You*, the narrator's body is identified with the natural world from which her confinement has severed her; in Doshi's *Burnt Sugar*, Tara's deteriorating mind is identified with the deteriorating urban landscape of Pune. In each case, the identification is not merely metaphorical: it is a structural argument about the common causes and the common conditions of women's bodily oppression and ecological exploitation.

The most basic strategy that is shared by Kandasamy and Doshi is the creation of what ecocritics have termed as the "body-land nexus," wherein the female body and the natural landscape are systematically linked in such a manner that any violence perpetrated upon one is also constituted as violence perpetrated upon the other, and any resistance offered by one is also constituted as resistance offered by the other. In *The Gypsy Goddess* by Kandasamy, the bodies of the Dalit women who were burned alive in Kilvenmani are linked to the delta landscape that they have worked hard to sustain; in *When I Hit You* by Kandasamy, the body of the narrator is linked to the natural world from which she has been disconnected by her confinement; in *"Burnt Sugar"* by Doshi, the deranged mind of Tara is linked to the deranged urban landscape of Pune. In each of these cases, the linking of the female body and the natural world is not merely figurative; it is constitutive.

Slow Violence and the Aesthetics of Accumulation

Both writers use the aesthetics of slow violence, as Nixon describes it, to represent the resistance of the environment. Kandasamy's novel works up to the Kilvenmani massacre as a series of small injuries, small humiliations, and small acts of resistance, a series of small events that constitute the social ecology of caste oppression. Doshi's novel works up to Tara's cognitive breakdown as a series of details about the environment, a series of events that constitute the ecological condition of urban entropy. In both cases, the form of the novel matches the politics of the novel, the politics of the crisis as a process rather than as an event.

Form as Ecological Resistance

In both cases, formal experimentalism is part of the environmental resistance. Kandasamy's hybridizing use of documentation, autofiction, and lyricism rejects the realism of the novel in much the same way that it rejects the



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caste-based, patriarchal conventionalities of the social world her novels portray. Doshi's non-linear narrative, unreliable narrator, and use of fragmentation as a structural element are part of the formal encoding of the environmental argument: the non-linear narrative reflects the non-linear ecology; the unreliable narrator reflects the unreliable urban environment that appears to be cohesive but has been quietly deteriorating.

Resistance as Recovery

The final, and perhaps most important, shared strategy is the emphasis on the idea that environmental resistance is not opposition, but recovery, the recovery of a relationship with the natural world that patriarchal and caste-based societies have destroyed. The narrator in Kandasamy's **When I Hit You** recovers her ecological relationship in the process of writing; the Dalit people in **The Gypsy Goddess** reclaim their place in the land in the process of political organizing; Antara, in Doshi's novel, in a less clear way, recovers her ecological relationship in the process of creating, in the process of writing, in the process of the novel itself. In each case, the process of resistance is also the process of ecological reorientation, the process of turning back to the natural world, away from the separation that patriarchal and caste societies have enforced.

Situating Kandasamy and Doshi in the Indian Ecofeminist Tradition

The environmental resistance in the three novels under consideration does not occur in a vacuum. Rather, it is part of a larger body of Indian women's environmental writing and activism that ranges from the Chipko Movement of the 1970s, in which the women's bodily relation with the forests of Uttarakhand formed the basis of an environmental resistance movement, through Vandana Shiva's theoretical work in eco-feminism, Arundhati Roy's activist writing, and Sarah Joseph's *Gift in Green*, to the new generation of Kandasamy and Doshi. What is particular to the contribution of Kandasamy and Doshi to this tradition is the emphasis that they place on the intersectionality of environmental resistance. Both writers argue that the crisis of the environment cannot be understood in separation from the crisis of caste (Kandasamy), or from the crisis of women's interiority (Doshi). There is no separate domain of the environment that needs to be defended by specialists; it is part of social life, inseparable from the conditions of women's existence, from caste and class, and from the psychological lives of damaged and healing selves.

Meena Kandasamy, in her position as a Dalit Feminist writer, lends an anti-caste dimension to her work on resistance that is not adequately developed in the ecofeminism movement in India, which, in its concern with the ecological practices of generic 'rural women,' failed to adequately address the issue of casteism in the distribution of ecological resources and the exclusion of certain women from access to these resources. Her argument that the destruction of the Kilvenmani people is at once a crime of caste, gender, and ecology is one of the most significant contributions to contemporary Indian eco-writing. Avni Doshi's contribution is on a rather different scale. She offers us the urban ecology of the postcolonial Indian metropolitan area within an ecofeminist context, which the tradition's previous emphasis on the rural or forest environment has not been able to accommodate. Doshi's *Pune* is not a natural environment in any conventional sense. However, it is an ecology, an environment of relations between human beings, built environments, and degraded elements of the natural world. The degradation of such an environment is just as politically important as the degradation of any forest or river. In this sense, too, Doshi's work can be seen as an extension of the ecofeminist tradition to the metropolitan spaces where the majority of India's women live.

CONCLUSION

Meena Kandasamy and Avni Doshi are part of one of the most significant transformations in contemporary Indian environmental literature, one that moves from the landscapes of wilderness, river, and forest that have been so dominant in the genre to the ecological spaces of the body, the apartment, and the city. The environmental resistance that both Kandasamy and Doshi offer is not one that is performed in spectacular confrontational ways, although Kandasamy's political activism does include that, but in the slow, incremental, and formal-experimentation work of making the ecological violence that patriarchal, caste-based, and developmental systems perform on women's bodies, women's minds, and the natural environments of the communities they regulate and control visible. In





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Kandasamy's *The Gypsy Goddess*, resistance is the assertion of the right of the Dalit community to the land whose fertility they have produced. In *When I Hit You*, resistance is the act of writing that the woman in the ecological prison of her marriage uses to reclaim her connection to language, community, and the natural world. Resistance in *Burnt Sugar*, the novel by Doshi, is an ambiguous act of resistance to personal and ecological degradation through the practice of art. These novels propose an understanding of environmental resistance that is both more intimate and more radical than the conventional understanding of environmentalism allows. They propose an environmental resistance that begins in the body, that is practiced in language, and that is inseparable from personal liberation.

The environmental crisis that India is facing in the contemporary period is not merely one of rivers, forests, and air, but also one of the intimate ecologies that human beings use in order to sustain their relationship to the world and to each other. Kandasamy and Doshi, in their own unique ways, have made the crisis of the intimate ecology visible, and have asserted, through the form and content of their fiction, that the solution to that crisis requires not merely changes in policy, but transformations in the social relationships that human beings have to women, to the non-human world, and to each other.

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RESEARCH ARTICLE

Rape Discourse and Expert Opinion: Attitudes Toward Survivors and Offenders in Contemporary Society

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The current study brings out the effective outcome of the emotions that a victim undergoes during and after a tragic event. Any tragedy that is to happen and that has happen involves the irresponsibility of a citizen or individual of any nation. Hereby this study deals with the vaporization of emotions. Researcher has interviewed heterogeneous experts, they were provided with the following questionnaires.

The questions are pertained to the following aspects.

1. The situation that made the rapists to be involved in the activity.
2. Cultural drawbacks and differences.
3. The role of education of sex.
4. The event of creating awareness.
5. The various responses depending on physic and psyche.
6. Everlasting acceptability by the family and friends.
7. Individual contribution to the fact.
8. A criticism on the media.
9. The survey on the data depending on the social group.
10. Consequences relating to the tragedy.

Interview is one of the most comprehensive ways of carrying out a research on a specific topic. It is more informative and enlightening than the personal experiences or questionnaire. The researcher has prepared a set of 10 questions to derive information on the following aspects.

1. Role of Government in constructing safety measures.
2. The active suggestions for punishing rapists.
3. The renewal of routine life as a victim.
4. The mental state of overcoming the issue.



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5. Influence of tragic emotions after marriage.
6. Physical disorders to be a reason.
7. Financial crisis to be a drawback.
8. Age factor – a hurdle?
9. On a time for the victims to break silence.
10. Empathy of an individual.

These are the major proposed questions to the heterogenous experts. The cases responded with different and unique responses depending on the questions asked.

CASE-1-GENDER:FEMALE, AGE: 39, PROFESSION: JUDICIAL MAGISTRATE

The researcher had a telephonic conversation with the expert and has come out with the following suggestions and criticisms. The case also has discussed a few real incidents that had various effects on the society as well as the victim. The views of the case are mentioned below. She implies on a few impacts that are to be specified and emphasised. According to the expert, the situation that instigated the rapist to get aroused, the social atmosphere responsible for the act, age group is a not an issue for rape, practical applications of sexual thoughts, hormonal changes are uncontrollable, lack of safety among the people, lack of respect for women, the growth factor that indulges both parents and teachers, lack of proper education on sex and The lack of awareness that leads to harassment. Also she added the role of media on it, In most of the cases, it is the media that spoils the life of the victim, more than merits, the media proposes demerits to the core, no traditional ethics are being followed in media, media, are trying to help the rapists, at times from punishments, few issues brought to light but few are not, because of the casualty of media. The expert also gives examples of incidents she witnessed as Judge, The case discusses a real incident of rape in which an 8 year old girl has been raped by a 14 year boy in the school premises. The victim has been dragged to a corner of the road and been taken into this cruelty. Through this, the case says that there is no proper education on the aspect of sex.

Another incident, In this issue, a 6th standard girl has been sexually assaulted by a boy of 10th standard of the same school, wherein she was killed immediately after the act. This has happened near Gudiyatham in Tamil Nadu. The girl has been taken to a farm and was raped. On investigating the boy, he has reported that he has been encouraged by the internet and the videos has helped him to be aroused.

CASE: 3, GENDER: MALE : 53, PROFESSION: DEPUTY SUPERINTENDENT OF POLICE.

The researcher had a telephonic conversation with the expert and held back the following details. According to the expert, the dominant sense of rape arises from the cultivation of impropriety. When there is no proper growth factor, the accused does not know the consequences of the event. He might focus only his feelings rather than the emotions and the sufferings of the victim. The subject had a more specific grading for the cultural changes of the society. Any negativity is fired up wherein the accused makes a detailed study on the daily activities of the victim. Education on sex is mandatory for the children as it might bring forth a vast change in the minds later on. Aliveness on the differentiation of the touches of men. He also says, It is the parents' duty to clarify the doubts of men but boys do hesitate to discuss on this topic. The subject also declares that it is mistake of the parents to help in the maturity of their children, Media's role on the rape issue is more prevalent, Media has both the merit and demerits for this mishap. It takes an easy access for the diseased minds to learn more on rape, It is the poor community women who are taken into account in large numbers. The reason behind this is their silence and he adds, when there is a lack of knowledge on sex for the poor, the rapists would take an eventual advantage on this criterion.

CASE: 4, PROFESSION: SOCIAL ACTIVISTS.

The researcher had a recorded telephonic conversation with a social activist, the followings are the views of the expert, she says that the situation contributes more to the issue than any other aspect. The fear of being alone might be secondary but the root cause for all the rapes is alcohol. Consumption of alcohol is the only reason for such cruelty. Rapists, very rarely attempt without alcohol. Cultural changes have a serious detailed impact on this issue as



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it helps to change the minds of the individual convincing them to handle any kind of offence. The other way of cultural change is being attractive. Wearing of attractive costumes and wardrobes can sometimes help the rapists to attempt for rape. The immediate reaction on hearing the rape cases is an extreme rage on men in common. The instant punishment must be 'shot at the spot.' While considering the punishments for the accused, there are no proper and legal threats for the accused. The most significant fact is that the family has to support them but they lack this ability on thinking that this might spoil the life of the victim's siblings. The media helps to exaggerate the tragedy and teaches the people how to attempt for such crimes. Sex education has its defects on the other side in letting men to be more curious on sex. Girl children may be given sex education but not for the boys. Lower community girls are deeply affected as it is an advantage for rapists to handle the poor people easily than the rich ones. In any village, the houses are set far and this could be a reason for rape. The mentality of victim changes from normal to abnormal condition. She might attempt suicide at any time. In order to avoid this situation, they are given counselling. The government has provided many measures to control the rate of rape by implementing many rules. The routine life of the victim is damaged wherein she remains the element of empathy. The mental progress is disturbed for the victim. There is a lack of guarantee of happiness in the life of the victim. A victim after the marriage fears of anything she does. There are chances for the victim to forget the cruelty once her life partner accepts her thoroughly.

CASE: 4: GENDER: FEMALE, POSITION: ACADEMIC PSYCHOLOGIST, ASSOCIATE PROFESSOR.

The researcher had a direct interview with the expert. She has come out with different views about the rapist and the victims. The below mentioned are the views of the case. She implies on a few impacts that are to be specified and emphasised. She says, situation is neutral and It depends totally on the individual perpetrators. The case starts feeling so helpless and failing in society. These kind of traumatic events create apathy. The case believes that there is strong connection between culture and rape. From the beginning it has been followed that man has to dominate and this cultural stereotype persists till now. The need for power, aggression and domination induce them to commit such cruel activity on women. Normally people are hesitant to speak taboo topics openly. This has to be changed. More than school, family has to take care of their children and teach them about things happening around, making them aware of everything. Sex education at the right age helps to prevent such issues. The case believes that educated family supports the victim and uneducated would send them out of the family. Without the influence of social, political and economic growth, such crime cannot happen autonomously. People, who are socially marginalised, economically deprived and politically supportless, suffer immensely from this issue. Media's part is to take proactive measure. Idea of showing it to people is to create awareness and it is like caution. Basically the particular people inclination is wrong, and hence they misuse it. After the traumatic event, the victim feels so guilty. She will have tsunami of emotions like depression, anxiety about future, apathy and anger. First of all, the victims should believe that they are not responsible for this traumatic event. Getting back to normal life is very important. They should be in group. They should have counselling therapy. The case does not really believe that punishment brings change. Change should happen at the grass root level by not picking up just one episode. She doesn't believe in capital punishment. If such people possess an ability to understand, he will not rape.

CASE : 5, GENDER: FEMALE (URBAN), AGE: 22

The researcher had a direct interview with the subject. The subject is a University student and her views on the topic have to be dealt deeply. She says, The first and the most emphasised point of the subject is that the incident depends on the situation. Any situation favouring the rapist can result in the absurdity. When there is a change in the culture, there would be a change in the attitude of women. There is a change in the minds of the individual to be more and more sociable. However this sociability might result in disaster. In dealing with the psychological consequences of the incident, it is noted that people are empathetic and are feeling frustrated. This is the result of the incapability of others in not paying any heed to the victims. Any event of tragedy is usually visualized as a story. This form of undergoing the horrible event lets out an anger or rage wherein the incapability resides.

If the victim is murdered, she is supported by her family. In case she is left alive, she is not accepted and she undergoes a terrific social calamity which might result in her suicide. The subject comes up with an outstanding personality and a victim of rape, Dr. Sunitha Krishnan, who with her enlightening will power and confidence, fought



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for the victims of the rape. She has also established a school for rape victims that ensure the providence of confidence and assurance of healthy life style. The subject seeks freedom of speech so that she would be able to come up with her own thoughts and feelings on the victims in the form of her writings. She also mentioned that she would definitely raise her voice on this tragic issue. This restriction exists because she is dependent on the family and is constrained to a few ideals of the family. There is a drastic change in the minds of the relations and friends after the incident, as the victim will be considered surely as a diseased individual. The behavioural manners and the attitude vary from person to person wherein she will undergo a devastating life. This might result in the pathetic condition of all those who are in and around the victim. There is no consideration for rape as an accident. It is usually considered a severe crime and the tragedy is that the victim faces the major controversies. There is no proper education on the punishments for the rapists as it might change the present situation on the incident. The subject also mentioned that there should be proper education on sex since childhood in order to avoid such terrible events. She also adds that media plays a vital role in letting the people know more on this disaster than that has happened. It exaggerates the issue in a detailed way wherein an individual have so many chances for them to learn more on the defects. It is part of the media to enact the punishment to take the crime under control.

She explains about the victims, The victim lives in frustration which results in vanity of life. When there is hopelessness in life, there are chances for the victim to attempt suicide. The only remedy for the woman to protect from rape is to defend herself in that critical situation. The instant punishment for the crime is to hang the accused so that the others would stop trying it. The other option for the punishment is to sterilize the accused. It is the duty of the family and the society to accept the victim as she is. She is neither patient nor a criminal. She is just a result of extreme cruelty. The defect in overcoming this doom is the traditional fear of loneliness. There arises a fear of darkness which results in doomed gloomy life style. Any victim if happened to witness the characteristics of the rapists would fear and feel threatened. The people around might cause a feeling of guilt in the minds of the victim when she is looked down sympathetically. This causes denudation of the victim, being ignored. There are chances for the victim to become normal after the incident and this happens only when the family and the society accepts her. The only way for the victims to overcome this dark solitude is to involve themselves fully in various fields. Concentrating on something that interests them can bring them out the sorrow and the mental pain. There are a number of ways to dissolve the emotions and the feelings of the rape issue. The important motive is to avoid the mingling with the other victims of same issues.

CASE: 6, GENDER : MALE (URBAN) AGE: 23

The researcher had a telephonic conversation with the case and has come out with the following suggestions and criticisms. The below mentioned are the views of the case. He implies on a few impacts that are to be specified and emphasised. He started talking about cultural difference by saying, Cultural difference cannot be the reason for this issue. Even centuries ago it has happened. The case's anger turns to media on the reason for its projection; it is the media that spoils the life of the victim. Sympathy should not be expressed to the victim. Sex education should be given to adolescent girls and not to the adolescent boys. It should be given separately. As the lower community people are poor and illiterate, rapist takes advantage of it. The suicidal thoughts of the victims are the resultant of the society. Penectomies will be the best punishment for this cruel activity. Victims are isolated from the society if she reveals herself as victim. The subject finally says, society should accept the victim and society must not see her as victim.

GENDER : FEMALE (RURAL), AGE: 22

The researcher had a direct interview with the case from rural background. The below mentioned are the views of the case. She says, It is the individual who use the situation for such cruel activity. Cultural changes cannot be the main cause, Irritated thought and empathy will be the first emotion for the case, The victims is deprived of family support, Differences exist only for a short period of time; as time elapses, the incident also elapses from victim's mind automatically, Media plays vital role but not in positive way, The entire world seems to be dark at first, hence suicidal thoughts arouse, The society blames the victim for getting raped. when it comes to punishment for the rapist, she says, hanging is insufficient for such cruel activity but rapist should be punished cruelly.





Hemanatchatra

GENDER : MALE (RURAL), AGE : 23

The researcher had a telephonic conversation with the case and has come out with the following suggestions and criticisms. The below mentioned are the views of the case. He implies on a few impacts that are to be specified and emphasised. The followings are his views, Situation is the main cause for this issue, aversion towards the rapist, Media has major role for this traumatic issue, common people are unaware of things happening around them. They are dumped in the dominated world, victims are murdered in the name of 'mercy killing' he also says, proper education will prevent this issue and he says, Immediate death sentence will be the best punishment for this cruel activity.

After the analysis of all the experts' views, it is proved that victims are not ready to be accepted by the society and in most case, by their own family members. People should understand that a traumatised victim undergoes an emotional upheaval. Instead of comforting her, the society blame her for being in the place and time, blames her dress. That's ridiculous. The researcher wanted to voice out for the traumatised victims. A severe punishment should be given to the rapist.

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RESEARCH ARTICLE

Conscience as confinement: An Existential–Psychological Reconfiguration of Punishment in Dostoevsky's novel *Crime and Punishment*

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ABSTRACT

This paper re-examines punishment in *Crime and Punishment* not as a legal reverberation but as an internal ailment that heads and surpasses legal sanction. Critics have long reconnoitred guilt, reclamation, and Christian morals in Dostoevsky's novel, but never concentrated on the essential dislocation of castigation from procedural authority to psychic configuration. This paper argues that the novelist Dostoevsky reconceptualise punishment as an existential–psychological regime enacted within conscience itself. Raskolnikov's suffering unfolds prior to arrest and independently of sentencing; the state formalizes what the self has already initiated. Drawing upon existential philosophy (Kierkegaard, Sartre), psychoanalytic moral theory (Freud), and accounts of disciplinary modernity (Foucault), this essay demonstrates that the novel anticipates modern theories of internalized authority and self-surveillance. Punishment becomes phenomenological before it becomes juridical. In relocating penal power from court to consciousness, Dostoevsky offers a prescient meditation on modern subject formation.

Keywords: Interiorized punishment; existential guilt; carceral subjectivity; moral phenomenology; disciplinary modernity; Dostoevsky; conscience; surveillance



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INTRODUCTION

Few novels have been examined as persistently as *Crime and Punishment*, and yet the question of punishment itself remains curiously under-theorized. Critical discussions frequently center on guilt, spiritual rebirth, nihilism, or Christian redemption. Others interpret the novel as a philosophical rebuttal to utilitarian ethics. In many such readings, punishment appears as a legal inevitability or as a redemptive instrument. What is often left implicit is a more radical possibility: that Dostoevsky quietly relocates punishment from the juridical sphere to the structure of consciousness. This essay proposes that Raskolnikov's punishment begins not with arrest, nor with confession, nor with exile to Siberia, but with the awakening of self-consciousness after the act. The law enters late; conscience arrives immediately. By the time the state intervenes, punishment has already taken hold in another register. The novel thus stages a transformation in penal logic: from externally imposed sanction to internally administered suffering.

The argument unfolds in three movements. First, I examine how Raskolnikov's philosophical experiment collapses into existential anxiety, suggesting that punishment arises from the impossibility of escaping moral embeddedness. Second, I analyze the phenomenology of guilt as embodied and spatialized experience, where the psyche becomes a tribunal and the city becomes an extension of interior confinement. Finally, I situate the novel within broader theories of disciplinary modernity, arguing that Dostoevsky anticipates later accounts of internalized power and subject formation.

The central claim is not merely that Raskolnikov feels guilty. It is that Dostoevsky reconceptualizes punishment itself as a form of interior carcerality — an invisible prison structured by self-surveillance, fragmentation, and moral anxiety.

Psychoanalytic theory clarifies the dynamics of internalized authority and self-reproach. Rather than retroactively imposing twentieth-century theory upon a nineteenth-century novel, the aim is to show how Dostoevsky dramatizes structures that later theorists articulate systematically. Existential phenomenology illuminates guilt as ontological condition rather than social emotion. An interdisciplinary hermeneutic approach is used in this paper. Theoretical reflections on disciplinary power help conceptualize punishment beyond spectacle or coercion. Close textual analysis remains foundational throughout.

The protagonist's "extraordinary man" thesis is often summarized as ideological arrogance. "Man is sometimes extraordinarily, passionately, in love with suffering" (Dostoevsky 451) Yet it is more unstable than that. His theory does not merely justify murder; it functions as a hypothetical flutter. He seeks to test whether he can exceed normal ethics — whether he belongs among those rare individuals who may violate ethical norms in service of historical necessity.

The murder of the pawnbroker is therefore less an act of greed than a philosophical experiment. If certain individuals may step "over" moral law for the greater good, then the crime becomes proof of exceptional status. The act is meant to confirm sovereignty. But the narrative quickly undermines this aspiration. The second, unintended killing of Lizaveta exposes the fragility of Raskolnikov's rational control. What was conceived as calculated transgression devolves into contingency and panic. Theory dissolves in blood.

Existential philosophy offers a helpful vocabulary here. Kierkegaard's description of anxiety as the "dizziness of freedom" resonates strongly with Raskolnikov's post-crime state. He attempts to inhabit absolute autonomy, yet freedom without moral mooring produces dizziness rather than authorisation. "Freedom and power, and above all power! Over all trembling creation and all the ant-heap!" (Dostoevsky 336) Sartre's later formulation that human beings are "condemned to be free" clarifies the paradox: one cannot escape responsibility by declaring oneself



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exceptional. The crime does not hoist Raskolnikov above moral law; it intensifies his awareness of it. Authority, breaks down into self-consciousness. What he confronts is not the triumph of autonomy but the inescapability of ethical relation. Punishment, in this sense, begins as ontological destabilization. Raskolnikov's psyche constructs its own tribunal. Ordinary encounters acquire accusatory charge. Casual remarks appear laden with hidden knowledge. Silence feels incriminating. He oscillates between defiance and paranoia, as though both prosecutor and defendant inhabit the same mind. One of the novel's most striking structural decisions is the delay of formal accusation. The investigation proceeds slowly; suspicion remains indirect. This delay is not merely narrative suspense. It foregrounds a crucial transformation: punishment unfolds independently of legal proof.

Psychoanalytic moral theory helps explain this dynamic. Freud later argues that guilt continues even without detection because authority is internalized. Yet Dostoevsky's portrayal extends beyond repression or neurosis. Raskolnikov's conscience is not abstract law but living dialogue — relentless, intrusive, inescapable. Significantly, his body participates in this tribunal. Fever, delirium, trembling, and exhaustion punctuate the narrative. The fainting episode at the police station — triggered not by accusation but by overheard conversation — reveals the body confessing before the mind consents. The organism registers guilt prior to juridical intervention. Punishment thus becomes somatic inscription. The body functions as penal surface; conscience as confinement architecture.

Dostoevsky's urban landscape reinforces interior imprisonment. Raskolnikov's room is repeatedly described as confined, throttling, and coffin-like. The metaphor does more than create mood; it anticipates burial and enclosure. Domestic space becomes cell. Saint Petersburg itself seems airless. Narrow stairwells, crowded streets, overheated taverns — these details accumulate into moral atmosphere. The city feels overheated with conscience. Public space becomes a field of imagined reconnaissance.

Here one senses a structure later theorized as disciplinary visibility. Yet unlike centralized surveillance, the gaze in Dostoevsky's novel is internalized. Raskolnikov does not need to be watched; he watches himself. Every passer by becomes a mirror. Every glance appears interpretive. The environment intensifies psychological confinement. Punishment is not merely emotional; it is spatially lived. He assumes that guilt will surface. Legal evidence becomes secondary to psychological inevitability. In suggesting that a guilty man inevitably revisits the scene of the crime, Porfiry articulates an anthropological claim: conscience seeks exposure.

This method anticipates the shift from spectacular punishment to corrective discipline. Yet the novel complicates any simple equivalence. Porfiry's strategy succeeds because Raskolnikov's conscience is already active. The state does not create punishment; it confirms it. The confession, when it arrives, feels less like capitulation to law than exhaustion before self-surveillance. Raskolnikov is never psychologically unified. Intellectual pride coexists with longing for human connection. Contempt for ordinary morality clashes with desperate need for recognition.

This fragmentation constitutes punishment. He becomes estranged not only from society but from himself. His interactions with his mother and sister are marked by discomfort, even hostility. Love becomes accusatory because it exposes vulnerability. Alienation here is neither exile nor imprisonment in the literal sense. It is self-division — the inability to inhabit a coherent moral identity. Modern accounts of subjectivity often describe the self as internally contested. Dostoevsky dramatizes these contest decades earlier. Punishment becomes estrangement from one's own continuity. If conscience functions as solitary tribunal, Sonya introduces dialogic possibility. She does not analyse Raskolnikov; she listens. Her suffering does not excuse his crime, yet it decontextualizes it within shared human fragility.

The confession scene between them is restrained rather than dramatic. There is no deafening moral commendation. Instead, there is quiet acknowledgment. In urging him to bow at the crossroads and acknowledge publicly, Sonya pleads for acknowledgment rather than mere defiance. Through her presence, punishment begins to shift. Conscience ceases to be purely isolating. Moral awareness becomes relational rather than solitary. Bakhtin's notion of polyphony





is relevant here. Raskolnikov's redemption emerges not through solitary reasoning but through encounter. Internal prison opens through dialogue.

The novel's conclusion complicates conventional expectations. Siberian imprisonment, rather than intensifying punishment, appears to stabilize Raskolnikov. The external prison provides structure that his fractured self-lacked. This inversion is significant. If the harshest suffering occurred before sentencing, then the juridical penalty functions almost therapeutically. The visible prison contrasts with the invisible one that preceded it. Dostoevsky thus challenges simplistic critiques of punishment. The state's authority is not glorified; rather, the novel suggests that interior disorder may exceed institutional coercion in severity. The paradox remains unsettling: external confinement may coincide with interior release.

Through displacing punishment within consciousness, Dostoevsky anticipates a distinctly modern configuration of power. In pre-modern regimes, punishment was public and spectacular. In modern regimes, it becomes subtle, corrective, internalized. Raskolnikov's suffering illustrates this transition. Surveillance operates from within. Discipline is self-administered. The subject becomes both prisoner and guard. The novel thereby prefigures theories of internalized authority and self-regulation. Yet Dostoevsky adds existential depth to what later theorists describe structurally. Punishment is not merely social control; it is ontological rupture. Conscience is not metaphorical prison. It is experiential enclosure.

Crime and Punishment redefines punishment as phenomenological condition rather than juridical aftermath. Raskolnikov is punished before he is arrested, imprisoned before he is sentenced, judged before he confesses. By staging conscience as carceral space, Dostoevsky relocates penal authority from state to self. The novel does not end in despair. Through relational encounter and acknowledgment, interior imprisonment becomes transformable. Punishment, in Dostoevsky's rendering, is not annihilation but reconstitution. The most severe prison is the divided conscience. The possibility of release lies not in evading judgment, but in inhabiting it truthfully. The novel anticipates existential philosophy's emphasis on responsibility, psychoanalysis's account of internalized judgment, and modern theories of disciplinary subjectivity.

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RESEARCH ARTICLE

August Wilson's *Gem Of The Ocean* As An Allegory

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ABSTRACT

August Wilson's *Gem of the Ocean* is an operatic melodrama. It's the first instalment play of the ten- play cycle which is popularly known as *Pittsburgh Cycle* or *Century Cycle* that presents the African American experience of the 20th century. The play is Wilson's most allegorical work dramatizing the African American history, cultural heritage and the predicaments of the blacks of America in general and of Pittsburgh, Hill District, Pennsylvania in particular. It is set in 1904 at 1839 Wylie Avenue. Though the play is set in 1904, it reflects the individual self and the social world of the whole decade in the lives of African Americans. The play has deep religious and spiritual significance. As the play's background is the time of the first Great Migration period of the blacks from the South to the North America in search of dignified and independent lives, it explores the acute mental trauma of them. The action of the play is a spiritual journey towards salvation from the sins. The present paper intends to bring forth the allegorical elements in the play.

Keywords: Sin, emancipation, spirituality, exploitation, African Americans, journey etc.

INTRODUCTION

The word allegory is derived from the Greek term 'allēgorein' which means "to speak figuratively." "An allegory is the expression by means of symbolic fictional figures and actions of truths or generalizations about human existence" (Webster's dictionary.com). In literature, allegory is a work that conveys truths or generalizations about human





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behaviour or experience. It is connotative rather than denotative in nature. The meaning of an allegory must be understood in two or three levels. The reader can understand it only through interpretive process. The outer meaning is less significant than the inner one. It is symbolic meaning that is more important than the lexical one. Allegories are like metaphors as the two illustrate an idea implicitly by making a comparison to the other. The only difference being allegories are full length stories with characters, but metaphors are simple figures of speech. John Bunyan's *Pilgrims' Progress* (1678) is the most notable example of allegory in English literature. The other remarkable allegorical works include Edmund Spenser's *The Faerie Queene* (1590), George Orwell's *Animal Farm* (1945), Nathaniel Hawthorne's *The Scarlet Letter* (1850), *Moby Dick* (1851) by Herman Melville etc. Generally, allegories are written in the form of short stories, fables, novels as there is ample scope in them to present something indirectly through simple narratives. Drama, on the other hand, has a little scope for allegory than the above genres. However, plays like *comedy of manners*, *absurd dramas* also depict society and human conduct implicitly through characters and events. August Wilson's *Gem of the Ocean* (2003) is one such play wherein African Slave Trade is presented indirectly through a spiritual journey undertaken by Citizen Barlow, the protagonist of the play. The present paper elucidates the allegorical elements in the play.

Explications of *Gem of the Ocean*

The external significance of the play is all about negroes' search for new life, predicaments of them in the process, crime, escape and search for redemption. However, implications of the play are far deeper than the outer meaning. The article first discusses the external meaning of the play. Citizen Barlow, the protagonist of the play, works at a local steel mill in Pittsburgh, Hill District, a north American city. The mill owners exploit the workers, who are all negroes, by paying meagre wages. Most of them migrated to the North from the Southern America because the slave owners were not letting the black slaves free although slavery was legally emancipated. Therefore, people like Citizen Barlow escaped secretly through the Underground Railroad. They reached Pittsburgh with loads of dreams and aspirations. However, even the North is not a bed of roses for them. It has its own thorns waiting for them.

Citizen Barlow and his friend Roper Lee join the mill for one and a half dollars as a day's pay. But on Friday, which is the payday, they are given only three dollars of which he must pay two dollars for the rent. They were also assured to be provided with something to eat at the time of joining. However, they are not provided so. He says to Aunt Ester, "What I'm gonna do? I got to eat. I bought a loaf of bread for a dime.... I ate half the bread.... Come payday they give me three dollars say the rest go on my bill. I had to give the man whatown the house two dollars. What I'm going to do Miss Tyler?" (Wilson, *Gem of the Ocean* 22). So, being desperate for money he stole a bucket of nails in the mill.

Unfortunately, an innocent worker, Garret Brown, was accused of the theft and was chased by Caesar Wilks, the black police. Brown felt it better to die rather than to be arrested and so, he committed suicide by jumping into a river. Knowing that he caused the death of Brown, Citizen is filled with guilt. His remorse makes him restless as it haunts him day and night. Hence, he wants to confess his guilt and to get his soul cleansed. So, he visits Aunt Ester, the cleanser of black souls. "I don't know Miss Tyler. I feel like I got a hole inside me. People say you can help me. I don't want to go to hell, Miss Tyler" (G.O.T.O. 23).

Aunt Ester, having pitied with him, guides him on a spiritual journey to the City of Bones on a boat called *The Gem of the Ocean*. Solly Two Kings, the former Underground Railroad conductor; Eli, the guard of Aunt Ester's house and Black Mary, the protégée of Aunt Ester, assist him in his journey. Citizen feels elated to see Garret Brown at the gates of the City of Bones. "The Gatekeeper... the Gatekeeper... It's Garret Brown the man who jumped in the river" (G.O.T.O. 52).

Aunt Ester asks him to confess his guilt to the man because she feels that we can right our wrongs by confessing them to the sufferers of the cause. Citizen feels it the right opportunity to redeem himself and immediately confesses, "It was me. I done it. My name is Citizen Barlow. I stole the bucket of nails" (G.O.T.O. 59). Thus, he can enter the city and returns having been washed off his soul. Sarah Bellamy's remarks are quite striking in this regard. "Citizen





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Barlow's trip to the city of Bones is a purification ritual in preparation for a life of service as well. He must atone for his sin before gaining entrance. The city is a place of reverence; it is searched, holy. One must be washed before entering its doors" (Bellamy, *The Birth*).

Having visited the city and got himself atoned Citizen becomes a responsible person and gets ready to take up the duty of Solly Two Kings i.e. liberating the blacks from the South to the North via Underground Railroad. His first responsibility is to bring Solly's sister back safely as she is tormented by her slave owners. The play ends at this point when he wears the hat and takes the walking stick of Solly as the latter is shot dead by Caesar for setting the mill on fire.

Implications of the play as an allegory

The article now discusses the implied meaning and significance of *Gem of the Ocean*. The play has far deeper sense than just the story of Citizen Barlow. Every character, object and event of the drama refers to a historical person, incident or thing of African American experience. Aunt Ester, for example, is said to be a 285-year-old woman but it is not so. Her age connotes the beginning of African slave trade to America. It's believed that the first ship carrying the slaves reached America on the day she was born. She is not just a character but a symbol of African tradition and culture in America. She is a link between the past and present African Americans as articulated by Elam who describes her as, "A critical figure mediating between the African past and the African American present, between the African past and Africanist-based spirituality" (Elam 184).

The protagonist, Citizen, was named after freedom to the blacks which was proclaimed on 22nd September 1862 by Abraham Lincoln. His name connotes not just a single man but the entire African people who became citizens of America after the slavery emancipation act, 1862. The antagonist, Caesar's name reminds us of slaves being named after ancient Greek and Roman kings and knights by white masters to belittle them. He's named after Julius Caesar, the great Roman military general. Similarly, Solly Two Kings' slave name was Uncle Alfred which he changed as Solly Two Kings once he became a free citizen. "You looking at Two Kings. That's David and Solomon.... Some people call me Solomon and some people call me David. I answer to either one. I don't know which one God gonna call me. If he calls me Uncle Alfred then we got a fight" (G.O.T.O. 27).

The journey taken up by Barlow to the City of Bones guided by Aunt Ester is totally allegorical. It refers to the Atlantic Slave Trade journey to America. It has deeper significance. Melinda D. Wilson, in her review of the play says, "However, in *Gem of the Ocean* the writer related the horrific ocean tale of the Middle Passage in such clear terms that the rides quickly turn from a story about African Americans to one about stolen Africans in America at the turn of the century" (728-729). It is remarkable to note that the journey which refers to the historical event of Middle Passage begins exactly at the middle passage of the play i.e. Act 2 Scene 1. The name of the play *Gem of the Ocean* denotes the name of the first slave ship from Africa. So, it is evident that August Wilson intentionally resorts to history in his plays to show the connection between the past and present to show a path for better future for his black fraternity.

The boat used for Citizen's journey is a paper boat that is moulded by Aunt Ester using her indenture document i.e. her bill of sale. Ester says, "Look at the boat, Mr. Citizen. That's a magic boat. There's a lot of power in that boat. Power is something. It's hard to control but it's hard to stand in the way of it" (G.O.T.O. 54). The statement alludes to the power of American slave masters who could buy or sell the slaves like property. Her bill of sale is no longer valid as she is no more a slave. Yet the white supremacy exists on the blacks. Caesar's arrest warrant against Aunt Ester for no serious crime in Act 2 Scene 4 is evidence of it. Thus, the legal papers also serve as allegorical devices for Wilson.

The City of Bones, where Citizen sails to, is in the heart of Atlantic Ocean through which Africans were traded as slaves by European agencies. It's formed out of the bones of the blacks who died during their journey to America. Some of them died due to sickness, a few committed suicides by jumping into the ocean as they didn't want to live like slaves and those who rebelled were forcibly thrown in the ocean.





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The city, which Aunt Ester declares that “is in the centre of the world and in time it will all come to light” (G.O.T.O. 54) emerged out of the white bones of the black slaves. It also connotes that though the Africans are dark externally their bones are equally white as those of the whites. Likewise, the blood of the two races is also equally red. However, the whites ignore the inner realities and feel superior to the blacks just by the virtue of their skin complexion. Wilson, through his theatrical weapon of drama, aims to censure such white attitude and intends them to realize how equal the two races are in spite of their skin colours. Citizen's spiritual journey to the City of Bones is quite significant as it symbolizes his visit of his ancestors and comes to know of their sacrifices. By visiting them he's redeemed and his mental peace is restored.

CONCLUSION

August Wilson who advocates the importance of being indebted to African culture proves it right through Aunt Ester who guides Citizen through a spiritual journey to the past. “Only by being touched by the past, by remembering the lessons of the ancestors, can the characters move forward. The African spiritualism conjoins with the practical American reality.” (Elam, Jr. 77). Although Wilson explores the African American predicament in the *Century Cycle*, he doesn't do so directly but in an implied and indirect way. So, the characters, places, events in the play alludes to the persons, places and incidents in the history of African American experience. The names of characters, places and objects in the play are like that of Bunyan's *Pilgrim's Progress*. The surface meaning of the play is simple yet there is complex deeper meaning that Wilson wants his audience to make out. So, the play has all qualities of an allegory.

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RESEARCH ARTICLE

Erratic Climate Change in India: Affective Climatology, Gendered Displacement, and the Literary Lens of *Memories of Rain*

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ABSTRACT

The article deals with the current acute crisis of unstable climate change in India shifting patterns of monsoon, devastating flooding in Kerala and Assam, long drought in Marathwada, unprecedented-intensity cyclones (Amphan, Fani), and repeated heat waves in northern India. Although, the agricultural loss and policy response have been the primary topics of discussion surrounding climate, the affective and gendered aspects of the disruption have been terribly neglected. To shed some light on these queries, this paper resorts to Sunetra Gupta article, *Memories of Rain*, as a secondary source, a literary text that makes visible the tangle between weather, memory, and selfhood. Based on feminist affect theory, mostly on the idea of affective economies by Sara Ahmed, the article presents the notion of affective climatology to theorise the influences of meteorological conditions on subjectivity. It claims that the monsoon is growing more erratic, the sensory record of belonging shatters. To the people who have been left behind in Kerala, in flood-stricken regions, or in Marathwada, during drought, the change in the ancient weather conditions is a gradual unmaking of the world as they have known it. The paper challenges the very meaning of silence as affective refusal, and makes an intervention in climate justice politics by showing that the embodied, emotional realities of environmental change should be central to our perception and reaction to the Indian climate crisis.

Keywords: erratic climate change, affective climatology, feminist affect theory, gendered displacement, India, monsoon, climate justice, *Memories of Rain*, embodiment, affective refusal



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INTRODUCTION

Introduction: The Unseen Dimensions of India's Climate Crisis

India is in a tricky situation. Over 2000 years the rhythms of the subcontinent have been managed by the monsoon, a predictable, life-sustaining power which controls agriculture, culture, spirituality and the finer details of everyday life. The coming of the monsoon rains has been celebrated in poetry, song and ritual; failure has brought famines and collective trauma. This climate-civilisation relation is more than practical, it is also affective in nature-the monsoon constructs the way Indians recall, belong, and define themselves within the world. And this old rhythm is disintegrating. In the last twenty years, India has experienced a series of climatic catastrophes that portend a drastic change in the environment. The disastrous floods in Kerala in 2018 and 2019 left millions without homes and transformed the understanding of the state towards its surroundings. Assam is threatened by floods every year which erode land and the permanence. The long droughts in Marathwada have caused agricultural distress, massive migration, and suicidal deaths of thousands of the farmers. Amphan and Fani, of record strength, were two cyclones that struck coastal West Bengal and Odisha respectively. The heat waves that have been occurring in most parts of northern India have exceeded the level of 50 making cities like Delhi, Jaipur and Churu to become inhabitable at least on extended periods. The monsoon itself now is unpredictable--it comes late, leaves early, descends in torrents that destroy instead of precautionary rain, and leaves parts of the land, and drowns others.

The climate argument that has risen in response to these crises has been defined by vital but limited issues: loss in agriculture and food security, damage to infrastructure and economic costs, policy response and adaptation. Such strategies are essential but they work within a paradigm which gives precedence to the quantifiable - crop outputs, losses in gross domestic product, kilometres of destroyed roads, displaced individuals - and ignores the emotional aspects of environmental change. The gap that this paper will discuss is critical: the affective and gendered aspects of climate disruption are severely neglected. What are the reshaping of weather patterns on subjectivity, memory and intimate nature of day-to-day living? What does the slow violence of climate breakdown mean when inscribed on the body, especially in the case of women whose lives are so bound up in the rhythms of the environment? What does it mean to lose not just a livelihood but a climate - the sensory record of home, the reliable regularity that organized the sense of time and place? These questions need a theoretical framework that is able to bridge the environmental, the emotional, the embodied.

This paper relies on the feminist affect theory (mainly, the idea of affective economies proposed by Sara Ahmed) to suggest that unpredictable climate change in India should not be perceived solely as an environmental crisis but rather as an affective crisis: a change that fundamentally changes the way people perceive belonging, memory, and selfhood. To theorise this, the paper presents the notion of affective climatology- analytical paradigm that shows the involvement of meteorological conditions in the formation of consciousness, memory and embodiment.

The paper resorts to literature as the second source to make visible what cannot be captured in policy reports and scientific data. The novel *Memories of Rain* (1992) by Sunetra Gupta does not reflect the modern-day climate crisis but creates a remarkable prism through which one can interpret the intertwining of weather and memory, as well as identity. Moni, the protagonist of the novel, bears in her the Calcutta monsoon of predictability, abundance and personal belonging. Her flight to England exposes her to a new meteorological order that is radically different: constant, chilly rain that is an indicator of alienation, confinement at home and gradual loss of self. In this juxtaposition, Gupta uncovers the role of climate as not as a backdrop but rather as an affective infrastructure -the force that forms consciousness, organizes memory and mediates the sense of home. The following is the structure of this paper. Section two provides the theoretical framework, which is based on the affect theory and feminist geography by Sara Ahmed to form the affective climatology. Section three explores the major problem which is unpredictable climate change in India where the changing monsoon patterns, extreme floods, droughts, cyclones, heat waves and the gendered aspect of this crisis have been recorded.

Section four presents *Memories of Rain* as a secondary source, discussing the role of rain as affective infrastructure and silence as affective refusal. Section five unites these threads and interprets the climate crisis in India through the





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literary prism in order to reveal the emotional aspects of environmental disturbance. The sixth section places the argument in the current interventions of climate justice, transnational feminism, and feminist resistance. The conclusion discusses the implications of this framework when thinking about and acting regarding the climate crisis in India.

Theoretical Framework: Feminist Affect Theory and Affective Climatology

Sara Ahmed's Affective Economies

In order to comprehend the connection between climate, subjectivity, and displacement, the paper will rely on the feminist affect theory, especially the works of Sara Ahmed. Ahmed (2004) in *The Cultural Politics of Emotion* questions the belief that emotions are psychological states that exist in individual subjects and are private. Rather, she posits that emotions are circulatory forces that circulate among bodies, objects, and spaces. Emotions are not something that people possess, but they come about in contact, gaining value and meaning in their circulations through social fields. To explain this circulation, Ahmed coins the term of affective economies. Emotions in an affective economy act as capital: they acquire value through circulation, sticking to some bodies and places and repelling others. Emotions perform things in the world- they match one body to another, or to another, to generate limits between what is considered us and what is considered other, and what is worthy of attention and care. This framework is essential in explaining climate since it goes beyond the fact that emotional responses to climate change are considered as secondary responses. Rather, it recommends that climate is a part of affective economies: some climates are associated with intimacy, belonging, and home; others with alienation, danger, and displacement.

"Emotions are not simply 'in' the body or 'in' the mind; they are produced through the very relationship between bodies and worlds." — Sara Ahmed

It is based on this understanding that this paper argues that climate disruption is an affective rupture a disruption in the relationship between body and environment that upsets subjectivity fundamentally.

Affective Climatology: A Proposed Concept

Trying to apply the framework by Ahmed to the sphere of climate and environment, the current paper presents an idea of affective climatology. This is a two-fold notion. First, it speculates on the involvement of meteorological conditions in the formation of consciousness, memory and embodiment. Climate is not a background upon which human experience plays its drama, but rather an active process which organizes the way we experience, recollect, and associate ourselves with the world. Second, affective climatology offers a model of understanding the felt aspects of climatic disturbance the sorrow of missing the old weather patterns, the confusion of unpredictable weather, the gradual loss of identity that comes with environmental change. Affective climatology is informed by the experiences of several fields. It draws on the insights of environmental humanities that climate is not a disinterested physical phenomenon but a cultural and affective category. Within feminist geography, it integrates a focus on the differentiated effects of climate on gendered experience, in that the bodies, labour and responsibilities of women make them uniquely susceptible to climate change. It takes the insights of affect theory that affect are not incidental responses to environmental events but are constitutive of the experience and perception of said events. This concept is also a reaction to a major gap in climate discussion. Scientific and policy solutions to the climate change problem are biased toward what is quantifiable: carbon emission, warming, sea-level rise, economic damages.

These are necessary, but they are not able to reflect the subjective aspects of the environmental change. Affective climatology provides a language in which it is possible to express what is lost when a climate changes not just crops and infrastructure, but a sensory storehouse, a rhythm of life, a sense of belonging to the world.

Feminist Geography and Embodied Experience

This theoretical framework is further enriched by feminist spatial thought. Doreen Massey, Gillian Rose and Linda McDowell have all shown that space is not a neutral space but a gendered space that various bodies can engage with and navigate differently. Feminist geography stresses that domestic interior, public sphere, and natural environment are all locations of gender production and struggle.



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Such an attitude is essential in realizing how climate disruption is experienced, especially in women. The life of women in most areas of India is intricately connected with nature cycles. Women are the main controllers of water, food and household resources; they are usually the first to feel the drought or flood impact because they are the ones who bear the consequences of these calamities due to the direct implications on their day-to-day activities. Feminist geography finds that these embodied everyday experiences need to be at the core of our perception of climate crisis, not considered as secondary to bigger issues. Feminist geography is concerned with the way domestic spaces the home, the kitchen, the courtyard are involved in mediating and experiencing climate. The displacement that Moni goes through as depicted in *Memories of Rain* is greatly influenced by the domestic interiors that Moni has to live in: the Calcutta house with the sound of the rain, the house in England with the rain turning into a cold and alien reality. Such spaces are not just places of action but agents of the generation of subjectivity.

Embodiment and the Politics of Silence

The body as a knowledge and resistance site has been integrated into this theoretical framework with a feminist approach. Things that are left unsaid, the feelings that cannot be expressed, and silences have been a major focus of the feminist theory. Instead of understanding silence as inactivity or lack, feminist critics have turned to the question of how silence might serve as a mode of resistance: a refusal to perform, to explain, make oneself available to assimilation. This paper redefines the silence of Moni in *Memories of Rain* as an act of refusal that was affective. Her silence is not the lack of agency, but another way of being in the world an embodied, non-verbal opposition to the pressures of assimilation and domestic containment. This reading relates to more general feminist discourse of how marginalised subjects escape by doing something that is not always decipherable within the paradigm of agency that identifies agency with vocal acts.

Primary Issue: Erratic Climate Change in India**Shifting Monsoon Patterns**

Indian monsoon is a highly complicated and far-reaching weather system on the planet. Its rhythms were astoundingly predictable, arriving in early June, slowly moving across the subcontinent, maintaining rainfall until July and August, and then retreating in September. This predictability organized the agricultural periods, religious holidays, nuptial periods and the daily beats of agricultural life throughout the sub-continent. In the last twenty years, this predictability has significantly been eroded. The monsoon is now characterized by what climatologists call an enhanced variability: a late start, a premature departure, a skewed spatial distribution and big outbursts of precipitation and extended dry periods. An example is the 2023 monsoon season which reported June deficits in rainfall across the nation of 36% and the July rainfall which was the highest in history resulting in devastating floods in various states. This trend extreme variability as opposed to merely decreased precipitation is typical of the effects of climate change in the area. The effects are much wider than agriculture. The old systems of knowledge that were established based on the predictable seasonal patterns are no longer useful. Producers who over many years have been accustomed to planting and harvesting at specific times are now faced with fundamental uncertainty. The emotional aspects of this change are immense: the monsoon was not only a weather phenomenon, but also a cultural and emotional landmark. Its caprice is a loss of direction, of the temporal cycles which organized collective and individual life.

Extreme Flooding Events

The 2018 and 2019 floods in Kerala are symbolic of the new climate regime. The state had 42% more rainfall than the average in 2018 and the destruction was not only a question of quantity. It received its rains in heavy downpours that overwhelmed infrastructure that was built in respect to a more predictable climate. More than a million displaced, more than 400 killed; whole villages under water weeks. The Kerala floods brought about the emotional aspects of climate disaster in a very harsh light. Not just material losses - homes, belongings, livelihoods - but the loss of a sense of safety and the turn to landscapes that were once familiar, into dangerous ones, were described by survivors. Rivers that were recreation and means of livelihood turned out to be sources of destruction. The hills which had characterized the beauty of the region turned into causes of fatal landslides. The disaster was not merely a phenomenon but a break in the interconnection between persons and place. The floods that occur in Assam bring



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another, yet, just as distressing trend every year. In contrast to the sudden heavy rains in Kerala, Assam has frequent floods which are becoming the order of the day and even worsening. Every year the state is flooded with huge territories; every year, the communities are rebuilt. This periodical trend is a gradual undermining of permanence - it is a constant sense of precarity that is infiltrated into the texture of life. To the population in flood prone areas the question is not whether the floods will occur but how big it will be and how much it will lose. Flooding in cities like Mumbai (2005, 2017, 2021) and Chennai (2015) demonstrates an additional aspect of climate disruption. These happenings crippling megacities reveal the vulnerability of the infrastructure to another climate. They also show the unequal distribution of climate vulnerability: the poorest citizens, those residing in informal settlements, are always the most impacted, losing both their homes and livelihoods as well as experiencing the slowest recovery routes.

Droughts and Water Scarcity

The Marathwada area of Maharashtra has become a household name when it comes to drought and distress of farmers. This series of droughts have destroyed agriculture and thousands of farmers have taken their own lives, a crisis that has emerged to be one of the most painful experiences of climate vulnerability in India. Droughts do not merely consist of lack of rain but are metamorphoses of whole lifeworlds: wells dry up, harvests fail, debts grow, and families disintegrate as men move into city in search of employment. The emotional aspects of drought and flood vary significantly. Where flood is instant and dramatic, drought is gradual and cumulative--a crisis that is years long, and destroys hope in bits. This theorisation of slow violence, introduced by Rob Nixon, which, rather than spectacular violence, is systemic, not an event but a prolonged process, is most suitable to describe the drought in the Marathwada: every dry season adds to the precarity of the next; every failed harvest adds to the structural crisis. Urban water crisis was a problem that was highlighted by the Chennai water crisis of 2019. Millions of people had to rely on water tankers when the reservoirs of the city became dry, and the cost of water increased significantly, showing the weakness of urban water infrastructure.

In the case of women, whose responsibility is the primary one in household water management, the crisis was translated into hours of waiting until tanker deliveries and having to endure circumstances of the highest level of shortage. The drainage of groundwater in the North and West of India is a more enduring and possibly unresolved crisis. The use of groundwater in the Green Revolution could never be long-term, and in some states, including Punjab, Haryana, and Rajasthan, the water tables are dropping at alarming rates. This is a slow-moving crisis- the crisis that will eventually decide on whether these areas will be habitable.

Intensifying Cyclones

One of the most severe cyclones in the Bay of Bengal was cyclone Amphan that hit West Bengal and Odisha in May 2020. The fact that it came in the COVID-19 pandemic made it a compounded crisis that overwhelmed response capabilities. The Sundarbans, the habitat of some of the most vulnerable communities in India, was destroyed. Historically the mangrove forests that were protecting the coastlines were violated; salt water intrusion was into the freshwater sources and long-term effects on agriculture and drinking water were experienced. Hurricane Fani that hit Odisha in 2019 illustrated the growing strength of the tropical systems and the importance of disaster preparedness. Fani was the most powerful cyclone to occur in the state since 1999 but the number of deaths was kept relatively low due to the massive evacuation efforts. However, this success should not blind one to the overall trend: the cyclones in the Bay of Bengal are getting increasingly more severe, with increased wind speed and storm surge. To the communities living on the coasts, this would be a more dangerous life, and every cyclone season would be accompanied by the threat of devastating destruction.

Recurring Heatwaves

Hot waves in the northern and central parts of India have become common during the summer months. The high temperatures of over 50 degree C in cities like Delhi, Jaipur and Churu are not rare but expected events. The human cost is high: death due to heat, labour disruption, and physical and mental fatigue of life in extreme temperatures. Disproportionately impacted are outdoor workers, such as farmers, construction workers, street vendors, who cannot escape to air-conditioned areas due to heatwaves. These laborers, who are mainly representing the marginalised



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groups, have to make the inexplicable decision of how to earn a living and monitor their health. The gendered aspect is also important: the care work of women never stops despite the increased temperature, and the bodies of women are more susceptible to heat stress.

Gendered Dimensions of Climate Disruption

In all these manifestations of unpredictable climate change, gender stands out as an essential axis of vulnerability and experience. Climate disruption is affecting women in India disproportionately due to a number of reasons that are interrelated. To begin with, women are main administrators of water, food and household resources. When there is drought, women walk further to get water; when there is flooding, women are expected to evacuate children, save home appliances and take care of the domestic environment given the circumstances of crisis. This labour can seldom be included in economic evaluations of climate effects, but it is the day-to-day experience of climate adjustment by millions of women. Second, climate disruption cuts across gender inequalities that already exist. Women lack access to resources, credit and decision-making structures; they are poorer; they experience more restraints to mobility and labor. These systemic inequalities undermine the ability of women to recover in case of climate shocks in a systematic manner. Third, migration is redefined by climate pressure. With agriculture no longer being viable, men are more likely to move to the city to find employment, and women are left to run rural households in more vulnerable positions. This change can both augment the loads of women and produce convoluting and conflicting types of agency. Lastly and most relevant to the main argument of this paper, the emotional aspects of climate disruption are gendered as well. The disappearance of well-known environmental rhythms, the sorrow of abandoning homeland, the fear of dark futures, all this is experienced unequally in terms of gender. But these emotional facts are mostly excluded in the climate discussion and climate discussion still continues to favor quantifiable effects more than experience.

Secondary Source: *Memories of Rain* as Literary Lens**Overview of the Novel**

The novel *Memories of Rain* by Sunetra Gupta (1992) cannot be easily categorised. It features the tale of Moni, a Calcutta woman who marries an Englishman, Anthony, and moves to England. The story moves back and forth between the memory of monsoon-dipped Calcutta and the frosty, grey existence of her English homeland. It is a migratory novel, a novel of endurance of love and dissolution of love, the functioning of memory, not as a chronology but as experience of immersion of the senses and feeling of returning. *Memories of Rain* is a novel about climate as an affective force at its core. Rain is not just a motif, or a symbolic tool, but the medium by which memory works, the tool which orders consciousness. The title of the novel indicates this: the novel is not a novel about rain, but one where rain is memory.

Rain as Affective Infrastructure

Rain as used in the novel by Gupta serves as what this paper refers to as affective infrastructure. It is not an inert component, a context in which actions take place, but a dynamic force that determines how the characters experience, recall and connect with the world. The Calcutta monsoon is captured in sensory detail: the beat of rain on tiled rooftops, the smell of wet soil, the sensation of the moisture on the skin, the taste of the rain-wet air. It is not only evocative description but the statement of the climate which has become constitutive of the subjectivity of Moni. The monsoon implies intimacy - between Moni and her mother, between Moni and nature, between Moni and a state of herself that existed before migration. It is sensuality: a body relationship to surroundings, which is pre-verbal and pre-rational. Most importantly, it is a pre-migratory belonging, being at home in the world, both geographical and affective. The rain in England is the opposite. It is described as long, grey, and cold and lies on a landscape that is never quite home. The contrast between the two rains is not only one of quantity or intensity but of quality: the monsoon rain is the rain of life; the English rain is the rain of death. This distinction is not objective--rain is rain--but affective. The same weather event generates radically dissimilar experience due to the affective economies it traverses.





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Climate and Memory

Of special relevance to the argument in this paper is how the novel handles the issue of memory. The process of memory in *Memories of Rain* is not linear and cognitive. Moni does not merely recall things in chronological order, but memory exists in rhythms of repetition, immersion and revisiting, which resemble rainfall itself. This is not just a narrative device but a substantive assertion concerning the nature of memory. According to Gupta, memory is not a storage system, but a circulation of affect- a movement of feeling which links past and present, self and environment. The vehicle of such a circulation is rain since rain is the substance that glues Moni body to her recalled world. The rain does not evoke individual memories but a condition, a sense of belonging that is beyond time. Such a conceptualisation of memory carries deeper implications to the way we conceptualise climate disruption. When the memory is organized around climate, when the monsoon has not been recalled, but actually is the medium by which memory is produced, then the crisis of climate is not just an environmental crisis but a crisis of memory. The sensory storehouse of belonging breaks apart when the monsoon turns unpredictable. Losing accustomed weather formations, what is lost is not only agricultural productivity, but a system of feeling, a sense of time.

Silence as Affective Refusal

The last aspect of the novel that is relevant to the argument presented in this paper is the issue of silence. Moni is not such a character who expresses her experience in pure, political words. The expression of her opposition to the pressure of assimilation, to the loss of her identity in England, is articulated not by voice but by silence, by withdrawal, by the inner maintenance of her memories of the monsoon. In this paper, the silence of Moni is redefined as affective refusal. Instead of hearing it as passivity a loss of speech, of resistance, of adaptation, it is perceived here as another way of being in the world. Moni rejects the act of being translated, to render herself readable, to fit into the framework of her new setting. This silence is not a lack but a quality of another order: the maintenance of a self which is not assimilable. This reading relates to a significant amount of feminist existing literature on the politics of silence. Feminist theorists have suggested that silence may serve as a resistance, a refusal to act, to elucidate, or to avail oneself of consumption. The necessity of women to speak, to share their experience, to represent their culture may in itself be a form of violence in the case of women in displacement. The silence of Moni is her rejection of such an economy of visibility.

Analysis: Reading India's Climate Crisis Through *Memories of Rain*

The Monsoon as Archive of Belonging

To Moni, the Calcutta monsoon is a place of sensory abundance and predictability not only nostalgia, but an archive: a place to store selfhood, belonging, and ways to be in the world. The rhythms of the monsoon organized her childhood, her relations with her mother, her time and space sense. She leaves India with this archive in her and it turns into an inner landscape against which she evaluates all subsequent experiences. This is what the unpredictable climate change in India is threatening. To the ones who are left in areas where even the monsoon has become erratic, sensory archive of belonging has not been lost in the process of migration but changed. The very monsoon which was the source of life and stability turns out to be a source of anxiety and loss. The tunes that organised the life of collectivity turn unreliable. The demise of the monsoon as a predictable rhythm is accompanied by the demise of time orientation. The association between time and meaning shatters when the seasons fail to come as they should, when the indications that have always been a sure guide to planting or harvesting are no longer available. This is an irreconcilable loss that cannot be quantified in economic terms, but it is a loss, an experience of loss that restructures the way individuals live their lives.

Climate Displacement as Affective Rupture

The emigration of Moni to England can be interpreted as the structural analogy to the inner displacement by the climate change. Environmental change has not physically displaced her, she has migrated on the basis of marriage. But her experience--the deprivation of a familiar climate, the loss of place in a new meteorological regime, the gradual loss of selfhood--is the same that climate-displaced people face. This does not mean voluntary migration is to be conflated with climate displacement, but only to indicate that literature can shed light on aspects of climate experience that are habitually submerged in policy discussions. The experience of Moni shows that climate is not



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only a physical environment but also an emotive territory, a place belonging, which is at the same time a geographical and emotional one. The loss of climate is the loss of a constitutive element of oneself. This emotional aspect is seldom addressed in the case of floods in Kerala or drought in Marathwada, where people are displaced. The policy discourse is concerned with resettlement, compensation, and infrastructure all needed, none of which is sufficient. Always lacking, however, is the consideration of the sorrow of the loss of climate, the confusion of living in a changed world, the gradual loss of identity which goes with environmental displacement.

The Gendered Body as Site of Climate Experience

The location of the convergence of climate, memory and displacement is the body of Moni. The monsoon is in her body--the dampness of her skin, the beating of the rain in her ears, the scent of wet soil in her mind. Her body recalls what the world around her refutes when she is in England. This corporal memory is not distinct of her consciousness but a constituent part of it. This has a direct bearing on the comprehension of the process of women facing climate disruption in India. Female bodies are the places where the environmental crisis is most frequently registered acutely. Women have to carry water through drought-stricken land; women have to cope with extreme circumstances when there is a flood; women have to endure physical and emotional consequences of running a household in growingly precarious conditions. However, these experiences of the body are always peripheral to climate discourse. The concern of policy, economics, and infrastructure makes the body irrelevant--as though climate disruption were felt mainly at the data level rather than at the level of sensation. The story of Moni says not: climate becomes lived and becomes lived in and through the body.

Affective Climatology in Practice

The combination of the theoretical framework, the main issue, and the literary lens will reveal in this paper affective climatology as a method of analysis. Affective climatology examines:

- The role of the meteorological conditions in the formation of consciousness, memory, and embodiment.
- How climate can be thought of as affective infrastructure - a structuring power of emotion and identity.
- How climate disruption is an affective discontinuity that alters the correlation between the body, memory and world.
- The gendering of these dimensions, whereby the burden falls on women in their bodies and lives in a disproportionate manner.

The application of this framework to the climate crisis in India makes evident aspects that are not visible in traditional methods. The sorrow of the farmers in Marathwada, the bewilderment of communities in flooded-out Kerala, the vulnerability of the coastal communities against the growing cyclones- these are not adjunctive to the actual crisis of environmental change. Crisis is what it is experienced. Affective climatology offers a discourse in which to express this lived experience.

Contemporary Interventions: Climate Justice, Transnational Feminism, and Affective Refusal**Climate Justice Discourse**

The climate justice movement has done vital work in future telling the inequities of climate change: that the most impactful effects are borne by those who have contributed least to carbon emissions; that climate change is multiplying the existing inequalities; that solutions should focus on the needs of vulnerable communities. The thesis of the paper is that climate justice should go beyond that: it needs to address the affective aspects of climate disruption. Justice is not simply a question of the material means, of compensation, of resettlement, of infrastructure, but of acknowledgment of losses that cannot be given up. The disappearance of a known climate, the sorrow of the changing environment, the confusion of unpredictable seasons--all these are types of loss that must be noted, although they can not be measured. Affective climatology also adds to the discussion on climate justice by arguing that the perceived aspects of environmental change are not peripheral but core. The fact that these dimensions are ignored or not sufficiently scientific by policy frameworks is itself complicit in a kind of epistemic violence- they refuse to acknowledge the loss.



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Migration, gender, and globalisation are other transnational feminist issues the paper interferes with. The experience that Moni shares in *Memories of Rain* throws light on the hidden expenses of cross-cultural marriage and displacement that have often been shrouded in jubilant accounts of globalisation. Transnational feminism has been vocal in its disavowal of migratory discourses of liberation that assume migration to be free of the gendered limitations and violence through which migrants are organized. This paper builds on this criticism by paying attention to the affective aspects of displacement, the gradual loss of self, the sadness of the lost belonging, the emotional work of assimilation. In the case of women in transnational marriages, the pressure to assimilate, to learn new languages, new practices, new ways of being, is usually complemented by the pressure to forget. It is often necessary to leave the self that existed in order to become a good wife in a new country. The silence of Moni is a rejection of this request—a saving of the self which cannot and will not be assimilated.

Silence as Feminist Resistance

Lastly, this paper is a contribution to the feminist discourse of resistance, agency, and politics of voice. The implicit valorisation of voice, as the means of resistance, speaking out, telling oneself, making oneself visible, is the mode of resistance yet is implicit in much of the contemporary feminist discourse. Silence in this context can be typically interpreted as inactivity, lack, or incompetence. The present paper will make the contrary argument, as feminist theorists have redefined silence as a type of agency. The silence of Moni is not a refusal to resist, but rather a refusal to engage in an economy of visibility that requires self-explaining. It is non-verbal, embodied manner of being that maintains a non-assimilated self. This reading has more general implications to the interpretation of how the marginalised subjects resist. Not every resistance can be read within the frameworks that hold the equivalence between agency and vocal expression. Recognizing silence as a resistance is to broaden our definition of what resistance may appear like and where we may find resistance.

CONCLUSION**Summary of Arguments**

As I have argued in this paper, erratic climate change in India should not just be perceived as an environmental crisis but an affective rupture, in other words, a change that, at its core, changes the way people feel belonging, memory, and selfhood. The paper theorised this by introducing the concept of affective climatology, using the feminist affect theory of Sara Ahmed to explain how the meteorological conditions are involved in subjectivity formation. The paper has analyzed the main problem of unpredictable climate change in India in various forms: changing monsoon patterns, severe floods in Kerala and Assam, droughts in Marathwada, increasing cyclones Amphan and Fani, and constant heat waves in northern India. It stated that the gendered aspects of this crisis such as the unequal distribution of the burden on women, the ways in which climate disruption crosses with preexisting inequalities are of dire need in current climate discussions. Using the secondary source *Memories of Rain* by Sunetra Gupta, the paper has shown how literary work may bring into visibility what a policy report and scientific data fail to record: the interplay between weather and memory, and selfhood; the role of rain as an affective infrastructure; the role of silence as an affective refusal.

Broader Implications

The implications of this paper are in various fields. In its argument concerning climate, it contends that the affective and gendered aspects of environmental change need to be taken into consideration. To the feminist theory it applies affect theory to climate and environment and suggests a new framework of analysis, affective climatology. In the case of literature, it also proves the value of literature as an invaluable source of knowledge about crises nowadays not only as a reflection of them but as a way to analyze them with the help of conceptual means. To achieve climate justice, the paper demands that justice encompass the understanding of affective loss: the sorrow of the loss of accustomed climates, the incomprehension of the transformative environmental change, the gradual loss of self that





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comes along with displacement. Such losses are not compensable, yet they can be recognised. Justice in itself is recognition.

Future Directions

The paper has provided some opportunities to further studies. Affective climatology can be applied to other locations and situations, whereby the question of how climate disruption forms subjectivity in various cultural and geographical contexts is considered. Gender-climate migration needs to be considered more closely, especially since climate-related displacement is increasing in the world. The contribution of literature and other cultural manifestations in expressing the sensory aspects of change in the environment should be explored more thoroughly and extensively by scholars. With an even more uncertain climate outlook in India, structures that can fully reflect the proportions of the crisis are becoming all the more pressing. One such framework is affective climatology, the manner of attending to the loss involved in changing climates, and the saving that climates carry into the memory and bodies of those who bear their climates with them.

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RESEARCH ARTICLE

Masculinity in Crisis: Infertility and Identity in Perumal Murugan's novel *One Part Woman*

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ABSTRACT

This research article delves into the crisis of masculinity found in the novel *One Part Woman* written by Perumal Murugan. This article focuses on the intersections between infertility, patriarchy, and male identity in patriarchal society. In a patriarchal society, masculinity is often defined by virility, sexual ability, and fathering children. As a result, men's infertility has become a social and psychological threat to a man's identity and self-esteem more than a personal or biological issue. Through Kali's character, the novel reveals the emotional pain, shame, and isolation faced by a man who cannot live up to society's ideals of manhood. While infertility is usually associated with women, Perumal Murugan shifts the focus to men's suffering and discusses the silence around male infertility in patriarchal discourse. The novel also describes Ponna's sufferings to demonstrate how reproductive expectations oppress women and impose strict gender roles. Ultimately, the novel critiques patriarchal systems that reduce both men and women to reproductive roles and demands for a more compassionate and inclusive understanding of gender identity beyond fertility and societal norms.

Keywords: Masculinity, Patriarchy, Male Infertility, Identity Crisis, Social Stigma, Gender Roles, Silence.

INTRODUCTION

Perumal Murugan in his novel *One Part Woman* critiques patriarchal norms by focusing on the character Kali, whose childlessness challenges traditional definitions of masculinity. The story of this novel revolves around the lives of Kali and Ponna, a married couple who reside in a rural area of Tamil Nadu called Tiruchengode. As a farmer, Kali also has livestock to care after. His childlessness is the one issue that causes the entire family to suffer, despite the fact



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that he makes a good living and provides for his mother and wife. The author describes the couple's joyful life as follows: "Other than the lack of a child they could call their own, there was nothing else missing in their lives. He fulfilled every wish of hers, perhaps because he had married her out of love" (OPW 28).

He immediately plants the portia tree in the front yard of his father-in-law's house after being married to Ponnayi. The tree thrives for twelve years, but the couple is not fortunate enough to have a kid during that time. As a result, the portia tree serves as a metaphor for Kali and Ponnayi's lack of children during their marriage. Despite multiple efforts at mating, one of Kali's cows is unable to produce a calf. To get rid of the cow, he plans to sell it to Gounder. Ponnayi is busy cleaning the cow shed while Kali is talking to Gounder. She overhears Gounder saying the following to Kali: "It is fate, mapilliai. That is just how some cows are. No matter what you do, they never get pregnant. Just quietly change the cow. If you say yes, I can fetch you one right away" (10). Though he says these words with a smile, Ponna recognizes the meaning immediately. Her heart feels heavy.

Kali is insulted by his friends and the public. Once his friend Bommidhi Mani teased him with a question: "Do you have children?" (OPW 19). Kali thinks of scolding him with the words: "I may or may not have children. What is it to you? Shut up and leave" (OPW 20). But he never yells. Something stops him from "reciprocating their rudeness" (OPW 20). Their vulgar jokes and insinuations expose the social expectation that a man's worth depends upon his ability to father a child. One of Kali's friends mockingly remarks that "work is not about this," while making a lewd gesture, suggesting that Kali has failed in his sexual "duty" (OPW 82). Kali likes to dance during the festival and he likes to spend time in the crowd. But Kali stops attending this dance when his friends teased him for being childless. People would talk in front of him as follows: "Only the man who induced morning sickness in his wife in the very second month of marriage was a real man" (OPW 82). Since his friends are interested only in teasing Kali, he gradually stops joining this crowd of old friends. He also knows that they have nicknamed him "the impotent one" (OPW 83). All these comments from his friends make him ponder the fact whether he is impotent or not. Though he is not interested in the second marriage because of his love for Ponna, the next reason that stops him from getting married is his fear of impotency. Another comment states that when a woman remains physically unchanged after marriage, it indicates that "the husband's 'work' was not up to mark" (OPW 82). Similarly, the metaphor comparing bodily intake and output — "it is not enough that the water you take in is great, the water you send out should be top-class too" (83) — directly associates male fertility with masculine competence. These remarks project how masculinity is closely linked with fertility and sexual performance within patriarchal society. In a book titled *Exploring Masculinity* says, Kamla Bhasin opines as follows: "A man who cannot perform sexually is called 'impotent', considered weak, powerless, non-male. According to this yardstick, a man's power/potency is located in his sexual organ. Impotence in a man is not just a shortcoming, it's a disgrace." (EM 35). In the same way Perumal Murugan has highlighted the psychological burden imposed upon men. This shows that patriarchal ideals of masculinity are fragile and are constantly subjected to public scrutiny and validation.

Ponna also experiences humiliation in her community because she is childless. She is repeatedly labelled as "barren" and excluded from social gatherings. People also believe that her presence might bring bad luck to their families. Neighbours and relatives mock her and blame her for any misfortune that occurs in their lives. For example, when Kadhivel's son is injured while staying at Ponna's house, the boy's mother angrily accuses Ponna. This incident is indeed suggesting that only a mother can properly care for a child, thereby blaming Ponna for the child's injury. This situation reveals the harsh criticism and emotional pain Ponna faces. It emphasizes the patriarchal belief that a woman's worth is tangled to her ability to have children.

Ponna and Kali involve in a sequence of religious rituals and traditional practices in their desperate attempt to conceive a child. Their actions include prayers, participation in ceremonies, and the consumption of bitter medicines given by Ponna's mother-in-law. This reflects the cultural pressures and expectations placed upon them. They also perform a goat sacrifice, light a lamp, and circle a sacred rock, signifying their profound commitment and willingness to take significant risks to overcome infertility. Murugan critiques this notion through the characters of Kali and Ponna. The author describes it as follows: "In the matter of offering prayers, Kali and Ponna left no stone unturned.





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They did not discriminate between small and big temples. They promised an offering to every god they encountered. For the forest gods, it was a goat sacrifice.... For some gods, the promises even doubled" (OPW 47).

Under continuous familial and societal pressure, mostly from her mother-in-law, Ponna is compelled to participate in the fourteen-day chariot festival at the Ardhanareeswara Temple. She unwillingly consents to the proposal and says, "If you want me to do this for the sake of this miserable child, I will" (OPW 86). This festival is characterized by its briefly relaxed social customs, allowing unions between men and women in quest of fertility. Kali fervently opposes Ponna's participation in the Chariot festival and the possibility of her having relations with another man. He also fears that this man might belong to an untouchable caste. For Kali, Ponna's potential pregnancy impends his constructed sense of masculinity, revealing his supposed impotence. On the other hand, Ponna's femininity is closely tied to her reproductive capacity. Her ability to conceive is essential not only for confirming her female identity but also for bearing an heir to bear familial influence and authority. This emphasizes how gender identities in the novel are socially constructed and enforced. Deviations from prescribed roles invites severe social condemnation. Perumal Murugan's novel thus reveals the oppressive nature of these gender norms and the psychological and social costs they exact on individuals.

Kali's fear of entering into a second marriage is a display of his deep insecurity about his masculinity and fertility. Despite societal pressure to remarry for the sake of producing an heir, Kali resists the idea. He fears that a second childless marriage would irrevocably confirm uncertainties of his impotence. He thinks as follows "if the second woman too could not get pregnant, his reputation as an impotent man would be engraved in stone" (OPW 84). Kali's refusal arises not only from emotional attachment to Ponna but also from a deep-seated fear of social humiliation. This echoes the patriarchal construction of manhood that equates male identity with reproductive success.

Perumal Murugan further describes Kali's psychological burden through his silence and inability to openly confront societal interference. Although he longs to shout, "I may or may not have children. What is it to you? Shut up and leave!" (20), he chooses to remain silent in the face of intrusive and judgmental comments whereas Ponna occasionally responds with sarcasm. Through Kali's fear, hesitation, and emotional restraint, Perumal Murugan deconstructs the myth of unwavering masculine strength. He exposes how patriarchal expectations trap men in a unyielding cycle of anxiety over fertility, virility, and social reputation.

Thus, this novel *One Part Woman* exposes the subtle foundations of patriarchal masculinity by presenting infertility as both a biological and social crisis. Through Kali's emotional suffering, silence, and fear of humiliation, Perumal Murugan shows how masculinity is shaped by societal expectations of virility and reproduction. The novel also critiques patriarchal norms that confine both men and women to reproductive roles. It eventually encourages for a more compassionate and expansive understanding of gender identity that transcends fertility and social validation.

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RESEARCH ARTICLE

Exploring the Feminist Legacy in Shashi Deshpande's *Moving On*

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ABSTRACT

Shashi Deshpande is a significant contributor to Indian feminist literature, meticulously exploring the complexities of women's identity and expressing a deep dissatisfaction with traditional gender roles. This individual's contributions are characterized by their distinctiveness and impact, as her voice achieves a notable equilibrium between subtlety and assertiveness within the dynamic and evolving context of contemporary Indian writing in English. Deshpande adeptly explores the complex layers of the female psyche, offering a deep analysis of the individual and collective societal challenges women face. The author's body of work effectively captures the essential qualities of womanhood, delving into their existence's psychological, emotional, and intellectual dimensions. Alongside addressing the conflicts and turmoil that often arise in these endeavours, she skilfully examines their deepest yearnings, ambitions, and goals. Deshpande explores various pressing societal issues prevalent in modern India through her compelling narrative, prominently featuring feminism and gender dynamics. In the narrative *Moving On*, the author delves into feminist themes through the depiction of the protagonist's determined quest for self-identity and her courageous defiance against the constraining forces of patriarchy. This study seeks to systematically analyse the complex interplay of feminist thought present in Deshpande's oeuvre, which is in alignment with the diverse and multifaceted Nature of Indian culture. This work highlights her profound insights into the complexities of human existence and acknowledges her substantial contributions to the literary field. Deshpande's writing invites readers to explore the intricate realities of modern womanhood, fostering a nuanced comprehension of the contemporary female experience in its entirety.

Keywords: femalepsyche, Indian societal issues, feminism, gender dynamics, modern womanhood.

INTRODUCTION

The study of feminism represents a significant and evolving field within modern intellectual and literary discussions, highlighting its swift development and growing importance in contemporary society. This complex movement



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involves essential ideologies that examine multiple aspects of human activity, such as politics, economics, culture, and social norms. Feminism fundamentally focuses on the emancipation of women, aiming to deconstruct the entrenched systemic inequalities and power disparities that exist within a largely male-centric society. Feminist thinkers and advocates engage in activism, scholarship, and artistic expression to rigorously challenge and redefine societal norms and expectations related to gender. This initiative aims to amplify women's voices and promote an inclusive discourse that examines the intersections of gender with race, class, sexuality, and various other social categories. The advocacy for rights and social justice within feminism seeks to empower women, facilitating their ability to assert their rights, pursue their aspirations, and redefine the narratives that have historically marginalized them. Feminism aims to effectuate transformation in individual experiences while also catalysing extensive societal change, advocating for a framework of equality and equity applicable to all members of society. Shashi Deshpande's writings underscore the evolution of social norms, which, despite undergoing transformation, have notably either endured or adopted new manifestations. Through deconstructing stereotypes that have historically limited women's roles, Deshpande challenges the reader to engage with their authentic essence. She aims to develop a novel portrayal of women that embodies both relatability and authenticity. Deshpande has carved a notable niche among contemporary Indian novelists by articulating the concept of freedom for Indian women in relation to the prevailing socio-cultural values and institutions of India. The author refrains from depicting excessively idealized female protagonists, opting instead to illustrate Indian women confronting authentic challenges as they negotiate the complexities of modernity and tradition.

As a woman, I have no country. As a woman my country is the whole world. -Virginia Woolf.

Simon de Beauvoir stated, "One is not born a woman; one becomes one," which holds special significance in India, where conventions and social taboos often restrict and inhibit women's individuality. The concept of femininity serves as a cultural construct that embodies societal perceptions of women. Shashi Deshpande elucidates the nuanced mechanisms of oppression and gender differentiation that exist within the familial institution and the broader context of male-dominated Indian society. As a writer, she offers critical analyses of the structures inherent in this patriarchal society. Their strength is evident in the selection of scenarios that resonate with a significant number of Indian women, emphasizing the experiences of women in the context of marital and domestic relationships. Bartky posits that women, regarded as free and autonomous individuals, navigate a societal landscape wherein men impose a perception of inferiority upon them, shaped by men's self-perceptions. Individuals are constrained by their subjugation through the mechanisms of male dominance over prevailing institutions and the overarching ideology.

To attain equality and fully realize their potential, women are required to move beyond their unique characteristics associated with femininity, thereby leading lives that are comparable to those of men; this necessitates the pursuit of autonomy. Beauvoir advocates for women's pursuit of autonomy and the exploration and cultivation of their genuine identities through experiential engagement, culminating in self-realization. This concept is relevant to Manjari as she engages with conflicting discourses in her quest for self-understanding and identity formation. Deshpande's latest novel, *Moving On*, presents a multifaceted narrative architecture that intricately intertwines various elements, drawing upon memory, lived experience, and textual documentation. The analysis utilizes the diaries of an individual who has passed away, resulting in a complex palimpsest of personal history that is intricately layered and intertwined within a dramatic framework. The narrative explores the intricate dynamics of affection and animosity between individuals, revealing the depth of their interactions through intense plotting and debate, thereby exposing the multifaceted Nature of human relationships. Deshpande presents a narrative that immerses readers in a realm of credible scenarios and intricately developed characters, eliciting empathy and engagement. The portrayal of every day yet profoundly authentic lives unfold within a meticulously crafted storyline.

Moving On examines the intricate dynamics within a Brahmin family, centering on the figures of Baba and Vasu, who are the parents of Manjari Ahuja. Manjari, a widow, presently occupies the ancestral residence located in Bangalore. In her pursuit of a mentally and physically enriching existence, she teaches yoga classes tailored for the children in her community as she progresses through the aging process. A persistent anxiety surrounds her regarding the



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potential unforeseen sale of the property registered under her daughter Sachi's name. The individual experiences a plethora of irrational fears, anxieties, fantasies, and nightmares concerning aging, illness, and mortality. In her advanced years, she demonstrates a tendency toward possessiveness, a behaviour commonly observed among elderly individuals.

Manjari faces challenges in navigating her relationship with the younger generation, exemplified by Raja, Abhishek, and her cherished daughter Sachi. Abhishek, currently a tenant and employed as a software engineer, aspires to relocate to the United States in pursuit of significant financial success. He frequently interacts with her, utilizing terminology associated with computing. The narrative presents a notable episode in which Manjari becomes immersed in a troubling fantasy characterized by themes of theft and the imminent danger of sexual assault by an unidentified assailant. Several disconcerting anonymous phone calls exacerbate the situation, each suggesting a possible transaction involving her cherished residence. The situation intensifies as she experiences an overwhelming compulsion to sell the house, yet only to an individual enveloped in an enigma, their identity remaining persistently obscured. This distressing incident is overlooked as a simple coincidence, perceived yet another commonplace event emblematic of the disorder frequently associated with life in the expansive urban environment.

The novel's structure is delineated into two primary sections—Section 1 and Section 2. Part 1 presents a citation from Erica Jong's "Inventing Memory": "All the stories that have ever been told are the stories of families—from Adam and Eve onward." In Part 2, a quotation from Italo Calvino's "If on a Winter's Night a Traveler" is presented: "The ultimate meaning to which all stories refer has two faces: the continuity of life and the inevitability of death." The analysis suggests that her novels depict the narratives of families reminiscent of Adam and Eve, who experience life and love and ultimately confront mortality.

In her recent work, *Moving On*, Shashi Deshpande examines the frequently intolerable monotony of life. The narrative is presented through dual perspectives: the father the 'bone doctor,' whose diary illuminates historical events, and his daughter, Manjari, also known as Jiji, who occupies a pivotal role in the storyline. Jiji's encounter with her father's diary prompts a critical examination of her past, encompassing her mother Mai—a writer who wielded love as a means of control—her sister Malu, who was estranged from her during childhood yet later emerges as a significant influence in Jiji's life, and her husband Shyam, a cinematographer, and the focus of profound longing, which ultimately contributes to her downfall. Jiji experiences a profound inundation of memories while simultaneously managing the complexities of her present existence. The narrative encompasses a rebellious daughter, presenting a challenge for connection; property sharks attempting to coerce her departure from her residence; a passionate young lover; and a steadfast friend—her "doppelganger"—who remains patiently in the background. The human body is a fundamental element in the narrative, influencing every event and action the characters undertake. It is a source of inspiration, instigation, betrayal, and reward.

In *Moving On*, Shashi Deshpande presents the character of Manjari, who embodies resistance to patriarchal ideology and endeavours to navigate her existence according to her own principles. The narrative commences with Baba's diary, progressively unveiling the character of Manjari as she contemplates her upbringing and the memories of her late parents. At thirty-five years of age, she is confronted with the reality of being a prematurely widowed individual, navigating the challenges of solitude following the loss of both parents and the absence of her adult children. This circumstance necessitates an examination of her environment and her sexual identity. In her engagement with the narrative, Manjari concurrently takes on the role of a reader of her father's diary. This investigation facilitates a re-examination of historical contexts and elucidates the complex dynamics of her parents' experiences. Manjari approaches her father's diary with a critical perspective, acknowledging that acts of transgression can lead to the emergence of alternative forms of knowledge.

The current situation warrants examination as she explores her recollections and reassesses previous occurrences and responses. The subject encounters the complexities associated with her role as a defiant daughter, navigating the predatory behaviours of unscrupulous property investors and the menacing presence of a sexual partner whose



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actions pose a significant threat to her stability. The challenges that emerge—originating from the interplay between nostalgia and reality, the influences of property dealers, the stifling of personal passion through secretive relationships, and the dichotomy between the fear of exposure and the yearning for connection—advance toward an unexpected resolution, navigating a complex emotional landscape. The narrative examines themes of betrayal and violation within its intricate relationships. Dr. Badri Narayan's father, belonging to the Brahmin caste, entered a marriage with an orphaned Harijan girl, thereby challenging established family traditions. Under the influence of his guru, he adopted Gandhism, resulting in a departure from his family's honour and a rejection of the established caste hierarchy, as highlighted in traditional texts such as the Vishnu Stotra and the Gayatri Mantra. As a result, he was positioned as an outsider, ultimately facing disownment and disinheritance from his father. Badri's mother was his father's second wife, and her horoscope featured an inauspicious Mangal, rendering their marriage socially unacceptable. Furthermore, Badri Narayan entered matrimony with an individual from a different caste. Upon perusing her father's diary, Manjari gains insight into the authentic dynamics of her parent's relationship, recognizing her prior misconceptions regarding their bond.

A significant disparity is evident between perceived accuracy and the fundamental Nature of reality. The notion of 'real' cannot be characterized as a singular, definitive entity; rather, it represents a complex interplay of various truths, each influenced by personal perception and experience. Manjari refrains from imposing her interpretation of truth on others, facilitating a diverse understanding range. Baba, driven by intense passion, exemplified the fundamental immediacy of human longing. His passion was a powerful motivator that drove his professional pursuits and profound love for his wife. In contrast, Mai did not respond to Baba's profound physical ardour. Instead, she skilfully avoided his affections by dedicating herself to writing, constructing a realm infused with her own fervour.

The unique disharmony that characterized each family member's lives resulted from their contributions. The previously harmonious relationships among spouses, individuals, and familial units began to deteriorate, resulting in a multifaceted network of affection intertwined with miscommunication. Ultimately, Baba reconciled with the understanding that his wife's level of enthusiasm did not align with his own fervent passion. This acceptance represented a significant turning point, emphasizing the disparity between his aspirations and the emotional dynamics within their marriage.

Manjari is confronted with the lingering effects of her past, a challenge that significantly hinders her ability to escape and establish a new trajectory. The narrative illustrates a common motif wherein the protagonist's personal experiences profoundly connect with the experiences of others. The delineation between reality and imagination becomes increasingly ambiguous, thereby complicating her pursuit of autonomy and self-determination. Pursuing genuine independence presents a complex array of challenges; however, Manjari exemplifies the essence of a defiant daughter who has sought to establish her own identity at different stages of her life. In this context, she stands out as a representative figure of radical feminism.

Shashi Deshpande's body of work reflects a conscious endeavour to underscore the constraints associated with the exclusivist position of feminism. Her narratives illustrate the complexities and nuances inherent in the feminist movement. Deshpande not only critiques this position but also endeavours to offer a reinterpretation of it. In her insightful essay, "Why I am a Feminist," the author reevaluates and expands her conception of feminism, promoting a more inclusive perspective that goes beyond the limitations typically linked to conventional interpretations. The continuous discourse present in her work prompts readers to reevaluate the boundaries of feminist ideology and fosters a more comprehensive comprehension of women's quests for autonomy in various contexts.

Manjari resolves to confront life independently, devoid of any support, whether moral or financial. Upon receiving the news of her mother's passing, she returns to her father. She has transcended all forms of hesitation. She consumes alcohol freely in the presence of her father and her cousin Raja. Raja expresses an interest in entering matrimony with her; however, she declines his proposals and establishes two conditions: The notion that marriage serves solely as a



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foundation of love or as a means of social security for a single woman is deemed unacceptable. Secondly, her familiarity with the contours of his body precludes any sense of erotic arousal, as their shared upbringing has established a deep-seated connection. Her resolute decision to abstain from marriage once more remains unyielding, rendering any form of persuasion or external factors—be they physical, financial, or emotional—ineffective in swaying her stance.

She acquires the skills necessary to operate her vehicle and uses it for taxi services. In response to challenges in securing a fulfilling employment opportunity, she engages in self-employment by setting up and managing a computer at her residence, where she types manuscripts for clients. The independence exhibited by the individual serves as a significant source of astonishment for Raja, who adheres to conventional patriarchal standards. She encounters a significant challenge in her life as individuals come to visit her and reach out anonymously. The decision to sell her ancestral home imposes significant mental strain on her. In the absence of a response to the impending threat, the underworld initiates an assault aimed at facilitating the sale of the property. In the face of external pressures from the criminal underworld and familial influence exerted by her cousin Raja, she exhibits a resolute determination to resist and engage in a struggle.

"This is their goal; they are attempting to make me into this cowardly, shivering mass of fear, but I refuse to be afraid" (167).

"I'm quite capable of looking after myself," she says, dismissing the dying automobile driver (88).

Raja's comprehension of her physical needs and how she addresses her hunger highlights his evident ambivalence towards her, prompting her to decline to turn around. It is essential for her to pursue her own path and make independent decisions without external influence. The narrative's conclusion is marked by a metaphorical separation following an extended and arduous journey; she initiates the vehicle and departs, symbolizing her quest for freedom. The inquiry of freedom devoid of attachment persists as she advances in her exploration. The concept of progression is characterized by a reciprocal journey, transitioning from internal states to external manifestations and vice versa, as indicated by the novel's title. The concept of the ego is inherently constrained and lacks true freedom.

Consequently, the narrative's exploration of selfhood and autonomy evolves in complexity throughout the novel. Manjari has pursued independence and autonomy through her various transgressions. Is it possible for her to attain freedom through solitary living? Is she capable of independently managing her affairs? Is it possible for her to transcend the denial of her aspirations? The issues at hand extend beyond the individual of Manjari, encompassing broader implications for feminist discourse and the collective well-being of humanity.

Manjari's pursuit of autonomy and independence is a theoretical challenge to patriarchal structures by emphasizing the recognition of personal strength as a woman, rather than engaging in direct confrontation. The challenges she faces in regulating her sexuality—characterized by the persistent demands of her physical body seeking fulfilment—prompt her to engage in frequent reflections on her father. To address her physical hunger, she engages in sleep with her renter, a significantly younger individual, yet strictly on her own terms, dictated by her desires and whims rather than his—"Only the body, his body, only my body, and my starved body." "Absence of cognitive processes and emotional responses, solely the presence of sensory experiences" (257).

The comprehension of her physical needs and how she addresses her hunger elucidates his evident ambivalence towards her, resulting in her decision to remain unyielding and not turn around. She needs to pursue her path and make independent choices without external influence. The conclusion of the narrative is marked by a metaphorical separation following an extended and arduous journey; the female protagonist initiates the vehicle and departs, symbolizing her quest for liberation. The concept of freedom devoid of attachment presents a persistent inquiry for her as she progresses. The process of progression encompasses an inward journey that extends outward, as well as an outward journey that returns inward, as indicated by the novel's title. The concept of the ego is inherently



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constrained and lacks true freedom. Consequently, the exploration of selfhood and autonomy within the narrative evolves in complexity throughout the novel.

Manjari has pursued independence and autonomy through her various transgressions. Is it possible for her to attain freedom through solitary living? Is she capable of living independently? Is it possible for her to transcend the denial of her own aspirations? The issues at hand extend beyond the individual of Manjari, encompassing broader implications for feminist discourse and the collective human experience. Beauvoir posits that while women possess freedom and autonomy, they frequently encounter a societal structure wherein men impose an inferior status upon them. Women encounter oppression because of male dominance within key institutions and prevailing ideologies, insufficient solidarity among women, biological imperatives that drive the need for partnerships, the entrenched Nature of oppressive structures that appear inherent and immutable, and, at times, their complicity in these systems. For women to attain equality and fully actualize their human potential, it is essential for them to move beyond their distinct femininity and endeavour to pursue lifestyles akin to those of men. Achieving autonomy is essential for individuals to explore and cultivate their genuine identities through experiential learning and self-discovery. This analysis pertains to Manjari, who engages with a range of conflicting discourses in her quest to comprehend her identity and its significance.

In her essay "Why I am a Feminist," Shashi Deshpande articulates that embracing one's womanhood should be regarded as a source of joy rather than a deficiency, divergence, or inferiority. Feminism does not position itself against men; instead, it aims to foster a more equitable, significant, and collaborative dynamic between men and women, departing from conventional sacrificial paradigms of relationships. The realization of women's potential is contingent upon the absence of oppression. Deshpande presents a family structure defined by equitable opportunities and privileges for both genders, fostering cooperation, compromise, and companionship.

The author contends that it is peculiar, irrational, and inequitable for feminist ideology to promote discontent among women regarding their roles as housewives, to advocate for the abandonment of husbands and families, or to endorse divorce in response to minor grievances—Deshpande advocates for the concept of relational autonomy in relation to women. Women ought to cultivate their ambitions and actively pursue their own goals for self-fulfilment rather than relying on men for economic, emotional, and psychological support. In contemporary societal dynamics, it is imperative to dismantle the distinct spheres traditionally assigned to men and women, advocating for a redefinition of their relationship as one characterized by equality and complementarity rather than dominance and relegation.

Chanchala K. Naik posits that the argument presented by Deshpande in the novel advocates for the concept of relational autonomy. The notion of 'relational autonomy' presents a novel interpretation of individuality, especially when examined through a feminist lens. The depiction of an individual is not as a solitary being; instead, it reflects a multifaceted amalgamation of social and cultural influences that are intricately connected to relationships within specific social, political, and historical frameworks.

In this context, Manjari stands out as a notable individual who represents opposition to patriarchal limitations. The protagonist's resolute decision to reject marriage to Raja represents her resistance to societal norms. Additionally, her fearless engagements with the mafia regarding her ancestral property illustrate her commitment to asserting her rights and preserving her heritage. Furthermore, her decision to operate her vehicle represents a declaration of autonomy, indicating her dismissal of conventional gender roles. Nevertheless, the trajectory of Manjari's experience is marked by various conflicts. The female experience involves navigating personal desires alongside the intricate expectations imposed by one's physical form. The relationship she shares with her tenant represents a significant turning point in her journey towards empowerment. It highlights her aspiration to break free from the longstanding conflict between genders, characterized by men's frequent assertion of control over women's autonomy.



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Through these experiences, Manjari exemplifies that a woman should assert her identity and agency rather than be diminished to a possession claimed by a man. The narrative significantly illustrates the critical role of self-definition and autonomy when confronted with societal pressures.

— "But you're a woman; you're a daughter," she asserts, her voice laced with defiance and disbelief (64).

In response to Raja's sharp accusation, she delves deeper into the "archive" concept, challenging its implications and significance. "I never thought you would sink so low," she retorts, her tone heavy with disappointment and betrayal (283).

Manjari reflects on the complexities associated with her decision to embrace an independent lifestyle as a woman. What are the implications of a woman residing independently? In pursuing conventional notions of femininity, she relinquishes the sari, the colourful attire that previously symbolized her identity. The individual adopts a short, angular hairstyle that evokes a traditionally masculine aesthetic, complemented by a facial expression that possesses the potential to halt passersby in their tracks. Nonetheless, despite her efforts to conceal my femininity, such attempts were ultimately ineffective. Men possess an uncanny ability to perceive what lies beneath the surface—"they can smell the woman within..."(284).

Manjari tests the idea that feminine uniqueness is solely shaped by male viewpoints, advocating for a more complex interpretation that paves the way for significant social and cultural transformation. The dynamic Nature of female identity is emphasized, illustrating its capacity to evolve independently and in response to societal influences. This evolution challenges existing stereotypes and facilitates new interpretations and expressions of femininity.

The narrative explores the bonding dynamics among women, contrasting the relationships illustrated in the accounts of Mai, Malu, Manjari, Gayatri, and Suchi. The notion of relational feminism critiques the conventional understanding of a self that is independent, autonomous, and impersonal. It posits that such a viewpoint neglects the fundamental reality of our interconnectedness and relationships' significant role in our existence. Relational feminists argue that the concept of an independent and self-sufficient female identity embodies what they refer to as a "Masculine Denial," which represents a suppression of the essential maternal connections that influence women's identities.

This comprehension has given rise to a counter-discourse aimed at challenging the reinforcement of a rigid hierarchical distinction between the so-called "impersonal" domains associated with the male ideal — defined as objective, disinterested, and public — and the "personal" domains connected to the female experience, which are subjective, contextual, and private. Through examining the complexities surrounding these experiences, relational feminists highlight the intrinsic connection between the personal and the political, asserting that women's lived experiences must be crucial in shaping the broader conversation on autonomy.

The notion of relational autonomy examines the intricate experiences of women, positing that genuine autonomy involves more than simple individual independence; it is significantly shaped by the relational contexts that permeate their lives. This analysis explores the nuanced interplay between supporting autonomy and outright rejection, presenting a refined examination of the complex terrain within feminist theory and practice. In this context, autonomy is redefined as a complex concept intricately connected to women's integration within their social environments, acknowledging them as individuals influenced by distinct experiences and elaborate relationships.

Deshpande highlights the importance of ongoing affirmation of freedom—encompassing thought, choice, and action—as deeply connected to the social and relational contexts shaping women's experiences. This perspective offers valuable insights into women's daily personal and political challenges in a gender-structured society, thereby enhancing our comprehension of their diverse struggles and achievements. The connections established among women and the depth of their experiences within these relationships significantly impact their autonomy and agency.



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The work *Moving On* investigates themes related to relational autonomy, offering nontraditional perspectives on love, marriage, sexuality, and domesticity. The character of Manjari exemplifies the qualities of contemporary femininity, challenging traditional notions of autonomy and interpersonal connections. As a survivor, she exemplifies relational autonomy—profoundly anchored in familial and interpersonal connections while remaining submissive to none. Manjari exemplifies the qualities of an affectionate daughter, a loving sister, a caring mother, and a supportive friend. A lack of imposition or demand characterizes her demeanor while she upholds her autonomy. She maintains a balanced approach towards her children, allowing them the freedom to develop and express their unique identities. Her perspective on life promotes a harmonious coexistence, emphasizing the importance of self-identity while respecting the individuality of others. It encourages individuals to live according to their principles while granting others the freedom to do the same.

This novel explores the theme of passion as it intricately weaves through the characters' journeys. Manjari and her father are connected through the insightful narratives found in his diaries and the touching memories shared by those who were once acquainted with him. Exploring the complex and frequently turbulent essence of physical passion leads to a duality of comprehension and conflict. This comprehension has given rise to a counter-discourse aimed at challenging the reinforcement of a rigid hierarchical distinction between the so-called "impersonal" domains associated with the male ideal — defined as objective, disinterested, and public — and the "personal" domains connected to the female experience, which are subjective, contextual, and private. Through examining the complexities surrounding these experiences, relational feminists highlight the intrinsic connection between the personal and the political, asserting that women's lived experiences must be crucial in shaping the broader conversation on autonomy.

The notion of relational autonomy examines the intricate experiences of women, positing that genuine autonomy involves more than simple individual independence; it is significantly shaped by the relational contexts that permeate their lives. This analysis explores the nuanced interplay between supporting autonomy and outright rejection, presenting a refined examination of the complex terrain within feminist theory and practice. In this context, autonomy is redefined as a complex concept intricately connected to women's integration within their social environments, acknowledging them as individuals influenced by distinct experiences and elaborate relationships. This understanding has led to the emergence of a counter-narrative that seeks to contest the perpetuation of a strict hierarchical separation between the so-called "impersonal" realms linked to the male archetype — characterized as objective, disinterested, and public — and the "personal" realms associated with the female experience, which are subjective, contextual, and private. An analysis of the complexities surrounding these experiences reveals that relational feminists aim to underscore the inherent link between personal and political realms, contending that women's lived experiences are essential in informing the broader discourse on autonomy.

The concept of relational autonomy explores the complex experiences of women, suggesting that genuine autonomy encompasses more than mere individual independence; it is profoundly influenced by the relational contexts surrounding their lives. This examination delves into the intricate relationship between the facilitation of autonomy and the phenomenon of outright rejection, offering a detailed investigation of the multifaceted landscape inherent in feminist theory and practice. In this framework, autonomy is reconceptualized as a multifaceted notion deeply intertwined with women's incorporation into their social contexts, recognizing them as individuals shaped by unique experiences and intricate relationships. This investigation into desire incurs a considerable cost, ultimately resulting in the fragmentation of their previously cohesive family structure, characterized by affectionate parents and their two intelligent daughters. Nevertheless, in the face of adversity and emotional turmoil, their vibrant experiences illuminate their existence, producing a radiance that underscores their inherent resilience. After the narrative, the characters are depicted as united—two diminutive lanterns illuminating the pervasive darkness of mortality that looms over all individuals. Although Deshpande's narrative is infused with themes of death and tragedy, it reveals a tender and profoundly human essence, ensuring that the story does not become morbid or tiresome. Instead, it serves as a celebration of the enduring strength of love and connection.





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CONCLUSION

Shashi Deshpande's novel *Moving On* features a complex narrative structure that intertwines themes of memory, experience, and written texts, particularly involving the diaries of the deceased. The story revolves around Jiji (Manjari), a widowed woman who returns home to care for her ailing father, Baba. After his death, she discovers his diary, prompting her to reflect on her life considering his revelations. Jiji's childhood was spent with her anatomist father and her mother, Mai, who writes romantic stories. Together with their extended family, they create an idyllic atmosphere. However, Jiji's present is filled with uncertainty as she grapples with choices about her future while living alone in the house her father left for her daughter, Sachi. Meanwhile, she receives disturbing calls urging her to sell the house and marriage proposals from Raja, BK's son. The narrative slowly reveals the disintegration of Jiji's family, beginning with her marriage to Shyam, a cinematographer who introduces her to passion. Deshpande explores the theme of the body through Baba's teachings and personal struggles as he faces his wife's illness and his own mortality. Jiji also confronts her desires and societal expectations as a single woman navigating these complexities. Manjari embodies a contemporary archetype of femininity, challenging traditional notions of autonomy and interpersonal connections. She engages in relational autonomy, maintaining connections with her family while also asserting her independence. In her roles as a daughter, sister, mother, and friend, she exhibits a balanced approach, characterized by neither demanding behaviour nor dependency, thereby granting her children the autonomy they require. Her methodology in navigating life exemplifies a harmonious balance between authentic oneself and acknowledging others' autonomy. Deshpande's works analyse the evolution of the New Indian Woman, emphasizing significant social and cultural changes in urban India that are shaped by economic advancement. The author's writings highlight the enduring Nature of social norms, which may either remain unchanged or transform into new forms. The deconstruction of restrictive stereotypes provides a more authentic representation of women. Deshpande's position among modern Indian novelists is well-established, particularly through her examination of the notion of freedom for Indian women, contextualized within their cultural frameworks. The author avoids creating idealized female protagonists, instead portraying women who struggle to balance modernity with tradition.

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RESEARCH ARTICLE

Psychoanalysis and Narrative Form: Unconscious Structures in Modernist Fiction

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ABSTRACT

This paper investigates the relationship between psychoanalytic theory and narrative form in modern literature, arguing that literary structure itself functions as a symbolic articulation of unconscious processes. While earlier scholarship has largely focused on character psychology, this study foregrounds narrative techniques—such as fragmentation, nonlinearity, and shifting perspectives—as structural manifestations of repression, memory, and trauma. Drawing on the theoretical frameworks of Sigmund Freud, Jacques Lacan, and Cathy Caruth, the paper offers detailed textual analysis of Franz Kafka's *The Metamorphosis*, Virginia Woolf's *Mrs. Dalloway*, and Toni Morrison's *Beloved*. It demonstrates that modern narrative experimentation embodies the logic of the unconscious rather than merely representing it. By integrating psychoanalytic theory with close reading and comparative analysis, the study contributes to contemporary debates in narrative theory and highlights the continued relevance of psychoanalysis in literary criticism.

Keywords: Psychoanalysis, Narrative Form, Modernism, Trauma, Freud, Lacan

INTRODUCTION

The emergence of psychoanalysis in the early twentieth century marked a decisive shift in the understanding of human subjectivity. Freud's formulation of the unconscious challenged the Enlightenment model of rational selfhood by positing that human behavior is shaped by repressed desires and unresolved conflicts.¹ This theoretical intervention profoundly influenced literary studies, enabling critics to interpret texts as sites where hidden psychological processes are encoded.



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Modernist literature developed within a historical context characterized by rapid industrialization, urbanization, and the psychological aftermath of global conflict. These conditions destabilized traditional notions of identity, prompting writers to experiment with new narrative forms capable of representing fragmented consciousness. This paper argues that such formal experimentation is not merely aesthetic but structurally analogous to unconscious processes described in psychoanalysis. It further proposes that narrative form functions as an active medium through which unconscious dynamics are organized and made intelligible.

LITERATURE REVIEW

Psychoanalytic criticism has significantly shaped literary theory. Freud's concept of repression suggests that unacceptable desires are excluded from consciousness but continue to operate indirectly through symbolic forms [2]. Early critics applied these ideas to interpret imagery, metaphor, and narrative symbolism. Lacan extends Freud's work by arguing that the unconscious is structured like a language, thereby emphasizing the role of signification and symbolic systems in shaping subjectivity [3]. Kristeva's concept of abjection further complicates identity formation by examining processes of exclusion that destabilize the boundaries of the self [4]. Trauma theory, particularly in the work of Cathy Caruth, highlights how traumatic experience resists direct representation and returns through fragmented and repetitive narrative forms [5]. Peter Brooks connects narrative structure with desire, suggesting that storytelling mirrors psychic processes [6] while Terry Eagleton situates psychoanalysis within broader ideological critique [7]. Slavoj Žižek integrates Lacanian theory with cultural analysis, emphasizing the ideological dimension of unconscious desire [8].

Despite these contributions, insufficient attention has been given to narrative form as a structural manifestation of unconscious processes. This study addresses that gap by focusing on formal strategies rather than solely thematic interpretation.

Theoretical Framework

Freud's structural model of the psyche—id, ego, and superego—provides a foundational framework for understanding repression and symbolic return [9]. Dreams operate through condensation and displacement, mechanisms that transform latent content into symbolic form. These mechanisms closely resemble literary techniques such as metaphor, imagery, and narrative displacement. Lacan's reinterpretation emphasizes language and the symbolic order. He argues that subjectivity is constituted through linguistic structures, making narrative discourse a crucial site for analyzing unconscious processes [10]. Disruptions in narrative coherence can therefore be interpreted as expressions of underlying symbolic tensions. Caruth's trauma theory introduces the idea that traumatic memory disrupts temporal continuity, appearing through repetition, fragmentation, and narrative disjunction [11]. This theoretical framework enables a reading of literary form as a representation of psychological rupture.

METHODOLOGY

This study adopts a qualitative interpretive methodology grounded in psychoanalytic hermeneutics and close textual analysis. The selected texts are examined in relation to narrative structure, temporal organization, and symbolic representation. A comparative approach is employed to identify shared structural patterns across different literary and cultural contexts. The selection of these texts is based on their canonical status within modernist and postmodern literature and their sustained engagement with psychological complexity, making them particularly suitable for psychoanalytic analysis.

Narrative Form and Modernism

Modernist literature departs from linear realism by employing techniques such as stream-of-consciousness, temporal disruption, and narrative fragmentation. These techniques mirror unconscious processes, which operate through association rather than logical sequence.



**Ankush Mishra****Kafka: Alienation and Repression**

In *The Metamorphosis*, Kafka presents Gregor Samsa's transformation as a symbolic externalization of repression. Gregor's sense of obligation and duty toward his family reveals the internal conflict between personal desire and social responsibility (Kafka, 1915). His metamorphosis can thus be interpreted as the manifestation of repressed subjectivity. Gregor's room functions as a psychological enclosure, while the removal of furniture symbolizes the erosion of identity. His inability to communicate reflects the limits of language in articulating unconscious experience. The narrative structure reinforces this isolation by restricting perspective and emphasizing interiority.

Kafka further intensifies this psychological condition through imagery of physical discomfort and bodily alienation. Gregor's struggle to control his new body—particularly his inability to get out of bed—illustrates the disjunction between conscious intention and unconscious forces. Additionally, the family's gradual withdrawal, especially his sister Grete's eventual rejection, underscores the collapse of symbolic identity within the social order.

Woolf: Memory and Temporality

Woolf's *Mrs. Dalloway* employs shifting perspectives and temporal fluidity to represent consciousness. Septimus Warren Smith's trauma is expressed through hallucinations and intrusive memories, as when "the world wavered and quivered," illustrating the instability of perception (Woolf, 1925). The recurring sound of Big Ben imposes chronological order upon subjective experience, creating tension between external time and internal memory. Woolf's narrative technique demonstrates how identity is constructed through the interplay of memory and perception. Clarissa Dalloway's reflections on her past—particularly her memories of Sally Seton—demonstrate how identity is continuously reconstructed through recollection. These memories emerge not as linear sequences but as associative flashes, reinforcing the psychoanalytic understanding of memory as non-linear and dynamic. Furthermore, Septimus's inability to distinguish between past and present highlights the persistence of trauma within consciousness. His visions of Evans exemplify the return of the repressed, where unresolved experiences intrude upon present perception.

Morrison: Trauma and Collective Memory

In *Beloved*, Morrison represents trauma through fragmented narrative voices and nonlinear structure. Sethe's declaration—"I will never run from another thing on this earth"—reveals the persistence of trauma within the present (Morrison, 1987). The character of Beloved embodies the return of repressed history, while the narrative's disjointed chronology reflects the disruption of temporal continuity. Morrison extends psychoanalytic interpretation beyond individual psychology to encompass collective memory. Morrison further develops this theme through the recurring motif of the "chokecherry tree" scar on Sethe's back, which symbolizes the physical inscription of trauma onto the body. This image functions as both a literal and symbolic representation of suffering that cannot be fully articulated through language. Additionally, the opening line "124 was spiteful" establishes the house itself as a site of memory and haunting, suggesting that trauma is embedded within space as well as consciousness. The shifting narrative voices, particularly in the monologues of Sethe, Denver, and Beloved, create a fragmented narrative structure that mirrors the process of reconstructing traumatic memory.

Comparative Analysis

Kafka, Woolf, and Morrison employ distinct narrative strategies, yet all utilize fragmentation to represent psychological complexity. Kafka's narrative reflects alienation, Woolf's explores temporality, and Morrison's addresses historical trauma. These strategies illustrate how narrative form operates as a structural analogue of unconscious processes.

DISCUSSION

A critical distinction between Freudian and Lacanian psychoanalysis further deepens the interpretation of narrative form. Freud conceptualizes the unconscious primarily in terms of repressed instinctual drives that return through symbolic representation. In contrast, Lacan shifts attention to the linguistic and symbolic structures that organize





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subjectivity. While Freud's model emphasizes psychological content, Lacan foregrounds the structural conditions through which meaning is produced. This distinction is crucial for literary analysis: narrative fragmentation can be interpreted not only as the return of repressed material but also as a manifestation of the symbolic order that structures subjectivity. By integrating both perspectives, this study demonstrates that narrative form operates simultaneously as a site of psychological expression and linguistic organization. The findings of this study suggest that narrative form operates as more than a stylistic device; it actively structures psychological meaning. By reproducing mechanisms such as repression, displacement, and fragmentation, literary narratives provide insight into the workings of the unconscious.

CONCLUSION

This study demonstrates that modern narrative form embodies unconscious processes rather than merely representing them. Psychoanalytic criticism thus remains essential for understanding modern literary form.

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RESEARCH ARTICLE

A Trinocular Systemic Functional Analysis of Ideational Meaning in Tamil Clauses

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ABSTRACT

This study analyses two Tamil clauses to show how ideational meaning is constructed in Tamil using the framework of Systemic Functional Linguistics (SFL) propounded by M.A.K. Halliday. Focusing on Halliday's trinocular perspective, the study analyses language from three complementary angles – meaning (from above), Grammar (from below) and Systemic Choices (from round about) using Halliday's Trinocular Perspective. Two simple Tamil clauses – one representing a Material Process (action) and the other a Relational Process (state or quality) are analysed. The results show how Tamil unifies experience through processes, participants, and circumstances. At the semantic level, in the clauses taken for analysis, the Material clause indicates actions, and the Relational clause denotes the quality of the noun discussed. At the Lexicogrammatical level, features such as case markers, verb morphology and phrase structure help the readers realise the meaning conveyed. While the Material clause depicts the way in which roles like Actor and Goal are coded through suffixes and agreement, the Relational clause reveals how qualities are conveyed through adjectives and copular structures. From the perspective of SFL, the study underlines how the speakers choose the process types and grammatical patterns to create meaning. In sum, the study presents the richness and flexibility of Tamil as a meaning-making system and shows the application of SFL for analysing Dravidian languages. The results also suggest significant perceptions on linguistic research and language education and training, particularly in multilingual academic settings.

Keywords: Systemic Functional Linguistics, Ideational meta function, Transitivity, Trinocular analysis, Tamil lexicogrammar



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INTRODUCTION

The Systemic Functional Linguistics (SFL) propounded by M.A.K.Halliday (1994) perceives language as a resource for making meaning. It views language as a social semiotic system. In this context, the Ideational Meta function represents human experience and enables speakers to construe actions, events, and states through linguistic structures. A key component of Ideational Meta function is the concept of Transitivity which explains how processes, participants and circumstances interact to produce meaning in clauses (Halliday & Matthiessen, 2014). SFL has wide application in the analysis of English and other languages, but its application has not been fully explored to analyse Dravidian languages such as Tamil. Tamil, which is an agglutinative language has a rich system of suffixation and morphological marking. It offers significant potential for examining how Ideational meanings are determined through lexicogrammatical resources (Krishnamurti, 2003). Specifically, the correlation between semantic roles and grammatical insight in Tamil offers a scope for testing the cross-linguistic application of SFL theories. This aim of this study is to analyse two simple Tamil clauses that represent Material Process and Relational Process. Further, the study analyses the realisation of Ideational meaning in Tamil clauses and the way in which Transitivity roles are encoded by lexicogrammatical features. Also, it presents the perceptions that emerge from a Trinocular analysis – from above (semantic meaning), from below (lexicogrammatical realisation) and from round about (systemic choices within the language) (Halliday & Matthiessen 2014). Thus, the study promotes the expansion of SFL research beyond English and focuses on the significance of Tamil as a meaning-making system, with propositions for both linguistic theory and pedagogy in multilingual contexts.

Theoretical Framework

Developed by M.A.K. Halliday (1994), Systemic Functional Linguistics views language as a meaning-making resource and a social semiotic system. According to this concept, linguistic choices are shaped by the context-based communicative needs. SFL focuses on the functions of the language and analyses how meaning is conveyed through different layers of linguistic organisation, especially semantics and lexicogrammar (Eggins, 2004). The core concept of SFL is the three meta functions – Ideational, Interpersonal and Textual - of the language. The Ideational meta function denotes experience and logical relations, the Interpersonal meta function deals with interaction and evaluation, and the Textual meta function shapes the discourse into coherent messages (Halliday & Hasan, 1985). The focus of the present research is the Ideational meta function and analyse how experience is encoded in clause structure.

The Ideational meta function is presented through Transitivity system which explains the representation of processes, participants and circumstances through clauses. There are different types of processes, but this study focuses on Material and Relational Processes. While Material Process represents actions and events involving participants such as Actor (the doer of the action) and Goal (the entity affected by the action), the Relational Process describes the state of being, rather than actions, identification and attribution. This involves participants such as Carrier and Attribute in attributive clauses (Thompson, 2014). In SFL, Transitivity goes beyond the traditional grammatical notion of transitive and intransitive verbs providing a semantic framework for understanding how experiences are structured in language. The process types, participant roles and circumstantial elements interact among themselves through clauses that represent real or imagined experiences (Halliday & Matthiessen, 2014).

The Trinocular perspective is a significant analytical principle in SFL. It proposes the three complementary viewpoints – ‘from above’, ‘from below’ and ‘from round about’ - based on which language should be examined. The analysis ‘from above’ focuses on the semantic level. Here, the meaning is interpreted in terms of experiential functions such as process and participant roles. ‘From below’ examines the way in which these meanings are realised at lexicogrammatical level. This includes morphological and syntactic structures. The view ‘from round about’ considers the system network of choices that are available within the language, and it also highlights the speakers’ selection of grammatical structure to express meaning (Halliday & Matthiessen, 2014). This Trinocular approach





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supports in analysing a language comprehensively connecting meaning, form and choice and this proves to be an ideal system for studying languages with rich morphological systems. The Dravidian language, Tamil, is agglutinative with case markers, verb morphology, and agreement features encoding relationships between participants and processes. The grammatical meanings are realised through suffixation (Schiffman, 1999; Andronov, 2003). Tamil has embedded copular structures in relational clauses with adjectives functioning as predicates without an explicit verb form (Lehmann, 1993). Such typological characteristics make Tamil appropriate for understanding the realisation of Ideational meaning through SFL. The present study applies the Trinocular framework to Tamil clauses and shows how semantic roles are mapped to lexicogrammatical forms scientifically thereby contributing to an extensive understanding of language as a meaning-making resource.

METHODOLOGY

The present research is based on a qualitative descriptive research design to analyse the realisation of ideational meaning in Tamil clauses within the SFL framework. This theory-driven study illustrates how meaning is constructed through the semantic and lexicogrammatical resources. Two Tamil clauses were taken for the study. The clauses were chosen in such a way that they represent two major process types - Material process (action) and Relational process (state or quality) - within the Transitivity system. The structures were simple and clear, and they were found appropriate for a focused and detailed Trinocular analysis. The analysis was done using the Trinocular perspective proposed by M.A.K.Halliday and Matthiessen (2014) and each clause was examined from three complementary angles - 'from above', that considers the semantic level identifying process types, participant roles and experiential meaning, 'from below' deals with the lexicogrammatical realisation of these meanings which includes case markers, suffixation, verb morphology and clause structure and 'from round about' focuses on systemic choices available within Tamil and it highlights the selection of grammatical patterns to communicate meaning.

Each Tamil clause is presented with transliteration, morpheme-by-morpheme glossing, and English translation. Standard linguistic glossing is done to specify grammatical functions like number, case and tense facilitating a transparent connection between semantic interpretation and grammatical form. Since the study is restricted to a small number of examples, it offers an in-depth analysis illustrating the effectiveness of the Trinocular SFL framework for analysing Tamil.

Data Analysis

The study analysed two Tamil clauses representing different process types within the SFL Transitivity system. The first clause shows Material Process expressing an action performed by the participants. The second clause demonstrates a Relational Process expressing a state or quality. Each clause is presented with transliteration, gloss, and English translation to facilitate the linguistic analysis and accessibility for non-Tamil readers.

Clause 1: Material Process

மாணவர்கள் புத்தகத்தை வாசித்தனர்

Transliteration

māṇavarkaḷ putthagaththai vāciththanar

Translation

The students read the book.

Gloss

- மாணவர் (māṇavar) = student
- -கள் (-kaḷ) = plural suffix
- புத்தகம் (putthagam) = book
- -த்தை (-ththai) = accusative case marker





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- வாசி (vāci) = read
- -த்தனர் (-ththananar) = past tense + plural agreement

Clause 2: Relational Process

புத்தகம் சுவாரஸ்யமானது

Transliteration

putthagam suvārasyamāṇathu

Translation

The book is interesting.

Gloss

- புத்தகம் (putthagam) = book
- சுவாரஸ்யமானது (suvārasyamāṇathu) = interesting

ANALYSIS AND DISCUSSION

Analysis of the Material Clause

From Above: Semantic Perspective

From the Semantic Perspective, the clause represents the Material process which denotes an action or an event. The Process is indicated through the verb வாசித்தனர் (read) showing an activity done by the participants. The Actor in the clause is மாணவர்கள் (students) who perform the action. The Goal is represented by புத்தகத்தை (the book), the entity affected by the process. Therefore, the clause presents an experiential meaning that involves an action carried out by a collection or a group of participants upon an object. This shows how Tamil organises an experience through a process-participant relationship within the ideational meta function.

From Below: Lexicogrammatical Perspective

At the lexicogrammatical level, the clause unfolds several important features of sentence construction in Tamil. The suffix -கள் (-kal), in the noun மாணவர்கள் indicates plurality and -த்தை (-ththai) in புத்தகத்தை is an accusative case marker which marks the noun as the object or Goal of the process. The verb வாசித்தனர் has morphological markers expressing tense and agreement. The suffixes present the past tense and the plural agreement with the Actor. This proves the agglutinative nature of Tamil, where grammatical meanings are comprehended through suffixes.

The structure of the clause is typical Tamil Subject-Object-Verb (SOV) word order. The verb is positioned at the end of the clause. The grammatical structures facilitate in systematically mapping the semantic roles with lexicogrammatical structures.

From Round About: Systemic Perspective

From the SFL perspective, the clause has a Material process representing an observable action. Since the clause focuses on physical activity, Material process has been chosen here although Tamil offers alternative process choices such as Relational and Mental process. The case marking and verbal agreement help in identifying the participant. The structure, thus, demonstrates how Tamil speakers utilise the grammatical properties to present the experiential meaning efficiently.

Analysis of the Relational Clause

From Above: Semantic Perspective

Semantically, the clause has a Relational Attributive process which delegates a quality to an object. The participant புத்தகம் (book) functions as a carrier, while சுவாரஸ்யமானது (interesting) functions as the Attribute. The Relational clause represents a state or quality associated with the Carrier. Therefore, the clause reflects the experiential function of an object.





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From Below: Lexicogrammatical Perspective

At the lexicogrammatical level, the clause shows the use of implicit copular structure which is a typological feature characteristic of Tamil. Unlike English, Tamil does not have an explicit verb equivalent to 'is' in present tense Relational clause. The word *சுவாரஸ்யமடனது* is the adjectival form and it functions as the predicate expressing the Attribute directly. The relational meaning can be comprehended through the clause structure. The absence of the explicit copular structure does not impair or reduce the clarity of expression. This shows how Tamil represents relational meanings through Adjectival morphology and predicate structures rather than through copular verbs.

From Round About: Systemic Perspective

In SFL view, the speaker selects a Relational process rather than a Material process because the purpose of communication is to describe a quality or nature and not an action. The clause shows how Tamil agrees with the precise expression of attribution through adjectival predicates. Also, the implicit copular structure proves that Tamil has an appropriate grammatical choice within the system contributing to its flexibility and establishing its meaning-making potential.

DISCUSSION OF FINDINGS

The study shows how the two clauses represent different process types and demonstrate distinct experiential meanings in Tamil. The Material encodes action through Actor, Goal, and Verbal Morphology and the Relational clause encodes features or traits through Carrier and Attribute.

Lexicogrammatically, both the clauses illustrate the importance of suffixation and morphology in Tamil. The Material clause depends more on case markers and verbal agreement, and the Relational clause relies on adjectival expression acting as predicate and the implicit copular structure.

CONCLUSION

Thus, the Trinocular study on Tamil clauses shows a close correlation between meaning, grammatical realisation and systemic choice. The findings prove the effectiveness of SFL in explaining how users of Tamil language organise experience linguistically through different process structures.

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RESEARCH ARTICLE

Study on Reading Literary Texts in Technical Language Classroom

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ABSTRACT

Literature is to be experienced, enjoyed, appreciated, and loved. Technical Education refers to the preparation of individuals to teach specific vocational skills, trades, or professions to students. Literary Text will provide students with the opportunities to experience and use the language more creatively and to develop greater awareness of the language they are learning. It also helps students develop empathy and understanding besides critical thinking skills. This essay offers an analysis derived from a study performed with Engineering students. It evaluates the effects of reading literary texts in engineering classroom. In the Elements of Literature (MX3082) classroom, a poem was given in a separate sheet to the third year under graduate students (III B.E Civil) for analysis of the text. Also, students were asked to prepare assignments on critical appreciation of fiction they read. The results showed that the majority of the students have positive perceptions towards using literary text in their study program. The outcome of this study is to make students understand the relevance of literature in human life and appreciate its aspects in developing finer sensibilities.

Keywords: Reading, Literature, Poem, Fiction, Classroom.



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INTRODUCTION

In Anna University regulation 2021 curriculum, it introduced Mandatory courses for fifth semester students which is 'Elements of Literature' (MX3082) for all engineering programs. The objective of this subject is to make the students aware about the aesthetic approach of human existence through an art form so that students will learn to appreciate different forms of literature as suitable modes of expressing human experience. The content of the syllabus were elements of poetry, elements of fiction and elements of drama. Initially, when brief introduction of relevance of literature was given it seemed absurd for engineering students as their domain is entirely technical but gradually they enjoyed. The classes allotted were three hours per week. [Friday 1.30 pm - 4.05pm]. They had enough time for discussions and interactions with each other. Students got benefitted learning to speak in English confidently without hesitation in seminars. It was leisure for them from routine work.

Literary Texts

Literary text holds a prominent role in students' personal development since the reader becomes emotionally attached with the text and this has positive effects not only on the personal growth but also on the whole learning process. Technical Education aims to provide practical skills and knowledge related to industry trends and prepares graduates for roles in engineering, medicine, and various other fields. But literary criticism is an important part of modern classroom teaching because it helps readers understand and engage with literature. It is the analysis, interpretation, and evaluation of works of literature, such as novels, short stories, essays, plays, and poetry. It is a way to help readers better understand and engage with a work of literature. A typical literary criticism begins with a summary of the text, examines its arguments, and ends with an evaluation.

Most importantly, by fostering a love of reading from a young age, students become independent learners whenever they pick up a book to read for pleasure, are actually improving their language skills. There is a strong expectation put on literature reading in the classroom, with the hope that this will allow students to gain an understanding of social, human, and cultural values through literature reading (Poulet, 1969). Also, it promotes the students four language skills – listening, speaking, reading and writing. According to Whitener (2019), reading literature inspires students to reflect, critique, analyze, interpret, and connect.

Literary Criticism

Practical criticism began in the 1920s with a series of experiments by I.A.Richards on his students to assess poems on their own devoid of information regarding authorship or any other additional information. Students responded to a variety of unidentified poems, and the student's summary were then dissected by Richards in hugely popular lectures, 'so popular that at times they had to be held in the streets' (Russo 93). In *Practical Criticism*, Richards advocates a close textual and verbal analysis of poetry. Language is made up of words and hence the study of words is of paramount importance in the understanding of a work of art. Words, according to Richards, communicate four kinds of meaning: Sense, Feeling, Tone, and Intention. The meaning of a poem rests in the readers analysis of the text and the response to it.

Poetry communicates feelings and emotions. It speaks not to the mind but to the heart. Science makes statements, poetry makes pseudo-statements that cannot be empirically tested and proved true or false. A statement is justified by its truth. On the other hand, the pseudo statement of poetry is justified by its imagination. Poetry analysis typically involves the careful examination of various literary elements. These elements include narration, setting, characters, theme, structure, rhythm, rhyme, figurative language, diction, tone, and mood. As the students were technical, they were not asked to do close reading of the text like I.A. Richards or no literary theory was adopted. The participants were asked to do superficial reading of Nissim Ezekiel's Poem "Night of the Scorpion" and individually they were asked to summarise the poem. The poem depicts a scene of rural Indian life where the speaker's mother is stung by a scorpion seeking shelter from ten hours of relentless rain and detailing the villagers' superstitious rituals.



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The mother's selfless love shines through as she thanks God the scorpion bit her and not her children All the participants were able to understand the theme of the poem and enjoyed the literary piece. They were very keen to read the poem and different interpretations were given on the superstitious beliefs found in poem. Students were devoid of any gadgets like mobile, internet or dictionary, thus difficult to grasp words like 'sceptic', 'rationalist', 'incantation' and 'diabolic'. 20 objective type questions were given to students to answer the questions, nearly 95 % of students answered correctly.

Reading Strategies

Reading is the foundation for lifelong success. When student develop a reading habit early, they are more likely to excel in their career, perform better in competitive exams, communicate confidently, and become lifelong learners. Strong reading skills contribute significantly to overall language development and academic performance. They follow different types of reading techniques according to their reading needs. Each technique plays a role in improving overall reading proficiency. Skimming involves quick reading to grasp the main idea or gist of a text, while scanning involves quick search for specific information or keywords in a text. Intensive reading requires a high level of focus and deliberate effort whereas extensive reading is meant to be a fun and pleasurable experience. As it is a literary text majority of the students followed skimming and extensive reading which was sufficient for engineering students.

Reading is an activity that leads to success because it's a primary act for gaining knowledge of any field. Due to the emergence of new digital technologies students have a variety of options for reading. Saaid &Wahab (2014) revealed that 62.2% of university students read digital-based material for leisure, 18.1% for research, and 12.7% for their study. Digital material provides easier and faster reading options for students. They do not bother to read long text which needs time and concentration to increase their vocabulary and understanding of gaining experience in various field. Thus, students were given task to prepare summary of any fiction which they would prefer. And asked to read in the class, they were enthusiastic to share their summary. Here some instances are given of students' critical appreciation of fiction. Thomas Hardy's *The Mayor of Casterbridge* taught the students that pride leads to ruin. Charlotte Perkins Gilman's *The Yellow Wallpaper* was a cautionary tale against looking down on women. Charles Dicken's *A Tale of Two Cities* centers on sacrifice and the power of love to overcome despair. The moral lessons of Jane Austen's *Pride and Prejudice* are that love and family are important, and that pride and prejudice can be dangerous. Yann Martel's *Life of Pi* explores how faith, resilience, and storytelling are essential for survival and finding meaning in suffering. While reading the summary, students felt better at inferring meaning, grasping general ideas, and reading faster. It helped them to build fluency and vocabulary. Also, it may nurture their life skills which can enable individuals to deal with everyday life and societal life. As the students were third year, they were mature enough to handle these reading of fictions in class room.

Literature provides pleasure to listeners and readers. It is a relaxing escape from daily problems, and it fills leisure moments. Developing a love of literature as a recreational activity is possibly the most important outcome of a literature programme. Literary texts enrich the language input in the classroom and stimulate language acquisition by providing 'meaningful and memorable contexts for processing and interpreting new language' (Lazar, 1993:17). Though students were technical they gave positive responses that literary text will develop their communication skills, and they showed their interest of including some literary pieces in their curriculum.

Reading Newspaper

Difficulty with reading is a common problem. Students not interested in reading novels, dramas or poems can be encouraged to read English newspapers. Integrating newspaper reading in engineering classrooms acts as a bridging technical theory with real-world applications. The benefits of reading newspaper in the classroom are manifold and have the potential to transform students to avid reader. It exposes students to diverse perspectives, business news, social issues and enhancing overall general knowledge. Reading Newspaper article is included in engineering syllabus of 'Technical English' subject of the first-year students. A task was given to students to share the read news in classroom. Most of the students showed interest sharing regional news and film news. Students can be encouraged



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to read political news, science, business, economical, sports news etc. It helps to improve the reading habit, communication skill and social awareness. This will not only enhance their reading skills but also update students' current affair knowledge. This applied in the classroom was fruitful besides reading literary text.

CONCLUSION

The 21st century has become the era of multi-media where books and newspapers are being replaced by television and the internet. College students are looking for new and faster ways to entertain themselves that does not require as much effort as reading and thinking. It is no longer seen as activity young students enjoy doing. The outcome of this is that the multi-media world is rapidly growing while the literature era is slowly fading away. As teachers, it is their responsibility to encourage students to do extensive reading, which involves learners reading texts for enjoyment and to develop general reading skills. Though it is struggle competing with the multi-media, students can be given literary text which is easy to read and understand and enhance their didactic values in life and society. Literature helps better understand lives and the world around us. Encounters with literature develop the concepts of identification, imagination, and empathy.

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RESEARCH ARTICLE

From Divine to Demon: Erasure of Women's Power–Rethinking of the Madonna-Whore Dichotomy and the Monstrous-Feminine in Popular Narratives

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ABSTRACT

This paper analyses how women's power, once visible in ancient cultural and religious narratives, gets gradually distorted, silenced, or erased through patriarchal storytelling. Early texts and traditions present women not as passive figures but as thinkers, warriors, devotees, and moral authorities like Gargi, Maitreyi, Draupadi, Kannagi, Andal, and a host of goddesses who embody cosmic power. However, as narratives are retold and institutionalized, women's agency is either idealized into obedience or punished as transgression. The present study analyses the fiction *Circe* by Madeline Miller and the movie *Barbie* (2023). Besides the present works also reconceptualises selected epics, and folk traditions using Madonna - Whore dichotomy and the monstrous feminine as seen in feminist and psycho analytical theories to trace how women's autonomy is systematically reshaped. Women who challenge social or male authority are often transformed into symbols-sacrifice, purity, or danger-thereby divesting them of their political and intellectual agency. Their stories survive, but their power does not. The paper then links this historical erasure with contemporary gender politics, which symbolically revere goddesses but engage in everyday discrimination against women. This paradox reveals a cultural logic that celebrates female power only when that power is abstract, spiritualized, or safely distant from real social structures. In lived reality, women continue to face barriers to leadership, knowledge production, economic mobility, and public space. The present paper reads cultural narratives as political texts, arguing that inequality is reproduced not only through law or economy but also through the storytelling that circumscribes what women can be. And when women exceed these limits, they are commonly rendered invisible, misrepresented, or morally disciplined-turned from divine into demon. Reclaiming women's power does



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not mean rejecting tradition but re-reading it critically. This paper calls for recovering suppressed voices, questioning inherited narratives, and breaking those cultural patterns that still turn living women into shadows of their potential.

Keywords: *Tradition, Divine, Demon Goddesses, Power, Feministic myth, Women's power*

INTRODUCTION

Patriarchal storytelling has systematically distorted women's power across epochs, transforming potent figures into idealized Madonnas or terrifying monsters, thereby erasing their agency. Ancient narratives and traditions from Vedic Upanishads to Tamil epics and Greek myths, initially depict women not as passive figures but as thinkers, warriors, devotees, moral authorities and intellectual powerhouses like Gargi debating sages, Draupadi commanding kings, Kannagi toppling kingdoms, Andal and a host of goddesses who embody cosmic power. However successive retellings have institutionalized them into passive purity or punished deviance. Women's agency is either idealized into obedience or penalised as transgression. The core argument posits narratives as political instruments reproducing inequality: women challenging authority become sacrificial symbols or dangers, their power abstracted into spiritual irrelevance—thereby divesting them of their political and intellectual agency, while real-world barriers persist. This paper subsequently connects this historical erasure with contemporary gender politics, which symbolically revere goddesses but engage in everyday discrimination against women. Linking historical myths to contemporary politics—goddess worship amid discrimination—this study reconceptualises epics and pop culture, advocating critical re-reading for reclamation. Through psychoanalytic and feminist frameworks, it reveals how storytelling circumscribes female potential, turning divine women demonic when autonomous. This paradox reveals a cultural logic that celebrates female power only when that power is abstract, spiritualized, or safely distant from real social structures. In lived reality, women continue to face barriers to leadership, knowledge production, economic mobility, and public space. The present paper reads cultural narratives as political texts, arguing that inequality is reproduced not only through law or economy but also through the storytelling that circumscribes what women can be. And when women exceed these limits, they are commonly rendered invisible, misrepresented, or morally disciplined—turned from divine into demon. Through the lenses of Madonna-Whore dichotomy (Freud) and monstrous-feminine (Creed) alongside Mulvey's male gaze, this paper traces this erasure in traditions with particular reference to contemporary fiction *Circe* by Madeline Miller and the movie *Barbie* (2023). Besides, the present work also reconceptualises selected epics, and folk traditions using Madonna - Whore dichotomy and the monstrous feminine as seen in feminist and psycho analytical theories to trace how women's autonomy is systematically reshaped. In addition this paper also demands for recovering suppressed voices, questioning inherited narratives, and breaking those cultural patterns that still turn living women into shadows of their potential as reclaiming women's power does not mean rejecting tradition but re-reading it critically.

Defining the Scope: The Binary of Deification and Demonization in Gender Politics

The representation of women within cultural, religious, and narrative traditions has historically been structured through a polarized framework that oscillates between deification and demonization. This binary is neither incidental nor merely symbolic; rather, it functions as a deeply embedded ideological apparatus that regulates gender roles and constrains women's agency within both textual and lived realities. At its core, this binary constructs womanhood as a site of contradiction. Women are either elevated to the status of the divine—embodying purity, sacrifice, nurturing, and moral perfection—or relegated to the realm of the demonic, characterized by excess, desire, rebellion, and perceived moral corruption. Importantly, these categories do not reflect women's lived experiences but rather impose externally constructed identities that serve patriarchal stability.

Deification, while ostensibly celebratory, operates as a subtle mechanism of erasure. The divine woman is revered but immobilized. She exists not as a subject but as an ideal—abstracted from material reality and stripped of agency.



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As scholars have noted, idealization often functions as a form of control, wherein the subject is elevated beyond critique but simultaneously denied participation in social and political life (Beauvoir 1949). The “goddess” figure, therefore, becomes a symbolic construct that demands perfection while precluding autonomy. This phenomenon is particularly evident in South Asian contexts, where female deities such as Durga, Lakshmi, and Saraswati are revered as embodiments of power. However, this symbolic reverence coexists with systemic gender inequalities, including restricted access to education, economic disparity, and limitations on bodily autonomy. This paradox underscores what Nivedita Menon describes as the “cultural mystification of women’s power,” wherein symbolic elevation masks structural subordination (Menon 2012).

Demonization, conversely, emerges as a response to female transgression. Women who deviate from prescribed roles—whether through sexual autonomy, intellectual assertion, or political resistance—are recoded as dangerous or deviant. This process aligns with Michel Foucault’s conception of discourse as a regulatory force that defines and disciplines acceptable behaviour (Foucault 1978). Within this framework, labelling women as “monstrous” or “immoral” serves to delegitimize their agency and justify their exclusion. The binary thus functions as a dual mechanism of containment:

- Deification neutralizes women through idealization, rendering them passive and untouchable.
- Demonization disciplines women through fear, marking deviation as socially and morally unacceptable.

Together, these processes create what may be termed a discursive enclosure, within which women’s identities are confined to extremes, leaving no space for complexity, contradiction, or self-definition. Furthermore, this binary is sustained through narrative repetition. Myths, epics, religious texts, and contemporary media continuously reproduce these archetypes, embedding them within cultural consciousness. As Judith Butler argues, gender is not an inherent identity but a performative construct, produced through repeated acts and reinforced through cultural narratives (Butler 1990). The persistence of the divine/demonic binary thus reflects not its naturalness but its continual reinforcement.

This repetition ensures that the binary is internalized not only at a societal level but also at the level of individual subjectivity. Women are often compelled to negotiate their identities within these constraints, calibrating their behaviour to avoid demonization while striving for unattainable ideals of perfection. Importantly, the binary also intersects with other axes of power, including class, caste, and race. The “ideal woman” is often implicitly defined through upper-caste, heteronormative, and patriarchal standards, while marginalized women are more readily subjected to demonization. This intersectional dimension complicates the binary, revealing it as a dynamic system that adapts to preserve existing hierarchies (Crenshaw 1989).

In contemporary contexts, this binary persists in more subtle forms. Media representations, for instance, continue to oscillate between glorifying women as symbols of virtue and vilifying them for perceived transgressions. Social media amplifies this dynamic, enabling rapid cycles of idealization and backlash that mirror historical patterns of worship and witch-hunting. Thus, defining the scope of this study requires recognizing that the binary of deification and demonization is not confined to mythological or literary traditions but extends into modern cultural, political, and digital landscapes. It operates across temporal and spatial boundaries, adapting to new contexts while retaining its core function: the regulation of women’s power.

This paper, therefore, positions this binary not as a descriptive category but as a critical problem—one that necessitates interrogation, deconstruction, and re-reading. By examining how this binary is constructed and sustained, the study seeks to uncover the mechanisms through which women’s agency is systematically reshaped and, ultimately, erased.





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Theoretical Frameworks

Psychoanalytic Theory: The Madonna–Whore Complex

The Madonna–Whore dichotomy, first articulated by Sigmund Freud, remains one of the most enduring psychoanalytic frameworks for understanding gendered perception. Freud observes a fundamental psychic split in heterosexual male desire: men tend to idealize women they respect (the “Madonna”) while desiring women they perceive as sexually available but morally inferior (the “Whore”) (Freud 1912). This division produces a structural inability to reconcile love and desire within a single female subject. While Freud situates this dichotomy within individual psychology, its implications extend far beyond the psyche into cultural and ideological formations. Feminist scholars have argued that this binary is not merely descriptive but prescriptive, shaping social expectations of femininity and reinforcing patriarchal control (Irigaray 1985; Rubin 1975). The Madonna–Whore complex thus becomes a cultural script through which women are categorized, evaluated, and disciplined. At a structural level, the dichotomy functions by denying women a unified identity. A woman who conforms to the Madonna ideal—pure, nurturing, self-sacrificing—is granted respect but deprived of agency and desire. Conversely, a woman who embodies sexual autonomy or assertiveness is relegated to the category of the Whore, thereby losing social legitimacy and moral authority. This division enforces a double bind: women cannot simultaneously inhabit respectability and autonomy.

The persistence of this binary can be understood through Louis Althusser’s notion of ideological state apparatuses, wherein institutions such as religion, family, and media reproduce dominant ideologies through normalization (Althusser 1971). The Madonna–Whore dichotomy is internalized through these structures, shaping not only how women are perceived but also how they perceive themselves. Moreover, the dichotomy operates as a mechanism of political erasure. By idealizing women, it strips them of the complexity required for leadership and decision-making. By demonizing them, it delegitimizes dissent and resistance. In both cases, the result is the same: the exclusion of women from positions of power. Importantly, this binary is not static; it evolves across historical and cultural contexts. In contemporary media, the dichotomy manifests in subtler forms—the “good girl” versus the “bad girl,” the “wife material” versus the “desirable woman.” These iterations demonstrate the adaptability of the framework, ensuring its continued relevance in modern gender politics. Thus, the Madonna–Whore complex must be understood not merely as a psychological phenomenon but as a discursive strategy that structures gender relations and sustains patriarchal hierarchies.

The Monstrous-Feminine: Abjection, Body, and Fear

Barbara Creed’s concept of the monstrous-feminine offers a critical expansion of psychoanalytic theory by foregrounding the role of the female body in the construction of horror and fear. Drawing upon Julia Kristeva’s theory of abjection, Creed argues that patriarchal culture constructs the female body—particularly its reproductive capacities—as a site of anxiety, excess, and contamination (Creed 1993; Kristeva 1982). Abjection, as defined by Kristeva, refers to that which disturbs identity, system, and order. It is associated with bodily fluids, decay, and processes that blur boundaries between self and other. The maternal body, in particular, becomes a primary site of abjection because it challenges the distinction between subject and object. This ambiguity generates discomfort, which is then translated into cultural representations of fear. Recent feminist film scholarship has begun to reinterpret the monstrous-feminine not merely as a site of abjection but as a space of resistance, where female monstrosity becomes a transformative and liberatory force (Creed 2022). Within this framework, the monstrous-feminine emerges as a figure that embodies these anxieties. Unlike traditional monsters, which are often external threats, the monstrous-feminine is intimately connected to the body, sexuality, and reproduction. She is not merely feared for her actions but for what she represents—a disruption of order.

This construction is evident in various archetypes:

- The witch, whose knowledge and autonomy threaten patriarchal authority
- The vampire, whose sexuality is both seductive and destructive
- The possessed woman, whose body becomes a site of uncontrollable excess





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In each case, female power is reframed as danger. The narrative logic justifies containment, punishment, or destruction as necessary responses to this threat. However, what is crucial here is that the monstrous-feminine is not an inherent quality but a discursive production. Women become monstrous not because of what they are, but because of how they are represented. This aligns with Foucault's understanding of power as productive rather than merely repressive—it produces categories, identities, and truths that shape social reality (Foucault 1978). Furthermore, the monstrous-feminine intersects with the Madonna–Whore dichotomy. While the Madonna is desexualized and idealized, the monstrous woman is hypersexualized and feared. Both representations serve to regulate female bodies—either by suppressing desire or by pathologizing it.

In contemporary contexts, the monstrous-feminine continues to evolve. It appears not only in horror cinema but also in media portrayals of women who defy normative expectations—ambitious women are labeled “ruthless,” outspoken women “aggressive,” and emotionally expressive women “unstable.” These labels function as modern iterations of monstrosity, disciplining women through language. Thus, the monstrous-feminine operates as a cultural technology of fear, ensuring that female autonomy remains constrained within acceptable limits.

The Male Gaze: Visuality and the Freezing of Female Agency

Laura Mulvey's theory of the male gaze provides a crucial link between psychoanalytic frameworks and visual culture. In her seminal essay “Visual Pleasure and Narrative Cinema,” Mulvey argues that mainstream cinema is structured around a gendered dynamic of looking, wherein men occupy the position of active viewers and women are positioned as passive objects of visual pleasure (Mulvey 1975). This dynamic is not merely aesthetic but ideological. The camera itself becomes an extension of the male gaze, framing women in ways that emphasize their appearance rather than their agency. Close-ups, slow pans, and stylized shots fragment the female body, reducing it to a series of visual pleasures rather than a coherent subject.

Mulvey identifies two primary modes of visual pleasure:

- Scopophilia: the pleasure of looking at another person as an object
- Voyeurism: the pleasure derived from controlling or scrutinizing the object

Both modes reinforce the objectification of women, positioning them as spectacles to be consumed rather than agents who act. Importantly, the male gaze also intersects with narrative structure. Women in cinema are often denied narrative agency; their stories are subordinated to male protagonists. Even when women appear central, their roles are frequently defined in relation to male desire. This visual economy reinforces the Madonna–Whore dichotomy. The “good woman” is framed with softness, modesty, and restraint, while the “bad woman” is sexualized and exoticized. In both cases, the framing serves to control how women are perceived. Moreover, the male gaze contributes to what may be termed the freezing of female agency. By reducing women to visual objects, it arrests their narrative development. They exist to be seen, not to act. Contemporary feminist film theory has expanded Mulvey's framework by examining alternative modes of representation, including the possibility of a “female gaze” that re-centers women's subjectivity. However, the persistence of the male gaze in mainstream media indicates the enduring power of patriarchal visual structures.

Synthesis of Theoretical Frameworks

Taken together, these three frameworks—Freud's Madonna–Whore dichotomy, Creed's monstrous-feminine, and Mulvey's male gaze—form an integrated analytical lens through which the representation of women can be understood.

- Freud explains the psychic division that categorizes women
- Creed reveals the cultural construction of fear surrounding female power
- Mulvey exposes the visual mechanisms that sustain these representations

Collectively, they demonstrate that the regulation of women's identities operates across multiple levels—psychological, cultural, and visual. These frameworks are not isolated but mutually reinforcing, creating a complex





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system that shapes how women are imagined, represented, and controlled. This theoretical foundation enables the subsequent analysis of mythological narratives, literary texts, and contemporary media, illustrating how these patterns persist and evolve across contexts.

The Core Thesis: The Binary Trap

At the heart of this study lies the argument that the Madonna–Whore dichotomy and the construction of the monstrous-feminine do not operate as isolated symbolic patterns but as an integrated system—a **binary trap**—that regulates, disciplines, and ultimately erases women’s power. This binary does not merely categorize women; it actively produces and constrains the conditions under which femininity can be recognized, validated, or punished. The term “binary trap” is used here to describe a closed ideological structure in which women are confined to two mutually exclusive and equally limiting positions: the idealized figure of purity and sacrifice, or the demonized figure of excess and transgression. What makes this structure particularly insidious is that it masquerades as a spectrum of representation, while in reality offering only two poles—neither of which permits full subjectivity.

The Madonna figure operates through idealization as containment. She is constructed as morally superior, emotionally resilient, and selfless to the point of erasure. However, this elevation is conditional. Her worth is contingent upon her compliance with prescribed norms—obedience, chastity, nurturing behavior, and emotional restraint. As Simone de Beauvoir observes, woman is positioned as “the Other,” defined not by her own subjectivity but in relation to male expectations (Beauvoir 1949). The Madonna, therefore, is not a free subject but a stabilized ideal, one that exists to uphold social order.

This idealization has significant political consequences. By demanding perfection, it denies women the “messiness” necessary for leadership—anger, ambition, contradiction, and risk. A woman who conforms to the Madonna ideal may be respected, but she is rarely permitted authority. Her role is to sustain, not to disrupt. Conversely, the figure of the Whore or the monstrous woman operates through demonization as discipline. Here, female agency is reframed as excess. Sexual autonomy becomes promiscuity; intellectual assertion becomes arrogance; emotional expression becomes instability. This transformation aligns with Judith Butler’s concept of gender performativity, wherein deviations from normative gender roles are sanctioned through social punishment (Butler 1990). The monstrous-feminine intensifies this process by rendering female power not just undesirable but terrifying. As Creed suggests, the female body becomes a site of abjection—something that must be controlled or expelled to maintain order (Creed 1993). Thus, women who exceed their prescribed roles are not merely criticized; they are symbolically expelled from the category of the human. The binary trap functions through a double-bind logic. Women are compelled to navigate a narrow path between idealization and demonization, constantly calibrating their behaviour to avoid crossing into the “wrong” category. Yet, this balance is inherently unstable. The same qualities that are celebrated in one context can be condemned in another. For instance, assertiveness may be praised as confidence in men but labelled as aggression in women. This instability ensures that women remain perpetually vulnerable to recategorization. A “good” woman can become a “bad” woman through a single act of deviation. This fluidity is not liberating but disciplinary, as it reinforces the need for constant self-regulation.

From a Foucauldian perspective, this binary can be understood as a form of disciplinary power that operates through internalization rather than coercion (Foucault 1978). Women are not only subjected to external judgment but also internalize these norms, shaping their own behaviour in anticipation of social response. The binary thus becomes self-sustaining, embedded within both cultural narratives and individual subjectivities. Importantly, the binary trap is not confined to mythological or literary texts; it permeates contemporary social and political discourse. Women in public life are frequently subjected to this dual framework. They are either celebrated as symbols of virtue—often in ways that diminish their complexity—or vilified for perceived transgressions. The language used to describe them—“too ambitious,” “too emotional,” “too aggressive”—reveals the persistence of this binary logic.

Furthermore, the binary intersects with structures of caste, class, and race, producing differentiated effects. Intersectional feminist theory highlights how marginalized women are more readily subjected to demonization, while privileged women are more likely to be idealized—though still constrained (Crenshaw 1989). This





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intersectionality underscores the adaptability of the binary, allowing it to function across diverse contexts while maintaining its core regulatory function. Another crucial dimension of the binary trap is its role in **narrative erasure**. Women's stories are not simply told; they are edited. Complex figures are simplified, contradictions are removed, and acts of resistance are reframed as moral failings. Over time, these narrative adjustments accumulate, resulting in a historical record that preserves women's presence but erases their power. This process can be seen as a form of what Gayatri Chakravorty Spivak terms "epistemic violence," wherein dominant discourses silence subaltern voices by controlling the conditions of representation (Spivak 1988). Women are not absent from narratives; rather, they are present in ways that distort their agency.

Thus, the binary trap operates across multiple levels:

- **Psychological**, through internalized gender norms
- **Cultural**, through myths, literature, and media
- **Political**, through language, representation, and institutional structures

It is not a static system but a dynamic one, capable of adapting to new contexts while retaining its core function of regulating women's power. This paper argues that the persistence of this binary is central to understanding the transition "from divine to demon." Women are not naturally positioned within these categories; they are placed there through narrative processes that transform power into either sanctity or threat. To dismantle this binary, it is necessary to move beyond its logic entirely—not by replacing one category with another, but by rejecting the framework that necessitates such categorization. This requires a re-reading of narratives that restores complexity, acknowledges contradiction, and re-centers women as subjects rather than symbols. Because the most radical disruption of the binary trap is not the elevation of women to divinity or the reclamation of monstrosity—but the insistence that women are neither.

From Victim to Villain

One of the most enduring narrative strategies within patriarchal discourse is the transformation of women from victims into villains. This process is neither accidental nor isolated; it is a systematic restructuring of narrative memory that reassigns blame, distorts agency, and ultimately justifies the control of women's bodies, desires, and knowledge. At its core, this transformation operates through what may be termed **narrative inversion**—a process by which women who experience violence, injustice, or marginalization are reconfigured as the source of disorder.

In this inversion, victimhood is erased, and transgression is imposed. The woman is no longer wronged; she becomes the wrong. This section examines three foundational figures—Eve, Medusa, and Sita—to illustrate how this inversion functions across religious, mythological, and cultural contexts. Each case reveals a distinct mode through which women's agency is reinterpreted as threat, thereby legitimizing their regulation.

Eve: Knowledge as Transgression

The figure of Eve in the Judeo-Christian tradition represents one of the earliest and most influential examples of narrative inversion. In the Genesis account, Eve's act of eating the forbidden fruit is framed as disobedience, resulting in the fall of humanity. However, this act can also be understood as a pursuit of knowledge—a desire to transcend imposed limitations. Elaine Pagels argues that early interpretations of Genesis were not monolithic; rather, they were shaped by theological and political interests that emphasized obedience and hierarchy (Pagels 1988). Within this framework, Eve's curiosity becomes a liability. Her act is not read as intellectual engagement but as moral failure.

The narrative thus establishes a foundational association between **female curiosity and danger**. Knowledge, when sought by women, is reframed as transgression. This framing has far-reaching implications, contributing to historical restrictions on women's access to education, authorship, and intellectual authority. Furthermore, Eve's punishment—pain in childbirth and subordination to man—naturalizes gender hierarchy. The narrative moves from symbolic act to material consequence, embedding inequality within divine order. From a Foucauldian perspective, this can be seen as the production of a "truth" about women—one that links their agency to disorder and legitimizes their control (Foucault 1978). Eve is not merely a character; she becomes a template through which women are understood and governed.





Medusa: The Politics of Transformation

The myth of Medusa offers a more explicit illustration of how victimhood is erased through narrative restructuring. In earlier versions of the myth, Medusa is a mortal woman who is assaulted by Poseidon within Athena's temple. Rather than punishing the perpetrator, Athena transforms Medusa into a monstrous figure with serpentine hair and a gaze that turns men to stone (Ovid, *Metamorphoses*). This transformation is deeply symbolic. Medusa's body becomes a site of punishment, her monstrosity serving as both consequence and containment. The violence inflicted upon her is displaced onto her identity, recasting her as inherently dangerous. Barbara Creed's framework of the monstrous-feminine is particularly relevant here. Medusa embodies the fear of female power—her gaze, which petrifies, can be interpreted as a metaphor for the destabilizing potential of female agency (Creed 1993). She reflects, rather than creates, male vulnerability. Her eventual beheading by Perseus further reinforces this dynamic. The act is framed as heroic, yet it is also an act of silencing. The woman who sees, who resists, who embodies trauma, must be eliminated to restore order. Importantly, Medusa's head continues to function as a weapon even after her death, suggesting that female power can be appropriated and controlled even as the female subject is destroyed. This reflects a broader cultural pattern in which women's bodies and symbols are utilized while their agency is denied. Thus, Medusa's story illustrates a two-step process of narrative inversion:

1. Victimhood is erased through transformation into monstrosity
2. Monstrosity is neutralized through destruction and appropriation

Sita: The Violence of Idealization

While Eve and Medusa are demonized, Sita represents a different trajectory—one in which women are idealized to the point of erasure. In the *Ramayana*, Sita is constructed as the epitome of virtue, devotion, and purity. However, this idealization is contingent upon her willingness to endure suffering. The Agni Pariksha, or trial by fire, serves as a critical moment in this narrative. Despite being abducted against her will, Sita is required to prove her chastity. Her body becomes a site of scrutiny, her virtue subject to public validation. This demand reveals the paradox of deification. Sita is revered as a goddess, yet this reverence does not protect her from suspicion or suffering. Instead, it intensifies the expectations placed upon her. As Uma Chakravarti notes, such narratives function to reinforce patriarchal norms by presenting idealized femininity as both desirable and obligatory (Chakravarti 2003). The violence here is not physical but symbolic. Sita's identity is reduced to her purity, her worth measured by her ability to conform to an unattainable standard. Her eventual withdrawal into the earth can be read as both a rejection of these expectations and a final act of erasure—she exits the narrative rather than continue to perform within it. From the perspective of the binary trap, Sita occupies the extreme end of the Madonna archetype. However, this position is no less restrictive than that of the demonized woman. Both are denied complexity; both are confined to roles that serve patriarchal logic.

Synthesis: Narrative Inversion as Control

The figures of Eve, Medusa, and Sita illustrate three distinct but interconnected mechanisms of narrative inversion:

- **Eve** transforms curiosity into sin, establishing a link between female knowledge and danger
- **Medusa** transforms victimhood into monstrosity, erasing trauma and legitimizing violence
- **Sita** transforms suffering into virtue, idealizing endurance and normalizing subjugation

In each case, the narrative does not merely reflect reality but actively reshapes it. Women's experiences are reinterpreted to align with existing power structures, ensuring that agency is either punished or neutralized. This process can be understood as a form of **epistemic control**, wherein the meaning of women's actions is determined by dominant discourses rather than by the women themselves (Spivak 1988). The result is a historical and cultural archive that preserves women's presence while distorting their power. Moreover, these narratives are not confined to the past. They continue to inform contemporary representations, influencing how women's actions are interpreted in media, politics, and everyday life. The woman who speaks out is still labeled disruptive; the woman who endures is still idealized. Thus, the transformation from victim to villain—or from subject to symbol—is not an isolated





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narrative device but a persistent cultural strategy. It ensures that women's power is never recognized on its own terms but is always mediated through frameworks of suspicion, fear, or idealization. To challenge this strategy, it is necessary to re-read these narratives critically, restoring the contexts and complexities that have been erased. This involves recognizing Eve as a seeker of knowledge, Medusa as a victim of violence, and Sita as a figure navigating impossible expectations. Because only by undoing these narrative inversions can women's agency be reclaimed from the structures that have long sought to contain it.

The Monstrous-Feminine: From the Attic to the Screen

The figure of the monstrous-feminine does not emerge suddenly within modern cinema; rather, it evolves through a long continuum of literary and cultural representations that encode anxiety surrounding female autonomy. From mythological figures like Medusa to literary characters confined within domestic spaces, and finally to cinematic portrayals of women as sites of horror and excess, the monstrous-feminine reflects a persistent cultural effort to contain and regulate women who resist normative roles. This section traces that evolution—from the symbolic confinement of women in literary spaces such as the attic to their hyper-visible yet still controlled representations on screen—demonstrating how patriarchal narratives adapt rather than disappear.

The Attic as a Space of Containment

In nineteenth-century literature, the figure of the “madwoman in the attic” emerges as a powerful metaphor for the repression of female desire, anger, and subjectivity. Sandra Gilbert and Susan Gubar famously analyze this trope in *The Madwoman in the Attic*, arguing that such characters represent the silenced double of the “ideal woman” (Gilbert and Gubar 1979). Bertha Mason in *Jane Eyre* serves as a canonical example. Confined to the attic, hidden from public view, and described as violent and irrational, Bertha embodies everything that the protagonist, Jane, must not become. Yet, as feminist critics have noted, Bertha's “madness” can be read as a response to confinement and erasure rather than an inherent condition.

The attic, in this sense, is not merely a physical space but a symbolic one. It represents the **containment of female excess**—those aspects of womanhood that cannot be accommodated within the ideals of passivity and obedience. Women who do not conform are not simply excluded; they are pathologized and hidden. This dynamic aligns closely with the concept of the monstrous-feminine. The woman becomes monstrous not because of her actions but because of her refusal to remain within prescribed boundaries. Her confinement serves to restore narrative order, ensuring that the idealized feminine remains uncontested.

From Literary Monster to Cinematic Body

With the advent of cinema, the monstrous-feminine undergoes a significant transformation. While literature often conceals or metaphorizes female excess, cinema renders it visible. The female body becomes the primary site through which monstrosity is expressed. Barbara Creed argues that horror cinema, in particular, constructs the female body as a source of abjection and terror, drawing attention to processes such as menstruation, childbirth, and sexual desire (Creed 1993). These bodily functions, which challenge boundaries and evoke ambiguity, are reinterpreted as threatening. Films such as *Carrie* (1976) exemplify this dynamic. Carrie's telekinetic powers are linked to her menstruation, framing female puberty as a moment of uncontrollable danger. Similarly, in *The Exorcist* (1973), the possessed female body becomes a site of grotesque transformation, reinforcing the association between femininity and instability. In these narratives, the female body is not neutral; it is charged with symbolic meaning. It becomes a terrain upon which cultural anxieties about sexuality, reproduction, and autonomy are projected. However, this visibility does not equate to agency. The cinematic monstrous-feminine is often subjected to punishment, containment, or destruction. The narrative arc typically resolves with the restoration of order through the elimination or neutralization of the female threat.

Surveillance, Spectacle, and Control

The transition from the attic to the screen also marks a shift from invisibility to hypervisibility. While literary monsters are hidden, cinematic monsters are displayed. Yet, this visibility is not empowering; it is structured through





what Laura Mulvey identifies as the male gaze (Mulvey 1975). The monstrous woman is both feared and fetishized. Her body is scrutinized, fragmented, and controlled through the camera's gaze. This dual positioning—simultaneously object of fear and object of desire—reinforces the Madonna–Whore dichotomy. Michel Foucault's concept of surveillance provides a useful lens here. In modern societies, power operates not only through repression but through observation and normalization (Foucault 1977). The cinematic screen becomes a site of surveillance, where female bodies are constantly monitored and judged. The monstrous-feminine, therefore, is not simply a figure within the narrative but a mechanism through which audiences are taught to perceive and evaluate women. The spectacle of monstrosity serves as both warning and instruction.

Contemporary Revisions: Reclaiming the Monster

While traditional representations of the monstrous-feminine emphasize fear and control, contemporary narratives have begun to challenge and reinterpret this trope. Rather than depicting the monstrous woman as an object of horror, these narratives reframe her as a subject with agency and voice. This shift can be understood as part of a broader feminist project aimed at reclaiming suppressed identities and re-reading dominant narratives. By centering the perspectives of women previously labelled as monstrous, these works disrupt the logic of the binary trap. Contemporary feminist horror reconfigures monstrosity as a mode of resistance, where exaggerated bodies, violence, and excess are mobilized to expose and critique patriarchal norms rather than reinforce them (Gaeta 2025). For instance, recent films and series increasingly explore the interiority of female characters, allowing audiences to understand the conditions that produce their actions. The monster is no longer inexplicable; she becomes intelligible. However, this reclamation is not without tension. Even as narratives attempt to subvert traditional tropes, they often remain constrained by existing structures of representation. The challenge, therefore, lies not only in reinterpreting the monstrous-feminine but in fundamentally altering the frameworks that produce it.

From Containment to Circulation

Another significant shift in contemporary culture is the movement from containment to circulation. While earlier narratives sought to confine the monstrous woman—whether in attics or isolated spaces—modern media circulates her image widely. Digital platforms amplify representations of female transgression, often subjecting women to rapid cycles of visibility and backlash. The monstrous-feminine is no longer hidden; she is shared, commented upon, and judged in real time. This circulation intensifies the regulatory function of the trope. The visibility of “monstrous” women serves as a cautionary example, reinforcing norms through public scrutiny. At the same time, it creates opportunities for resistance, as women reclaim and redefine these labels.

Synthesis: Evolution Without Liberation

The movement from the attic to the screen illustrates not a linear progression toward liberation but an evolution in the methods of control. While the forms of representation have changed, the underlying logic remains consistent.

- In literature, the monstrous woman is **hidden and silenced**
- In cinema, she is **displayed and punished**
- In digital culture, she is **circulated and scrutinized**

In each case, the monstrous-feminine functions as a mechanism for regulating female autonomy. The shift from invisibility to visibility does not necessarily grant agency; it often introduces new forms of control. Thus, the monstrous-feminine must be understood as a dynamic construct—one that adapts to changing cultural contexts while continuing to serve its primary function: the containment of women's power. This section sets the stage for the subsequent analysis of *Circe* and *Barbie*, which represent contemporary attempts to disrupt and reconfigure this long-standing narrative tradition.

Case Study I: *Circe* – Reclaiming the Monstrous-Feminine

Madeline Miller's *Circe* (2018) offers a critical reimagining of a mythological figure historically positioned within the framework of the monstrous-feminine. In Homer's *Odyssey*, Circe appears as a marginal yet threatening figure—a sorceress who seduces men and transforms them into animals, thereby embodying both sexual danger and moral





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corruption. However, Miller's retelling disrupts this representation by shifting narrative authority to Circe herself, transforming her from an object of fear into a subject of articulation. This narrative shift is not merely stylistic but ideological. By granting Circe a voice, Miller challenges the epistemic structures that have historically defined female figures through external, often male-centered, perspectives. As Gayatri Spivak argues, the subaltern is not simply unheard but structurally prevented from speaking within dominant discourse (Spivak 1988). *Circe* intervenes in this silence, allowing the so-called "monster" to narrate her own story.

Voice, Subjectivity, and Narrative Reclamation

One of the most significant aspects of Miller's *Circe* is its use of first-person narration. Circe is no longer described; she describes. This shift destabilizes the traditional framework of the male gaze, as the reader is compelled to engage with her interiority rather than observe her as an object.

Early in the novel, Circe reflects on her marginality among the gods:

"I was not desirable. If I was not wanted, I would make myself feared" (Miller 2018, p. 47).

This statement encapsulates the transition from invisibility to monstrosity. Circe's transformation is not inherent but reactive—a response to exclusion and devaluation. Here, monstrosity emerges not as a natural condition but as a socially produced identity, aligning with Foucault's notion that identities are constructed through discursive practices (Foucault 1978). Her voice reclaims what patriarchal narratives had obscured: the emotional, intellectual, and experiential dimensions of her existence. She is not merely a sorceress; she is a thinker, an observer, and a creator of knowledge.

Witchcraft as Knowledge and Resistance

In classical mythology, Circe's witchcraft is framed as dangerous and deceptive. However, Miller reinterprets witchcraft as a form of knowledge production and resistance. Circe's engagement with pharmaka (herbal magic) represents a deliberate act of learning, experimentation, and self-definition.

She states:

"I learned to mix and measure, to weigh and judge. I learned to make things that could change the world" (Miller 2018, p. 89).

This passage reframes witchcraft from superstition to epistemology. Circe's power is not innate but cultivated, positioning her within a tradition of intellectual labor often denied to women. This aligns with feminist critiques of knowledge production, which highlight how women's contributions have historically been marginalized or reclassified as illegitimate (Rossiter 1993). Moreover, her witchcraft operates outside institutional structures, challenging the authority of the Olympian order. By creating knowledge independently, Circe disrupts hierarchical systems that privilege divine and male-centered forms of power.

Transformation as Revelation, Not Punishment

Perhaps the most iconic aspect of Circe's myth is her ability to transform men into animals. In traditional narratives, this act is interpreted as evidence of her cruelty and danger. However, Miller reconfigures this transformation as an act of revelation rather than corruption.

Circe explains:

"I merely show them what they are" (Miller 2018, p. 123).

This line is crucial. Transformation is not an imposition but an exposure. The men who are turned into pigs are not altered in essence; their inner nature is made visible. This inversion challenges the patriarchal assumption that female power corrupts male virtue. Instead, it suggests that male behavior is already marked by excess, which is merely unveiled by Circe's magic. From the perspective of the monstrous-feminine, this reconfiguration is significant. Circe's power does not produce monstrosity; it reveals it. The fear she generates is not of transformation itself but of recognition—of seeing what has been concealed.

Exile and the Politics of Isolation

Circe's exile to the island of Aiaia is initially framed as punishment, reinforcing the trope of isolating powerful women. However, Miller transforms exile into a space of autonomy and self-creation. Circe reflects:





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“I lived alone for many years. I was not afraid. I was free” (Miller 2018, p. 102).

This statement marks a critical departure from traditional narratives, where isolation is synonymous with suffering or madness. Instead, exile becomes a condition for self-definition, allowing Circe to exist outside the constraints of divine hierarchy and patriarchal surveillance. This reimagining aligns with feminist spatial theory, which examines how spaces can function as sites of both oppression and resistance. The island, while initially a site of confinement, becomes a space where Circe can develop her identity on her own terms.

Sexuality, Consent, and Power

Miller’s *Circe* also engages directly with themes of sexuality and consent, challenging traditional representations of female desire as dangerous or manipulative. Circe’s relationships with figures such as Hermes and Odysseus are characterized by negotiation and mutual recognition rather than domination. However, the novel also confronts sexual violence explicitly. Circe’s encounter with sailors who attempt to assault her marks a turning point in her narrative. In response, she transforms them into pigs—a moment that redefines her use of power. She states: “I would not be prey again” (Miller 2018, p. 134). This declaration reframes her actions as defensive rather than predatory. The transformation becomes an assertion of bodily autonomy, challenging narratives that depict female power as inherently unjustified. From the perspective of the monstrous-feminine, this moment is crucial. Circe embraces the label of monster not as a mark of shame but as a strategy of survival. She becomes what patriarchal narratives fear, but on her own terms.

Motherhood and the Reconfiguration of Power

Circe’s role as a mother further complicates her identity, disrupting the binary between nurturing femininity and monstrous autonomy. Her relationship with her son, Telegonus, is marked by care, protection, and instruction. However, this motherhood is not idealized. It is fraught with difficulty, reflecting the complexities of balancing autonomy with responsibility. Circe does not abandon her identity as a witch; rather, she integrates it into her role as a mother. This integration challenges the Madonna–Whore dichotomy by demonstrating that nurturing and power are not mutually exclusive. Circe is neither purely maternal nor purely monstrous; she exists beyond these categories.

Choosing Mortality: The Ultimate Act of Agency

The novel concludes with Circe’s decision to relinquish her immortality and become human. This choice is significant, as it represents a rejection of divine hierarchy and an embrace of self-determined existence. Circe reflects: “I would not be a divinity who had nothing to say” (Miller 2018, p. 376).

Here, immortality is associated with stagnation and silence, while mortality offers the possibility of change, growth, and meaning. Circe’s choice can be read as an assertion of agency, prioritizing lived experience over symbolic power. This ending disrupts the traditional trajectory of mythological narratives, where transformation often results in punishment or loss. Instead, Circe’s transformation is self-directed, marking a shift from imposed identity to chosen existence.

Synthesis: Reclaiming the Monster

Miller’s *Circe* fundamentally reconfigures the monstrous-feminine by shifting the narrative perspective and redefining the terms of power. The novel demonstrates that monstrosity is not an inherent quality but a label imposed upon women who resist containment. Through voice, knowledge, transformation, and choice, Circe reclaims her identity from the structures that sought to define her. She is no longer a cautionary figure but a complex subject whose story challenges the binary trap of Madonna and monster. In doing so, *Circe* exemplifies the potential of narrative re-reading as a form of resistance. It does not reject myth but reinterprets it, revealing the suppressed possibilities within familiar stories.

Case Study II: *Barbie* (2023) – Deconstructing the Ideal Woman and Rewriting the Binary

Greta Gerwig’s *Barbie* (2023) operates as a complex meta-text that interrogates the construction of femininity within late capitalist and postfeminist frameworks. While the film initially presents itself as a celebration of idealized womanhood, it gradually dismantles the very structures that sustain such ideals, exposing the instability of the





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Madonna–Whore dichotomy and the mechanisms through which female identity is regulated. Unlike traditional narratives that impose meaning upon female characters, *Barbie* foregrounds the **constructed nature of identity itself**. The protagonist, Barbie, is not born but manufactured—literally produced as an object of consumption. This premise directly echoes Judith Butler’s assertion that gender is not innate but performed through repeated cultural acts (Butler 1990). Barbie, therefore, embodies gender as performance in its most explicit form.

Barbie Land: The Illusion of Feminine Perfection

Barbie Land is introduced as a utopian space where women occupy all positions of power—presidents, doctors, lawyers—while men exist in marginal, decorative roles. At first glance, this appears to be a feminist reversal of patriarchal structures. However, this reversal is not a dismantling but a mirroring. Barbie herself articulates this illusion of perfection when she states:

“Every night is girls’ night. Every day is the best day ever” (*Barbie*, 2023).

This repetition signals not authenticity but **scripted existence**. Barbie’s world operates through routine and performance, suggesting that perfection is not lived but enacted. The absence of conflict or contradiction reveals the artificiality of this system. Scholars such as Rosalind Gill argue that postfeminist media often presents empowerment as an individual, aestheticized experience rather than a structural reality (Gill 2007). Barbie Land exemplifies this logic. Women appear empowered, but their power is superficial, confined within a controlled environment that lacks genuine autonomy. Thus, Barbie Land represents the **ultimate Madonna space**—a world of idealized femininity that is visually appealing but fundamentally hollow.

The Crisis of Stereotypical Barbie: Cracks in the Ideal

The narrative begins to destabilize when Barbie experiences an existential crisis. Her sudden thoughts of death disrupt the seamless perfection of Barbie Land, introducing the possibility of imperfection and vulnerability. She confesses:

“Do you guys ever think about dying?” (*Barbie*, 2023).

This moment is pivotal. It marks the intrusion of reality into a constructed fantasy. Barbie’s body, previously flawless, begins to change—her feet flatten, cellulite appears. These changes symbolize the breakdown of the idealized feminine form. From a psychoanalytic perspective, this disruption can be understood as a confrontation with the Real—what lies beyond symbolic structures (Lacan 1977). Barbie’s crisis exposes the limits of the Madonna archetype, revealing that perfection cannot sustain subjectivity. Her transformation also aligns with the monstrous-feminine. As her body deviates from the ideal, she becomes “imperfect,” edging toward what the system perceives as undesirable or abnormal. The fear is not of monstrosity itself but of deviation from perfection.

The Real World: Encountering Patriarchy

Barbie’s journey into the real world marks a critical shift from illusion to confrontation. Here, she encounters a society structured by patriarchal norms, where women are objectified, dismissed, and subjected to surveillance. She observes:

“I feel... conscious. Like everyone is looking at me” (*Barbie*, 2023).

This statement reflects the internalization of the male gaze. Barbie, once the object of admiration in Barbie Land, becomes the object of scrutiny in the real world. Her visibility transforms from celebration to vulnerability. Laura Mulvey’s concept of the male gaze is directly applicable here. Barbie’s body is no longer simply seen; it is evaluated, sexualized, and controlled (Mulvey 1975). The shift reveals that visibility, rather than empowerment, can function as a mechanism of regulation.

At the same time, Barbie encounters Gloria, whose monologue articulates the contradictions of contemporary femininity:

“You have to be thin, but not too thin... you have to lead, but you can’t squash other people’s ideas” (*Barbie*, 2023).

This speech encapsulates the **double-bind logic** of the binary trap. Women are expected to embody conflicting qualities simultaneously, ensuring that they can never fully succeed. As Gill notes, postfeminist discourse often frames empowerment as a matter of personal responsibility while ignoring structural constraints (Gill 2007).





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Ken, Patriarchy, and the Fear of Female Autonomy

While Barbie confronts patriarchy, Ken embraces it. His discovery of male dominance in the real world leads him to import patriarchal structures into Barbie Land, transforming it into “Kendom.” Ken’s assertion – “I’m just Ken... and that’s enough” (*Barbie*, 2023) – reflects a newfound sense of identity rooted in dominance rather than self-definition.

This subplot highlights the fragility of patriarchal systems. Ken’s version of patriarchy is exaggerated, almost parodic, suggesting that such systems are performative rather than natural. However, it also reveals the ease with which patriarchal logic can be internalized and reproduced. Barbie Land, once a site of female dominance, is quickly restructured into a system where women are subordinated. From a theoretical perspective, this aligns with Althusser’s concept of ideology as something that is not imposed externally but internalized and reproduced by individuals (Althusser 1971).

Becoming Human: Rejecting the Binary

The film’s conclusion marks a significant departure from traditional narratives. Barbie chooses to leave behind her idealized existence and become human. This decision is not framed as loss but as liberation. She states:

“I want to be part of the people that make meaning, not the thing that’s made” (*Barbie*, 2023).

This line directly challenges the objectification that has defined her existence. Barbie rejects both the Madonna (perfect doll) and the monstrous (imperfect deviation) categories, opting instead for subjectivity. This transition resonates with Simone de Beauvoir’s assertion that woman is not born but becomes (Beauvoir 1949). Barbie’s journey is not about achieving perfection but about embracing becoming – uncertain, flawed, and self-directed.

Critical Reception and Feminist Interpretations

Critical responses to *Barbie* have highlighted its complex engagement with feminist discourse. Angela McRobbie argues that postfeminist media often incorporates feminist ideas only to neutralize them (McRobbie 2009). However, *Barbie* resists this neutralization by exposing the contradictions within postfeminist narratives. Similarly, Sophie Gilbert (2023) notes that the film “uses the iconography of perfection to critique the very structures that produce it,” suggesting that its strength lies in its self-reflexivity. At the same time, some critics have pointed out limitations. Banet-Weiser (2018) argues that commodified feminism risks being absorbed into capitalist frameworks, raising questions about whether *Barbie* can fully escape the system it critiques. These tensions do not weaken the film’s argument but rather highlight its complexity. *Barbie* operates within the structures it critiques, making its intervention both powerful and paradoxical.

Synthesis: Breaking the Dollhouse

Recent studies in feminist media scholarship highlight how the monstrous-feminine continues to be mobilized within digital subcultures, particularly in misogynistic online spaces that frame female autonomy as threatening (Feminist Media Studies 2022). *Barbie* dismantles the binary trap not by reversing it but by exposing its artificiality. The film demonstrates that both idealization and demonization are constructed categories that limit women’s identities. Through Barbie’s journey, the film articulates a crucial insight: the problem is not choosing between being perfect or being flawed – it is the existence of a system that demands such a choice. In rejecting her status as both object and ideal, Barbie reclaims subjectivity. She becomes neither Madonna nor monster but something far more disruptive:

A woman who is unfinished, evolving, and self-defined.

Philosophical Context: Becoming, Not Being

At the foundation of this study lies a philosophical question: what does it mean to be a woman within a system that defines womanhood before women can define themselves? The preceding sections have demonstrated that femininity is not an inherent condition but a structured and regulated identity. To fully understand this, it is necessary to situate the argument within broader philosophical discourse. Simone de Beauvoir’s seminal assertion –

“One is not born, but rather becomes, a woman” (Beauvoir 1949, p. 267) – provides the conceptual anchor for this analysis. Beauvoir challenges biological determinism, arguing that womanhood is constructed through social,



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cultural, and historical processes. This “becoming” is not neutral; it is shaped by systems that assign meaning, value, and limitation to gendered existence. Judith Butler extends this argument by conceptualizing gender as performative—a series of repeated acts that produce the illusion of a stable identity (Butler 1990). These acts are not freely chosen but regulated by norms that determine what is intelligible as “feminine.” Within this framework, the Madonna–Whore dichotomy and the monstrous-feminine can be understood as scripts of performance, dictating how women are expected to embody or resist femininity. Importantly, these philosophical perspectives reveal that identity is not merely imposed from outside but internalized and enacted. Women navigate these scripts, often negotiating between compliance and resistance. The binary trap operates precisely at this level—it structures the conditions under which identity can be performed, ensuring that deviation is met with sanction.

Michel Foucault’s notion of power as diffuse and productive further complicates this understanding. Power does not simply prohibit; it produces categories, discourses, and subjectivities (Foucault 1978). The identities of “goddess,” “mother,” “witch,” and “monster” are not natural classifications but outcomes of discursive processes that define what women are allowed to be. From this perspective, the transformation from divine to demon is not a shift in essence but a shift in discursive positioning. The same woman can be revered or condemned depending on how her actions are interpreted within prevailing frameworks of meaning. Additionally, Gayatri Spivak’s concept of epistemic violence highlights how dominant narratives silence or distort subaltern voices (Spivak 1988). Women’s experiences are often mediated through structures that prevent them from being fully understood on their own terms. This is particularly evident in the reinterpretation of mythological and literary figures, where women’s agency is overwritten by patriarchal readings.

Thus, the philosophical context of this study underscores a crucial insight: the problem is not simply representation, but the conditions under which representation becomes possible. To challenge these conditions, it is necessary to move beyond binary frameworks and toward a conception of identity that accommodates multiplicity, contradiction, and change.

CONCLUSION AND FUTURE DIRECTIONS: RECLAIMING THE NARRATIVE

This paper has argued that the movement from divine to demon is not a natural evolution but a deliberate narrative strategy embedded within patriarchal systems of knowledge and representation. Across mythological texts, literary traditions, cinematic narratives, and contemporary media, women’s power is consistently reshaped through processes of idealization and demonization. The Madonna–Whore dichotomy and the monstrous-feminine function as complementary mechanisms within this system. One elevates women beyond humanity, stripping them of agency through perfection; the other reduces them to objects of fear, delegitimizing their autonomy. Together, they form a binary trap that constrains women’s identities and limits the possibilities of their representation. The analysis of figures such as Eve, Medusa, and Sita demonstrated how narrative inversion transforms victims into villains or saints, erasing the complexity of their experiences. The case studies of *Circe* and *Barbie* illustrated contemporary efforts to reclaim and reconfigure these narratives, offering alternative frameworks that center female subjectivity.

The paradox identified throughout this study remains central: women are symbolically celebrated but materially constrained. Goddesses are worshipped, yet women’s access to power remains limited. Visibility is increased, yet authority is restricted. Representation expands, yet recognition remains uneven. To address this paradox, the paper proposes a shift from reinterpretation to reclamation. Reclaiming women’s power does not require rejecting tradition but re-engaging with it critically. This involves revisiting canonical texts and narratives to uncover suppressed meanings and alternative interpretations. For instance, reading Medusa as a victim of violence rather than a monster, or Sita as a figure negotiating systemic constraints rather than embodying passive virtue, allows for a reconfiguration of narrative authority. Such re-readings challenge the stability of dominant interpretations, revealing that tradition is not fixed but open to contestation. Central to this process is the restoration of voice. As demonstrated in *Circe*, narrative perspective plays a crucial role in shaping meaning. Allowing women to speak within their own narratives





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disrupts the structures that have historically defined them. This requires not only producing new narratives but also amplifying marginalized voices within existing frameworks. It involves recognizing women as subjects of knowledge rather than objects of representation. The journey from divine to demon is not a fall—it is a rewriting. Women were never only goddesses or monsters. They were thinkers, creators, rebels, and survivors. What has changed is not their nature, but the stories told about them—and the systems those stories sustain. To reclaim women's power is not to return to some imagined past but to reimagine the present. It is to question the narratives that define possibility and to create new ones that expand it. Because the most disruptive figure in any system is not the goddess who is worshipped or the monster who is feared—but the woman who refuses to be reduced to either.

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RESEARCH ARTICLE

A Literary Perspective: Exile and Cognitive Dissonance in Divakaruni's Sister of My Heart

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ABSTRACT

Dispora has the dialectics of both belonging and longing. The yearning to return and the desire to accommodate keep on influencing the people who journey to new countries. The dynamics of migration are intricate and multifaceted which encompass a wide array of emotions, sensations, passions and even sometimes resentments in diaspora. Hence, survival for women folk in exiled settings happen to be overwhelmingly agonising as they struggle in contradiction of exile, the tensions of kin and work, and the limitations necessitated equally by old and new male-controlled structures. While they endeavour to uphold their familial ethnicity, on the other hand they challenge to accept substantial values, professional flexibility, and develop cultural customs within transnational intervals. The works of Chitra Banerjee Divakaruni distinctly echo these complicated dimensions of displacement in her narrative. This paper seeks to examine the intricate nature of individual exodus through selected writings of the author. The purported study focuses on investigating the psyche of feminine migrants who repeatedly grapple with the quandaries of exile and displacement. It seeks to investigate the persistent themes such as exile, isolation, cognitive dissonance, remoteness, and indigenous dislocation undergone by women in diasporic perspectives.

Keywords: Cognitive dissonance, dislocation, exile, isolation, psychological rebellion, displacement, emotional, chauvinism

INTRODUCTION

Dislocation brings about an impact on migrants, shaping their uniqueness and sense of belonging. Exile and relocation ensuing from relocation are substantial ongoing truths that have severely deployed the artistic landscape of modern narratives. Chitra Divakaruni, a multi-ethnic, postcolonial diasporic Indian writer residing in the US, is a



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prominent conspicuous existing author in Indian literature. Across her works, she expresses the deep-engrained torment, anxiety, and emotional turbulence suffered by displaced womankind. Her stories depict the multifaceted confrontations confronted by women equally in India and in the U S, emphasizing intricacies of migrant existence. As the environments of migrants resume to progress, so too do the approaches embraced by these women to overwhelm the ordeal of dislocation and cultural estrangement.

When individuals enthusiastically drift to settle in an alternative part of the earth, they choose to journey with a resolution that fosters visions in their thoughts -daydreams of an upgraded life and a dwelling that would entrancingly transform their state of fortitude and accord them a restored identity. In one's interface with migrant literature one acquaintances dislocation not just spatially but also from environmental standards, where the prototypical facades of human relocation comprise- the migrant visions, the craving to escape, enforced migration, exile, surviving with the remoteness, pull of reminiscence and wistfulness prevailing between times and spaces.

When individuals voluntarily move to settle in a faraway dreamy land they do with willpower in their visions nurturing dreams and thoughts to reinstate a new identity. The contrasted aspects like the longing to escape, struggle to sustain distance, constrained displacements prevailing between times and spaces, pull of reminiscence and wistfulness are exhibit in the migrants. Meenakshi Thapans' analysis on womenfolk is, "She lives in both the traditional and modern worlds." (361)

Even if existence is progressing on with the advancement of expertise, immemorial established everyday jobs of womankind are nonetheless during in the humankind. Modern women are committed to break free from conventional restraints and are enthusiastically encountered in reliving their responsibilities, individualities, and associations within a humanity. Even after migration the anxiety between faithfulness towards custom and the aspiration for autonomy forms a focal characteristic of their progressive diasporic life unfamiliar ethnic circumstances. According to Chitra Banerjee Divakaruni women who are wedged amongst their ancient past and a advanced present endure to suffer this cultural skirmish. As a hypothetical framework, diaspora highlights that encounters are persistently intervened and that intimate and integrated tales are re-explained over period. Avtar Brah's theoretical interpretation of exodus is that,

It is within this confluence of narrativity that 'diasporic community' is differently imagined... And we have to think about questions of home and belonging. (45)

For Brah, diaspora is an altered way of investigating the stipulation of relocations that echoes a expedition towards resolution. In the existing era of digital communication, movement, crusade, and relocation have boosted the distinguishing attributes of recent culture, individuals are relocating, ever-changing for revolution a r scenarios touching the humanity to a notable boundary. Owing to several motives and immense prospects in the initial periods' relocation was typically imposed and was predominantly for the excluding benefited and deprived classes. In Arnold's words, "Migration becomes the most obvious path to a better life and greater prosperity" (196). Nonetheless, in the concluding epoch relocation was mostly owing to humankind's predisposition concerning career benefits.

Divakaruni, a preeminent novelist of the Indian Diaspora has portrayed 'migratory sensibility' as the imperative theme in her novels. Her novels are the narratives of immigrant women experiences. She has constantly voiced concerns concerning womenfolk's experiences of expulsion in their native land as well as their host land. Being estranged from their indigenous ethos, women frequently occupy a marginal perception, hooked between ethos, and undergo instincts of estrangement and remoteness. Divakaruni's novels correspond to this theory. In *The Location of Culture*, according to Bhabha space and time overlap to create intricate illustrations of alteration and identity, past and present.



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Women folks are accorded with a stupendous position in nearly all rites when competing them with deities. Newspaper reportage and statistics speak volumes about the sagacity of revulsion faced by women who are independent, valiant, and resolute to be on their own. Thus, on one side, women are alleged in great esteem but in everyday reality, within the family, and the social milieu their situation is uncanny, unbelievable, and shocking. When an issue of their empowerment arises, no efforts are intensely taken.

Empowerment facilitates womankind to break the ethnic, economical, communal and spiritual constraints. Women assert themselves through empowerment, by confronting and surpassing these limitations. Women folk emphasize themselves by overcoming these constraints. Divakaruni has envisioned feminine characters who are in the lead of performances centred on vision and conviction. Divakaruni's personalities frequently traverse between inspiration and existence, eventually carving out spaces of sovereignty, and self-fulfilment in a confounded humanity. She exhibits female protagonists who arise as powerful entities in this intricate globe.

Scattering out, inclination towards a homeland and periphery maintenance are the three underlying divisions that are extensively implied to be the fundamentals of Diaspora. The complete echelon of change is reflected in the cycle of moving and shifting by relocating oneself in the large sphere of tradition and custom. The ethos, attitude, perspicacity, discrimination and erudition all seem to merge in the psyche of the immigrants thereby creating a consciousness which was never before of one's own identity, individuality and distinctiveness. Individuals by relocating and trans-positioning, in general, undergo transformation and proceed towards integration, inclusion and reconciliation. The change in the milieu and recent social settings with a different cultural situation pose a challenge to the migrants.

The pursuit for financial betterment, better life and better position are the causes for migration. There are two factors which make people relocate from one place to another. As an alternative of the adverse 'push' aspect it is the 'pull' aspect that is primarily the impetus for movement in Divakaruni's narratives. Divakaruni's central character also fits in the definition provided by Safran as they "maintain a memory, vision or myth about their original homeland (... the group's consciousness and solidarity are importantly defined by this continuing relationship with the homeland" (83-84). Though the protagonists are displaced they also get relocated in the new contexts which offer them new challenges. On the optimistic side, the independence offered to them by the new land provides new opportunities though there is also a sensation of rift. Migration from the homeland merges with the arrival in the host land but it also creates emptiness. The 'Past' develops into a passionate stimulating substance and intends to redevelop and transmute the existing state. Push and pull relating 'convention and innovation besides' beliefs and desires' also can be perceived.

In diaspora womenfolk time and again endure encounters like alienation, and assimilation the demand for reunion. As womenfolk scuffle when they combat in contradiction of exile. Consequently, survival for them is unbearable. They confront versus exile, problems within and outside the family, constraints of tradition and ethnicity which are all forms of patriarchies.

The protagonists of Divakaruni contrive themselves to countenance the rigid realities of human life in the unfamiliar terrain. Divakaruni's narratives resonate these traits of migration in her tales. Her novels *Sister of My Heart*, *Vine of Desire*, *The Mistress of Spices* and *Oleander Girl* elicit misery of every female's scuffle whilst demanding to acclimatize in the exotic beliefs. Womanhood's perception of seclusion and the necessity for self-acknowledgement appeal to their brawl for distinctiveness amidst customs of patriarchy. Margaret Abraham perceives that "ethnicity, gender, class, race, and citizenship are all important aspects in the construction of self and community for South Asian immigrants in the United States" (451).

Divakaruni's writings avow that diaspora is not solely scattering or dispersal of migrants but a motif of consciousness that encompasses various conflicting characteristics of them. Women kind who find themselves in displacement realize that they are simultaneously elements of various values. Divakaruni presents the womankind



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who are frayed concerning the beliefs of the 'Modern' and 'Old Humanity' grappling to sculpt an identity of their own. She addresses the affairs such as interracial relationships, patriarchal issues, racism, economic disparity, arranged marriages, pregnancy, miscarriage, and divorce. In a meeting with Neila C. Seshadri, she states that she initiated to author regarding what was of more significance in her life and that was the approach in which relocation had brought about a alteration in her life and it certainly questions her life. The intention for expulsion varies for every single narrative. The form of an expatriate is categorised by Naficy as "a process of perpetual becoming, involving separation from home, a period of liminality and in-betweenness that can be temporary or permanent, and incorporation into the dominant host society that can be partial or complete" (455). These days, countless womenfolk are wandering as distinctive emigrants in the far away land. According to Edward Said exile accentuates more on dislocation rather than the control of migration, that counterparts equally to its convincing space and its competence associated with the humanity. Critic Said asserts:

Exiles, unlike travellers, bear the mark of history in their personal narratives of loss and thus desire the stability of belonging, ... is the beginning of exile. (34)

A few events, similar to the terrorist strike on the World Trade Centre, and Godhra riots attribute in her novels. She has analysed the repercussions of such incidents in the personal lives of the people through her novels. Her personal immigrant experience in Ohio has helped her articulate the feelings of loneliness and cultural separation that suffuse in all the novels. All her protagonists are wedged in, amidst the traditions and beliefs of their heritage as well as that of their new homeland. She has mirrored the factual India through her characters. The characters of Banerjee's narratives habitually experience quandary owing to the network of chauvinism. The individuals' scuffle, serve, resist in contrast to or are correlated with antagonism, desolation, bitterness, acknowledgement, consideration and response.

The protagonists repeatedly move backwards and onwards involving the commotion at home besides household arrangement of a conventional chauvinism framework with its formidable gender uniqueness. The social surroundings examine the living of womankind through the approach which they have under no circumstances visualized of. Chitra Divakaruni as an archetypal of the widespread complications of discernment, fracas besides chaos in the humanity has shaped an innovative crusade bursting with ensigns and facets of India. *Sister of My Heart* commemorates Indian women's migration to the U.S. as an expedition from the subjugated and despondent state to sovereignty and discovery of the self. This novel is set in India.

Sister of My Heart is an extended narrative of Divakaruni's tale 'The Ultrasound'. We unearth an eye-opening introduction to Indian culture in this novel. This novel is a venture by Divakaruni to behold India and its humanity. Chitra Banerjee has dealt with Indian women's personal identity as well as their migrant notion through this novel. She is reminded of her days in India and by recalling her commemorations beyond the characters she has accomplished to reinvent Indian convention in this work of fiction. Anand Mulloo's texts endeavour to restore Divakaruni's proclamation. He has stated that exploring back with reminiscence with regard to the motherland, immigrants endeavour to rebuild imaginary native lands or spaces like 'Little India' which is eventually influenced by aspiration and leisure pursuit.

The narrative commences with the birth of the sisters of heart—Sudha and Anju—and concludes with them reuniting in America once separated for some years. The tale is told by Sudha and Anju in alternating episodes, tracing their commencement of persistence in India and concluding with another beginning—that of their diasporic survival. Viewed in the perspective of Divakaruni's oeuvre, *Sister of My Heart* captures the perspective of the opening piece. The sequel to it is *The Vine of Desire*. The novel highlights the motherland realities which pave the way to the deportation of her womanly characters, Anju and Sudha, to a new terrestrial space. Sheila Rowbotham's interpretation is valuable in this milieu: "But always we are split in two, ...we were always in transit, immigrants into an alien country" (31).





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Manipulated by strict patriarchal standards, Aunt Pishi, the sister of Bijoy, symbolizes the oppressed feminine of a former era. As a victim of rigid patriarchy, she is denied an alternative to create a living of her own. As the three mothers are competent in providing physical, emotional, and cultural vitality to their family, they are portrayed as the cultural backbone of the family. Divakaruni, through this novel, has examined its objectivity of goodness as well as the adverse attributes of the humanity through which she was raised. Both are inseparable, and Anju's attraction towards Sunil, who strides into their store, reveals her disposition towards radicalism. Both Sudha and Anju are wedded on the same day. "Like no-one else in the entire world will" (SH 24). They counterpart each other, reconnoitring perceptions and enduring as supreme examples of the contemporary Indian woman.

Dislocation, in *Sister of My Heart*, is intensely faced within the native land itself. Exile can strike within oneself, at home, or within one's own nation. Sudha is dominated by her oppressive mother-in-law, and Anju too remains emotionally tied to her past; neither of their married lives ends in bliss. Anju remains tied to the past emotionally, often lingering over her optimistic youth. She endlessly thinks about her earlier times and reflects on her closeness with Sudha. Vijay Mishra observes in this context that relocation within the native land is "the traumatic moment ...which produces a feeling of melancholia" (8).

In several Asian homes, personal room is often limited, and this becomes the breaking point for many women. Mankind and womankind voyage deliberately or insistently in pursuit of opportunities and, in turn, end up in hybrid, liminal, and trivial spaces to establish a new identity. Sudha steps out of her husband's overpowering household after taking Anju's suggestion and, in addition, establishes a space for her daughter Datiya and herself within this rigid civilization.

As Anju acts as a mediator, Divakaruni's central character gathers valour and ultimately drifts to America, a territory that would extend to her an occasion to be sovereign. Sudha arises as a lady of influence and willpower whilst the bond between her and her offspring is confronted. She moves forward from being a subordinated woman to becoming a progressive mother who opposes restrictions on her rights. She asserts her autonomy, undergoes a profound transformation, and thinks progressively about America, remarking, "America has its own problems, ...for America was full of mothers like me" (SH 294).

Anju's past life nags her regarding her mother's health, Pishi's life, and Aunt Nalini's experiences. Homesickness and memories of her mother and motherland make her restless at all times. Memory is no longer extensively deemed "as a stable space of identity but as a process of displacement itself" (Baronian et al. 12). Migrants find themselves struggling to assimilate into a new home among unfamiliar people. Typical Indian women often face this dilemma after their dislocation from home. According to critic Avtar Brah, "Home" is a mythic place of desire in the diasporic imagination (192).

Divakaruni has epitomized this idea of "home," which reflects both the locale and its inherent traditions and culture. Diaspora has become a new framework for culture and identity that claims recognition for people who suffer from oppression or discrimination. Nostalgia deteriorates Anju's condition. She expresses her pangs of longing to meet her sister: "I need you, I need you so much" (SH 310). She suffers a miscarriage. Sudha narrates a traditional fairy tale to Anju about a princess incarcerated in a fortress of snakes, waiting to be rescued—a narrative that provides her with relief and emotional solace.

In the novel, one can see that the women characters' past experiences function as a mechanism of self-recovery. It helps them retrieve their strength in their struggle against subjugation. Anh Hua, in relation to memory and remembrance, mentions:

"The struggle for memory can help to create spaces where one is able to redeem and reclaim the past... Remembrance is not simply to document but to construct the new" (147).





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The dynamics of remembrance and reminiscence resulting from loss are distinctive qualities of diaspora. Bell Hooks has stated that the recovery of memory proposes “both a sagacity of re-union and a perseverance of relief” (158). A person’s life becomes a written text that is reliant on other texts. The inscriptions of home and environment gradually evolve in ways that are not products of choice but are left to circumstances. Both sisters imagine that migration will bring autonomy for Sudha, enabling her to carve out a new life, earn her own living, and provide the necessary support for her daughter, Dayita. People move between spaces across time and geography. Sudha’s chief objective is to find a safe place where she can rebuild her life. Though physically distanced, changes in everyday realities are transformed into reassuring certainties for the cousins.

Sudha thus transforms herself into a rebellious woman by violating the constraints of a marriage considered sacred by society. She successfully frees herself from the overwhelming pressures of convention and takes the significant step of moving to the United States with her daughter, Dayita. She intends to offer emotional support to Anju, who is depressed following her miscarriage.

Migration can be viewed as an influence that encourages immigrant women to broaden their options and opportunities. In contrast to Anju, Sudha’s relocation is not primarily motivated by an attraction to America but by a desire to alleviate her suffering and seek liberation from her existing circumstances. Sudha’s migration is not merely the result of fascination with America; rather, it is an attempt to heal herself and escape the pain she endures in her homeland. At the beginning of her transition, Sudha remarks, “A future built by women out of their own wits, their own hands” (SH 317).

Stuart Hall voices the notion of identity as follows: “Identities are never unified and, in late modern times, increasingly fragmented and fractured ... discourse, practices and positions” (4).

Interim concepts like *hybridity*, *alterity*, and *transculturalization* are vital in understanding uniqueness in diasporic perspectives. They accentuate the merging of ethnicities and the familiarity of being located as the “other” within predominant social configurations. There are various push and pull factors which elucidate the reasons for migration. Push factors are considered negative influences that induce migrants to leave an area, whereas pull factors are constructive elements, such as economic opportunities, that attract migrants.

Diaspora has consequently surfaced as a mode of cognizance in the narrative of Chitra Banerjee Divakaruni, where the centre of attention is on the immeasurable encounters, circumstances, beliefs, and perceptions of distinctiveness. In literature, an alter ego is repeatedly a tributary identity of a character that discloses inner conflict or opposition. Cicero coined the term as part of his philosophical construct in first-century Rome, describing it as “a second self, a trusted friend.” The term *alter ego* is correspondingly cast off to entitle the best friend of another character in a narrative.

Sudha is incapable of despising Anju, as she observes her as her “other half,” with whom her bond is eternal. Sudha emerges as a woman of empowerment and fortitude. When women encounter disputes in exilic settings, they develop responses that initiate newfound perceptions and possibilities. They articulate their demands and strive for change within challenging circumstances through an adaptable and transformative progression.

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RESEARCH ARTICLE

Interpreting Young Adult Voice in Shyam Selvadurai's *Funny Boy*

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ABSTRACT

Funny Boy can be classified as a *bildungsroman* or “coming of age” novel, by Shyam Selvadurai, a Sri Lankan writer writes in English from Canada. It chronicles the life of Arjie Chelvaratnam, the protagonist. It consists of six chapters and they explicate his sexual awakening in the wake of the civil war in Sri Lanka. In each chapter, he discloses his inward changes and also the traumatic socio-political life around him. He is seven years old when the story begins. The story unfolds the incidents occurred in his life between 1977 and 1983, the crucial period in Sri Lankan history. During these years, the ethnic conflict was at its peak and it results his family's emigration to Canada. The novel has already been explored in various angles. This paper is an attempt to interpret it from a new lens, that show Arjie inclines his queerness, his homosexuality, at personal level and also how he perceives the intensity of the ethnic conflict at national level as a young adult.

Keywords: sexual awakening, civil war, homosexual inclinations, ethnic conflict

INTRODUCTION

Selvadurai's debut novel, *Funny Boy* narrates the story of (Arjun) Arjie Chelvaratnam, a seven-year-old protagonist. It explores Arjie's sexuality in the wake of the ethnic conflict from Arjie's point of view. Starting in 1977, it uncovers how Arjie's maturing process through presenting the ethnic conflict from 1958 to 1983. This paper is an attempt to read it from the young adult literary narrative. As stated, the young narrator, Arjie narrates his childhood experience and expectations, wishes, involvement, temperament, the unsympathetic life in the midst of the elders and his eagle-eye view of the ethnic conflict and also his self-realisation. This paper groups this novel as a young adult fiction as it resembles some of the elements of the young adult literature. Such literary productions are gradually emerging and Cindy Lou Daniels clarifies it as “often grouped as a sub-division within the category of children's literature” (*The Alan Review*, 78). Pertaining to the features of children's literature, Lou Daniels inscribes the merit of children's





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literature as: “children’s literature scholarship is by no means invalid; it sheds much light on literature as a whole as well as the genre it discusses (*The Alan Review*, 78). Similarly, Emily Wilcox comments on the Young Adult Literature is “relatively recent phenomenon, with the term only coined in the 1960s as a way of describing titles catering for children between the ages of 12 to 18” (1).

Funny Boy is composed of six discrete chapters, “Pigs Can’t Fly,” “Radha Aunty,” “See No Evil, Hear No Evil,” “Small Choices,” “The Best School of All,” and “Riot Journal: An Epilogue” to vitalise both personal and public awareness of Arjie. The first story, “Pigs Can’t Fly,” discusses how Arjie identifies his funny nature while spending his spend-the-day at his grandparents’ home. As a child, he prefers to dressing up in saris and playing with girls, instead of playing cricket with boys, and as a teen enters into a relationship with a male classmate. In bride and bride game, he dresses up like a bride in a sari; his cousins help him to put on a veil and make-up. He asserts his position among the female cousins: “If it was cooking-cooking we were playing, I was the chef; if it was Cinderella or Thumbelina, I was the much-beleaguered heroine of these tales” (FB,4). Mallika Vasugi Govindarajoo et al in their “Elements Of Young Adult Literature in Prescribed Novels for Malaysian Schools” quote Herz and Gallo’s (1996) nature of young adult literature as “a young adult protagonist, the point of view of a young adult, coming-of-age issues that are relevant to young adults, the story being marketed specifically to young adults, and the story being one that young adults willingly choose to read” (272).

Funny Boy fulfils all the above cited nuances. Arjie is a young protagonist-narrator, though he is a child, he is not reluctant in his portrayal of the adult world. From age seven to thirteen and his maturation process is very much evident to make the story as the coming-of-age novel. He is always found among his female cousins. His aunty, Kunthi drags him in front of his parents and others to notify his transgressing behaviour. Highly terrified in sari already, he feels ashamed of him and feels “The sari suddenly felt suffocating around my body, and the hairpins, which held the veil in place, picked at my scalp” (FB,13). His uncle Cyril also remarks at him: “looks like you have a funny one here” (FB,14). As a young boy he narrates the childhood reality. His father blames his mother for his funny behaviour, permitting him to play with her saris. He hears his father referring him as “If he turns out funny like that Rankotwera boys, if he turns out to be the laughing-stock of Columbo” (FB,14). His father also observes that this kind of childish game would make him funny when he grows up.

Arjie voluntarily ventures into his mother’s room while she is dressing and playing with her jewellery. For him, “Entering that room was . . . a greater boon than that granted by any god to a mortal” (FB,15). After he is caught, he is not permitted to his Amma’s room, but remains outside her room while she dresses up inside and he “could hear the rustle of the sari as it brushed along the floor” (FB,16). As a young boy, Arjie is perplexed that he fails to realise his guilt “It was clear to me that I had something wrong, but what it was I couldn’t comprehend. I thought of what my father had said about turning out “funny. The word “funny” as I understand it meant either humorous or strange as in the expression. “that’s funny” (FB,17).

To change his nature, his Amma informs his elder brother Diggy to include Arjie in his cricket team. Diggy rejects her request calling him a “useless . . . We’ll never win if he’s on our team” (FB,19). He refuses to play cricket and asks his Amma “Why do I have to play with the boys” (FB,19). His Amma responds to him “Because the sky is so high and pigs can’t play, that’s why” (FB,19). As a boy he longs to play “bride-bride” and is helpless at this time, he thinks “it was impossible for the girls to play bride-bride” (FB, 21). So, he hides the sari in the car. When one of his cousins, Sonali clarifies his Amma whether Arjie could play with girls, she reiterates Sonali “Because the sky is so high and pigs can’t fly” (FB,23).

When Arjie plays cricket with the boys, Sanjay teases him as a “girlie-boy” (FB,25) and he is terrified with the unexpected nickname ‘girlie-boy.’ He is cornered in the batting order also. His brother grabs the bat, tells him “You go . . . We don’t need you” (FB,28). He then chases Arjie with the bat to beat. Sensing the danger there, Arjie escapes. This captures the trivial world of the children where raw emotions, actions and reactions gain momentum and thus form the narration that is conceived as young adult narration. The boyish demeanour is once revealed by him “If you





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let me play, I will give it [sari] to you when it's time for the bride to get ready" (FB,30). In the tug of war between Her Fatness and Arjie, the sari is torn and the sleeve of her dress is torn. When his Ammachi, grandmother rebukes him as "vamban" (FB,37), he escapes to the seashore with the sari and bemoans at this incident a lot.

As a result of this embarrassing incident, Arjie senses his 'in-betweenness.' He affirms it "I would be caught between the boys' and the girls' worlds, not belonging or wanted in either" (FB,39). It happens to an adult but Arjie experiences it. It's a kind of displacement, not belonging to both the worlds. Adrienne Vitullo in his "Displacement in Young Adult Literature: A Thematic Analysis" notes the similar kind of displacement as

"Displacement, often an effect of socio-political conflict, is increasingly a theme in adolescents' lives, and therefore a prevalent theme in the ways they see the world. Providing spaces for adolescents to discuss their relationships to displacement through Young Adult (YA) texts can provide educators a possible way to support to adolescents at this critical time in their lives" (<https://pmc.ncbi.nlm.nih.gov/articles/PMC9361240/>).

He could realise his transformation as a matured boy, enduring "the lunches and teas when the cousins would talk to one another" (FB,39-40). He brings the torn sari back home believing "the future that awaited me" (FB,40). Through this experience, he acquires a power to manage all situations independently and he realises the children's world and the world of the elders.

Arjie narrates ethnic clashes that collapsed the life of the people in the subsequent chapters. "Radha Aunty," the second chapter, deals with his father's youngest sister, Radha who returns to Sri Lanka after her stay in the USA for four years. It exposes the country's waking ethnic conflict. As a seven-year-old boy, he is excited over the marriage of Radha with Rajan, the son of his Appachi's family friend, Mr. Nagendra. To make him more responsible, his Janaki, the servant-maid allows him to read her love comics. He compares the two characters of his favourite love comic, namely, Mani-lal and Sakuntalawith Rajan Nagendra and Radha Aunty. He imagines her as "a strong resemblance to that goddess of the Sinhala screen Malini Fonseka . . . with big rounded hips . . . a fair complexion and large khol-rimmed eyes . . . hair was straight and made into an elaborate coiffure on the top of my head, and she wore a Manipuri sari with a gold border" (FB,43).

When Radha returns, he is shocked because "She was a karapi, as dark as a labourer . . . her long hair was frizzy like Ammachi's . . . She was thin, not plump . . . "flat like a boy" . . . Instead of sari, she wore a halter-top and strange trousers that were tight to the knee and then became wider" (FB,46). Though he has this opinion about her, she advises his Ammachi not to treat him as a servant boy. He understands her "different from other adults" (FB,48). In fact, she permits him to play in her bedroom where he feels more liberated. She sticks a star on his forehead, applies lipstick, and paints his eyelids and put rouge on his cheek and darkens a birthmark above his lip. He confesses his transformation "now I had lost my earlier shyness. I donned several of her chains and bangles and studied the effect in the mirror . . . coloured his nails" (FB,51). Besides, he advertently shows his fingers to Her Fatness. He thinks: "so that she would notice my nails. When she saw them, her face became clouded with jealousy" (FB,53).

Arjie is thrilled witnessing the play, *The Pied Piper of Hamelin* in which he finds the characters are children and he is more thoughtful of the fact that "they got to wear make-up and costumes and dance around the stage" (FB,54). Later, he is curious about the story of another play, *The King and I* in which the English governess teaches "English and other Western subjects to the king's children and wives" (FB,54). Though the story does not end in marriage, he expects it to be concluded with marriage. When he clarifies it, his Amma explains it to him "Because at that time people don't marry outside their race" (FB,54). At present, he expresses his adult behaviour the play should end with married. When he intends to give happy ending of the story, asking his Amma: "if it was now, would they have married" (FB,54). This indicates how knowledge about the mixed marriages, but his Amma agitatedly responds: "Because most people marry their own kind" (FB,54).





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Bucher T. Katherine. "Understanding Young Adult" observes that

"As young adult literature has matured, authors have begun to incorporate more complex characters, subjects, and situations (Cart, 2001). The boundaries of young adult literature have expanded as authors explore topics of cruelty and crime, personal abuse, and racial violence (Dresang, 1999), accompanied by a change in the perspectives represented in literature (7).

In *Funny Boy*, Selvadurai incorporates Arjie as a more complex character, introduces most complex political subject and his family it drawn into many difficult situations during the course of the ethnic conflict. The whole family is caught in a complex situation while Radha loves Anil, Daryl's death announces uncertain political climate, and the untold suffering of the Tamils during 1983 clash. Therefore, the young boy narrator blurs his boundary without confining in his own childhood territory and intrudes into the adult world where he could perceive only political turmoil and its consequences. Through a chain of incidents and situations, his personality is shaped. His realisation on the enmity between the Sinhalese and the Tamils over their governance is disclosed when Radha Aunty develops a love affair with a Sinhalese man, Anil Jayasinghe after her rehearsal of the play, *The King and I*.

Arjie is conscious of his surrounding, but not enough matured to learn what has happened to his family members in the past. He partially thinks that Ammachi is biased against Anil's being a Sinhalese and calls her, a racist. He reacts this innocently as "I wondered why Anil's being Sinhalese upset her so? I was in a Sinhala class at school and my friends were Sinhalese. My parents' best friends were, too. Even our servant was Sinhalese, and, in fact, we spoke with her only in Sinhalese. So what did it matter whether Anil was Sinhalese or not?" (FB, 58-59).

The brutal murder of Arjie's great-grandfather in the 1958 ethnic conflict disapproves their marriage. As a boy, he learns the very crux of the problem that's spoiling the peace of the family and learns from his father that his great-grandfather, Ammachi's father was killed by the Sinhalese "because he was Tamil" (FB, 60). Arjie reveals his boyish attitude and mentality to his father: "But you're Tamil and I'm Tamil and nobody's killing us" (FB, 61). Arjie's world is being enlarged from bride-bridal to ethnic conflict.

Shyam Selvadurai shaped Arjie as a balanced character because he is keen on the world of children when he is with children and behaves as a mature adult by capturing the socio-political condition. He turns into a vibrant individual when he joins Radha Aunty because he earns a space to exercise his freedom and obtains power to observe the external world. His potential as a boy narrator is proved when he narrates the effects of "Sinhala Only" policy introduced by S. W. R. D. Bandaranaike, the then Prime Minister to deprive of the Tamils of their rights. By doing so, the government carefully eliminated the educated Indians from the civil services and other government positions. It was a blow to the Tamils. When the country expected a unifying factor, English language "served a politically useful role as an important unifying factor in the country" (K. M. de Silva, 47). So, Sinhala was made mandatory in government business establishments. The Sinhalese chauvinism was evident through the abolition of English medium schools and classes were taught in Sinhala language. Ravi Kant Dubey in his *Indo-Sri-Lanka Relations: With Special Reference to Tamil Problem* underscores the Sinhala fanaticism as "it was made compulsory to inscribe Sri (a Sinhala specious word) on all number plates of vehicles. (84-85).

Arjie's Amma repeats to him about the massacre: "The Sinhalese wanted to make Sinhala the only national language, and the Tamils did not like this. So there was a riot and many Tamils were killed" (FB, 61). As a boy wants to know more about the adult world and his inquisitiveness strengthens the plot of the novel. He could realise his Ammachi's mentality to some extent and he anticipates whether she would support the government or the Tigers who "wanted a separate country" (FB, 61). At this juncture, his father admits him to the Sinhala class because he believes that Sinhala would be "the real language of the future" (FB, 61). She condemns Arjie's father for admitting him in the Sinhala class that he is "betraying the Tamils" (FB, 61). But his father senses the hegemony of the language in the current scenario and seeks hope for Sinhala only. Pointing out this crucial turn, Charles Sarvan, in his "Shyam Selvadurai's *Funny Boy*: Test and Context," in *Sri Lanka: Literary Essays and Sketches* remarks it as: "the father sees Sinhala not only as the new





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language of political hegemony and economic opportunity but also of physical safety—speaking Sinhala, one could, during times of anti-Tamil riot, attempt to pass off as Sinhalese” (50).

His Ammachi witnesses that the Tigers are striving hard to get a separate state. Through this narration, Arjie grabs every opportunity to comprehend the political climate. As a child narrator, he is competent to note the politics in the children’s world, that is, cricket is played “against other Sinhalese classes, the boys in our [Tamils] class played the Tamil class . . . when the match was over the players parted without shaking hands or patting each other on the back” (FB, 62).

Arjie understands better that Radha’s being a Tamil forbids her relationship with Anil. Further, she explains to Anil that “Her [Ammachi’s] father was killed in the fifty-eight riots” (FB, 68). As a young observer, he listens to Anil’s determination: “If you like me, together we can make our parents accept us” (FB, 74). But his Ammachi forbids this relationship. Finally, Radha is sent to Jaffna. She reminds Radha the danger ahead of her “Otherwise, people in mixed marriages will find themselves in a terrible dilemma” (FB, 79).

Another character, Aunt Doris, a Burgher and the director of *The Kind and* briefs the shortcomings of the intermarriage. She marries Paskaran, a Tamil against her family wishes. She says that she is the real victim of the mixed marriage. After her marriage, her father strictly forbids her mother and sisters contacting each other and all of a sudden, they migrated to England without informing her, leaving “no address or anything” (81). Later, she learns from a mutual friend that her father had passed away. When she contacts her sisters, she finds that she has lost the previous affinity and she feels that they have become strangers and she feels that it is too late for her to contact and by the time her husband also dies and she is left alone. Before leaving for Jaffna, Radha meets Anil and they complete all arrangements for the marriage. She feels more confident: “Everything is set. When I come back from Jaffna [,] we’re going to do it. I don’t care what his parents or my parents say” (FB, 84). The riots break out while Radha is returning from Jaffna and she realises the real core of the ethnic conflict as she witnesses “Sinhalese people began throwing stones and bottles on the train” and learns that “The government is going to declare a curfew” (FB, 86). Mr. Rasiah, Ammachi’s family friend, rescues her speaking “good Sinhalese and the men had believed he was Sinhalese” (90). When Anil visits Radha’s house and notices a drastic change in Radha and regularly takes part in the rehearsal again but remains steady to stay away from Anil.

Prior to the riot, Arjie deciphers that intermarriages were possible between the Tamils and the Sinhalese, if they loved each other. But after witnessing the volatile political situation he comes to term that such marriages are impossible. Through Radha’s life he is aware of the complexities of life and this exemplary incident strengthens Arjie’s realisation.

The narration about Daryl, a Sri Lankan-Burgher journalist from Australia, wants to study the war and violation of human rights in Jaffna. He is on a two-month vacation when his father is for Europe to promote his hotel business. He perceives the war as: War . . . signified guns and soldiers and armoured cars” (FB, 109). He wants “to investigate if this was true and do an article to his newspaper” (FB, 110). Arjie regards about POTA that it is “a new law that allowed the police and the army to arrest anybody they thought might be a terrorist without something called a warrant . . . tool for state terrorism” (FB, 110). Daryl desperately holds a partial opinion that “nothing will happen to [him]. . . Neither the army nor the Tigers care about someone who looks like a foreigner” (FB, 117). His visit a week long one in Jaffna where he learns that “people are being tortured and killed” (FB, 117).

As a child narrator, his knowledge grows about the unimaginable atrocities done during the civil war. He, along with all members, learns that “the Jaffna library was burned by the police this morning. Ninety-thousand books were set on fire” (FB, 122). Only Daryl’s body is rescued. Arjie’s mother meets Q. C. Appadurai, her father’s friend and a civil rights lawyer to make an appeal to Daryl’s death. He advises her not to probe into it and guides her: “These days one must be like three wise monkeys. See no evil, hear no evil, speak no evil” (FB, 141). Since the investigation is dangerous to her family, he warns her that her phone would be tapped if she continues her enquiry. She conforms





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that it is being tapped. She visits BelihulOya to meet the servant boy, Somaratne to enquire the cause of Daryl's murder. The conflict not only affected the middle and upper middle and upper classes of people, but also ordinary peasants. Arjie's consciousness towards this also grows through the ruthless murder of the servant boy, Somaratne's elder brother in the 1971 insurrection by the army. A lot of oppositions prevent Arjie's mother not to enquire more about Daryl's death. In addition to the above, Arjie learns that the army and the LTTE abduction many youth and detained them for any number of days and tortured them.

FunnyBoy records the ethnic tension which converts mundane matter into sensitive issues. "Small Choices" sums up the life of a Tamil boy, JeganParameswaran, the son of Grace Parameswaran from Jaffna. He is admonished when he tries to correct the fellow staff. Based on the complaint launched on him by the manager, Jegan misunderstands him and remarks, "It's a Tamil-Sinhala thing, isn't it? . . . It's ridiculous" (FB, 172). He reminds Jegan of the existing political situation: "The political climate is not conducive. With the Tigers killing Sinhala policemen and the Tamil partly calling for separation, the Sinhalese are very anti-Tamils right now" (FB, 172). Jegan is so scared and upset because "During the riots, the mob came here calling out my name. If it wasn't for my manager and other senior staff, this hotel would have been destroyed" (FB, 173). Being a Tamil is a threat not only to his life, but also to his workplace. Arjie's father notifies him that "the truth is I have given you a high position and there's bound to be more resentment in part because you're Tamil" (FB, 173).

Arjie is keenly brooding over the conversation between his father and Jegan in which his father tells Jegan, "We cannot live like this under constant threat from the Sinhalese, always second-class citizens in our own country . . . "Here you can be killed by the Sinhalese and there you can be killed by the police or the Tigers" (FB, 176). The post independent Sri Lanka's identity has erased all such greater glory of the country as a result of the ethnic clash. Jegan is suspected as a Tiger who is involved in an assassination attempt on a Tamil minister. He is arrested under the Prevention of Terrorism Act and the news item carrying "The suspect, JeganParameswaran resides with a well-known Tamil hotelier" (FB, 183) is also widely published. Jegan's post at the hotel triggers jealousy among the Sinhalese staff and they try to fabricate notorious stories about him, connecting him to the Tigers. By the time, Arjie's mother exhibits her fear in speaking Tamil language, "One doesn't feel safe speaking Tamil these days" (FB, 190). Sensing the continuous threat and danger, Arjie's Amma suggests emigrating to Canada or Australia. But his father confronts her emphatically: "I'll never emigrate. I've seen the way people live in foreign countries" (FB, 195). He expresses his helpless nature: "What would I do there. The only job I'd be fit for would be a taxi driver or a petrol station man" (FB, 196).

The Sinhalese supremacy damage the livelihood of other ethnic communities. As such, Arjie's parents are deprived of the opportunity to vote and "A member of parliament arrived with his thugs, held the voting officials at gunpoint, and then proceeded to stuff the ballot boxes with false ballots" (FB, 207). Later, his family learns that the government has won and that "They would remain in power for another six years" (FB, 207). His father determines to live in the country and says: "Never, I will never leave this country" (FB, 207).

The fifth chapter, "The Best School of All" narrates Arjie's experience at Victoria Academy when he is studying in the Sinala class. His father admits him to the Queen Victoria Academy believing that it would "force you to become a man" (FB, 210). Diggy, his elder brother, also notifies Arjie about his queer nature "He [his father] doesn't want you turning out funny or anything like that" (FB, 210). When he said that Arjie is excited and expresses it secretly "I felt a flush rise into my face" (FB, 210). From his reaction, his queer quality is intensified. A contradictory is observed here is that his father wants to change him into a man, but he develops his homosexual afflictions with Soyza Shehan and he finds himself looking at him oftenduring the classes. Arjie describes his physical features as "his body was well-proportioned and lacked awkwardness of most other boys of his age. His face was full of contrasts. His upper lip was thin, his lower lip full; his forehead was fine and well-shaped, his eyebrows thick and unruly. Yet the overall effect was attractive" (FB, 217). Jonathan Culler in his, *Literary Theory: A Very Short Introduction* *Funny Boys* situates it as "literature is one of the places where this idea of sex is constructed, where we find promoted the idea that people's





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deepest identities are tied to the kind of desire they feel for another human being" (8). He is thrilled to find himself "it became evident to me that Soyza had certain power" (FB, 217) and thereby he finds his sexual orientation.

At the same time, Diggy alerts him the conflict between Mr. Abeyasinghe, the Principal, nick-named Black Tie, and Mr. Lokubandara, a "political appointee" (FB, 212) who wants to make the Academy a Buddhist school. His intention is revealed: Since all Buddhists are Sinhalese, that means the school would be a Sinhala school, and there would no place for Tamils in it" (FB, 220). But the Black Tie opposes Lokubandara's egalitarian worldview proposing that the school should be open for all races and religions.

When the principal, Black Tie slaps Soyza, Arjie is melted. Diggy understands the growing relationship of Arjie with Soyza and warns him: "I'm going to tell you something about Soyza because I don't want you to become like him" (FB, 231). And cites that during the free hour, "He has sex with the head prefect . . . Don't say I didn't warn you. If you remain Soyza's friend, people will think you're like him and you'll become the laughing stock of the whole school" (FB, 232). But Soyza is a good relief for Arjie when the principal beats him with the cane for not reading the poems which are meant for the recitation during the annual day. He takes pleasure articulating "Shehan" (FB, 242). He is quite clear that he is caught between the terror of the principal and "the relief and pleasure" of thinking of Soyza. He dreams of Soyza when he is alone. On one occasion Soyza kisses Arjie on his lips and casually moves and he is unable to see Arjie's eyes. He is in a turmoil now and he exhibits it: "I was still trying to recover from the impact of that kiss, trying to understand what it meant (FB, 250) and feels that "something was coming undone between us" (FB, 250).

He exhibits his full queer nature. When he is alone at home, he imagines Soyza all the time and says
First my mind's eye rested on Shehan's face, the fullness of his lower lip, the slight ridge above his upper lip . . . imagined him kissing me, not quickly but slowly, lingeringly, so that I could feel the full impact of the kiss. I tried to remember the instant when his tongue touched mine. It had been rough and wet . . . I . . . not only liked that kiss but was also eager to experience it again in all its detail and sensation. (FB, 251)

From that time onwards, he strongly believes that his friendship with Soyza has brought out "power and hidden possibilities" (FB, 256). While playing hide and seek in his home, Arjie sex with Soyza and regrets when he appears before his Amma and Appa and feels that "I saw that had committed a terrible crime against them, against the trust and love they had given me . . . I had done, beg to be absolved of my crime, but the deed was already done and it couldn't be taken back" (FB, 262). He thinks of his father: "He had been right try to protect me from what he feared was inside me, but he had failed" (FB, 262). Finally, he behaves as if a man apologises for his grave mistake. Even after that he feels "With the terrible regret of a realization come too late, I saw that I had misjudged what we had done in the garage. Shehan had not debased me or degraded me, but rather had offered me his love" (FB, 269). Without his company he feels "As long as you were there, I didn't mind being "ills and burdens" (FB, 271). Towards the end of this chapter, he realises that the relationship he has had with Shehan Soyza has altered his relationship with his Amma and feels alienated "I was no longer a part of my family in the same way. I now inhabited a world they didn't understand and into which they couldn't follow me" (FB, 284-85). Thus, Arjie is aware of his sexuality and feels like an adult and wants no longer hurt his family.

The final chapter of the novel, "Riot Journal: An Epilogue" pictures the July clash which broke out on 25th July, 1983 as a result of the murder of thirteen soldiers by the Tigers. Arjie minutes the incidents carefully in the form of a diary: His narrative capacity is shown in this chapter. At 09.30 am, on 25th July, 1983, "All the Tamil houses there [Kanaththa] are burnt, and the trouble has begun to spread to other parts of Colombo as well" (FB, 287). Through his Amma, he learns that in fact, the riot is sponsored by the government. He is well aware that the Sinhalese mobs arrive at the street, possessing the "electoral lists, they know which houses are Tamil and which houses aren't" (FB, 289).





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He learns that

“all the Tamil shops had been set on fire and the mobs were looting everything . . . the police and army just stood by, watching, and some of them even cheered the mobs and joined in the looting and burning . . . There was a car in the middle of the road [Galle Road] with a family inside it. The car was surrounded by thugs . . . The thugs were siphoning petrol out of it and pouring the petrol on the car. (FB, 291).”

The life of his family members is in great danger when the mob sets Arjie’s house on fire and the hotel is severely damaged. To escape from the rioters, Arjie’s mother places a ladder against the sidewall to go into Perera’s garden. His Amma removes “her thali (the wedlock) and gold bangles” (FB, 293) and his Appa seizes their “birth certificates and bankbooks” (FB, 293). They are well prepared to escape at any moment to any place. Arjie writes his riot journal with the help of a torch. When the mob comes to Arjie’s house, all escape through the ladder into Perera’s home and hide in the store room. The furious mob reaches Arjie’s house breaking the glass of the door. The mob leaves the house after setting fire to it.

At 12.30 pm on 26th, Arjie enters the house with others, saying “I was struck by how uniform and characterless the rooms looked, with their debris of furniture and charred walls. They, too, seemed to have shrunk in size” (FB, 297).

He writes:

I was suddenly aware that records were not music but plastic, which had now melted into black puddles; that my books were mere paper that had browned and now came apart between my fingers. Legs, posts and arms of well-known furniture, once polished smooth and rich brown in hue now that they had cracked open revealed the whiteness of common wood. (FB, 297-298)

He speaks in remorse: “I try to remind myself that the house is destroyed, that we will never live in it again” (FB, 298). Finally, Sena Uncle arrives in his van and picks them up from his home. Arjie learns that his Ammachi’s house has been destroyed and that they are going to KanthyAunty’s house to Colombo Seven. At 6.00 pm on 26th July, they take shelter in Sena Uncle’s house creates problems to him because he receives an anonymous phone call and the caller brands him “a traitor for sheltering Tamils” (FB, 299). The rioters destroy all the grocery stores owned by the Tamils. The hotel Arjie’s father owns is severely damaged by the rioters. The president expresses “no sympathy for what . . . Tamils have suffered, nor did he condemn the actions of the thugs” (FB, 303).

Eventually, Arjie’s father realises they “no longer belong in this country” (FB, 304). On 02nd August, a mob sets “the car on fire with Ammachi and Appachi inside it” (FB, 306). When Arjie visits his burnt house on 27th August, he finds “everything was not burned had been stolen. Whatever had remained intact, furniture, uncharred beams, doors, windows, even the hinges and the rain pipes, had been taken” (FB, 311). Arjie cries out for the loss of his house.

Selvadurai’s *Funny Boy* discusses the life of Arjie, the protagonist, in the wake of the ethnic conflict in Sri Lanka. Set during the escalating civil war in Sri Lanka, the novel recapitulates the terrible ethnic riots of the 1958 as a result of the Sinhala-only policy and July clash of 1983. He presents ethnic conflicts through Arjie, Radha Aunty, Arjie’s Aunt, Daryl Uncle, a friend of Arjie’s mother, and Jegan, a Tamil Boy who joins the hotel run by Arjie’s father. Mallika Vasugi Govindarajoo et al. quote (Brozo & Simpson 1995; Wells 2010; Wolf 2007) the nuances of the young adult literature as “the presence of strong young adult protagonists who are often portrayed as perceptive, sensitive, intelligent and independent; The point of view and voice of the young adult protagonist is projected, and it is their actions that often drive the major outcomes in the stories. Themes and issues in YAL are relevant and meaningful to young adults and often parallel their own lives in significant ways (274). Fuoss, Kirk remarks in his article a new dimension: “A Portrait of the Adolescent as a Young Gay: The Politics of Male Homosexuality in Young Adult Fiction” that

Young adult novels addressing male homosexuality are political on at least two levels, content and circulation/reception. These novels are political at the level of content to the extent that they position male





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homosexuality within a normative spectrum marking acceptable and deviant forms of same-sex love, acceptable and deviant forms of familial organization, and acceptable and deviant forms of interacting with those who transgress these norms. (160)

Exploring the young adult narration, this paper attempts to vitalise the worldview of the child narrator, his growing awareness about his sexuality, his demarcation at home, the exclusion from the boys' world, undermining view of his parents, his intensive attachment to the female cousins, his dramatic narrative of the ethnic conflict, his eye-opening knowledge on politics, his displacement, homosexual nature and the repercussive effects of the civil war are coherently brought out. In young adult fictions, the narrator would be of from 12 to 18 years old. But, in *Funny Boy*, Arjie excels in his portrayal of his personal, political and national world. The story roughly covers six years of Arjie's life, from 1977 to 1983. Though Arjie is under the age twelve, his knowledge over the minute occurrence children's world, his own realisation and his position in the family, his family members' opinion about him, his understanding of racism is quite amazing. Sarah Jane Mukherjee in her "Understanding Representation in Young Adult Literature Through the Voices of Young People" observes the similar view that the "storylines often closely associated with coming of age, including first love, friendship, and familial tensions, romantic relationships, sexuality, health, and social hardship" (59).

Arjie is so perceptive in what is happening to his personal self as well as to other people. He is sensitive to the ethnic conflict that render that shattered not only the Tamils but also other ethnic minorities. Selvadurai interweaves ethnic conflict with the plot exquisitely. The peaceful life of the people is shattered by the political attitude of the leaders. As a Sri Lankan-Canadian Tamil writer, Selvadurai's *Funny Boy* talks about the politics of language and its impact on the minority ethnic communities of Sri Lanka, especially the Tamils and the Burghers. Throughout the novel, Arjie identifies himself as an important persona as all incidents round him. As a young narrator, he could understand what others think and react over the incidents happening at home or what is happening around him outside. He realises his identity within the family as well as his place in the world at a large spectrum.

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RESEARCH ARTICLE

Enhancing Reading Comprehension in EFL Contexts: A Synthesis of Strategy-Based Instruction and Metacognitive Awareness

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ABSTRACT

The reading comprehension is one of the elements of the academic achievement and life-long learning, especially in the English as a Foreign Language context. This paper will generalize the results of various empirical and theoretical research in order to analyze how reading strategies and metacognitive awareness can enhance the comprehension ability of the learners. Based on an action research, descriptive qualitative studies and metacognitive frameworks, the research identifies major strategies including predicting, visualizing, questioning, summarizing, inferring and forming connections. The evaluation shows that the implementation of these methods through explicit instruction and appropriate strategic integration of them can help learners to engage more, comprehend and be more independent. In addition, the paper highlights the significance of the teacher mediation and adaptive instructional practices to promote effective reading contexts. The results add to the existing literature and support the idea of teaching reading as a strategy and the necessity of including metacognitive awareness in teaching language.

Keywords: Reading comprehension; EFL learners; metacognitive strategies; strategy-based instruction; reading pedagogy; action research.



**Sathees Kumar and Murugan**

INTRODUCTION

It is a well-known fact that reading is one of the core skills that are necessary in academic success and personal growth. It helps learners to gain knowledge, analyze information, and react critically to texts. Nevertheless, the reading comprehension, especially in second or foreign language situations, is a very challenging issue because of the linguistic, cognitive, and pedagogical factors.

The focus of reading in modern education has changed to strategic and metacognition of reading materials rather than decoding the text. Studies have shown that readers who are effective are active and use strategies to build meaning, track understanding and review textual content. The result is that strategy-based instructions have become one of the key pedagogical solutions in enhancing the reading capabilities.

Theoretical Framework Reading Strategies and Metacognition.

Deliberate and goal oriented actions that aid in comprehension and meaning construction are defined as reading strategies. Such strategies can be broken down into three major categories:

- **Global strategies** (e.g., previewing, predicting)
- **Problem-solving strategies** (e.g., re-reading, adjusting pace)
- **Support strategies** (e.g., note-taking, summarizing)

Particular attention should be paid to the metacognitive ones since they imply planning, monitoring, and evaluating the reading process. By having metacognitive awareness, learners are in a greater position to control their understanding and adjust their methods based on the requirements of the text.

Research studies have shown that EFL learners often depend on the strategies of solving problems when faced with a problem, implying that they are reactive learners of reading, not proactive learners of reading. This puts us in a position to note that strategic reading must be taught systematically.

Fundamental Reading Instructions in Comprehension Building.

An overview of the chosen studies reveals six major strategies of the reading instruction:

Predicting

Predicting helps the learners to engage their previous knowledge and set a goal of reading. It creates interaction and hypothesis testing in the process of reading.

Visualizing

Visualization is building mental pictures within the textual information thus increasing the memory and understanding.

Making Connections

The strategy connects textual material to the prior knowledge with:

Text-to-self

Text-to-text

Text-to-world connections

These relations enhance interpretative meaning and situational significance.

Summarizing

The process of summarizing makes the learners find the main ideas and summarize information, which promotes the development of critical thinking and organization skills.



**Sathees Kumar and Murugan****Questioning**

Asking provokes active reading and helps to understand the text by asking questions and thinking.

Inferring

Inferring is the ability to read between the lines in order to get implicit meanings, themes and intentions by the author.

All these strategies make reading interactive and cognitive as opposed to a passive activity.

Methodological Perspectives

The reviewed studies use different research techniques:

Action Research: This was done in the middle-level learners to determine the effects of explicit strategy teaching in reading comprehension.

Descriptive Qualitative Research: Investigates practises of teachers and strategies in the classroom in the context of real educational situations.

Survey-Based Research: Tested both awareness of metacognition and the pattern of strategy use of the investigated students.

All these methodological approaches offer a complete understanding of the instructional practices as well as the behaviors of learners.

FINDINGS AND DISCUSSION**Effect of Strategy Teaching.**

The comprehension of reading techniques can greatly enhance the reading awareness of the learners. First, students usually show insufficient knowledge of strategic reading, but, with systematic training, the performance and interest increase the measurable level of performance and engagement .

Role of Teachers

The teachers contribute significantly to:

Modeling strategies

Debriefing practice (individual, group, and independent)

Differentiating teaching according to the needs of learners.

The success of reading instructions is partially determined by the skill of the teacher to integrate and apply the strategies accordingly instead of using only one strategy.

Strategy Combination and Classroom Dynamics.

It has been indicated that a combined approach that is neither too much, nor too little is more effective. Excessive use can subdue the learners but deliberate and properly designed integration will improve the understanding and classroom activity of the learners.

Metacognitive Awareness and Learner Autonomy.

Metacognitive and awareness enable the students to become independent readers. They:

Assess their comprehension.

Dynamic strategy adjustments.

Critically respond to texts.

This independence is critical to academic and a lifetime learning.





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Pedagogical Implications

The discussion of findings could imply the following implications to the teaching practice:

Set Strategy Teaching: Teachers ought to teach strategies of reading systematically and model.

Scaffolded Learning: The learning instructions should be given in form of guided practice and then to independent application.

Metacognitive Training: It is necessary to train the learners to think about their reading.

Flexible Strategy Use: The teaching needs to be adjusted to the circumstances of the learners and their knowledge level.

Interactive Learning Environments: Group work improves interaction and understanding.

CONCLUSION

This study highlights the importance of reading strategies and metacognitive awareness in the increase of reading comprehension among EFL learners. Strategy-based instruction with effective teacher mediation contributes to better results in the learners and increased interest in the texts. Further studies are required in the futures that embrace bigger and more diversified samples and longitudinal effects of strategy teaching on academic performances.

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RESEARCH ARTICLE

Plant Dreaming and Animal Calling: Indigenous Epistemologies as Psychological Healing Modalities in *Solar Storms*

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ABSTRACT

Linda Hogan's Solar Storms does not simply refer to trauma as a personal wound but rather as a bloody tear in the world of the living. This paper presents how Indigenous epistemologies, such as plant dreaming and animal calling, operate as the most important psychological healing modalities of the protagonist, Angel, and her people. Having been abandoned by foster care and with a scarred face, the journey to the north is a denial of the animate world back into the inanimate world, where knowledge is not represented in institutions but in the land. Angel learns about plants being relatives and that they should be sung to, respected, and not simply extracted, through the old people, such as Dora-Rouge and Tulik. Her fantasies of redroot and wolfsbane are used as diagnostic tools and physical and spiritual curing instruments in places where Western medicine is not available or applicable. Similarly, animal calling has nothing to do with superstition, in which Agnes communicates with the glacier bear coat and the bush to water is an example of a psychological relationship founded on kinship rather than domination. These customs restore efficacy to characters displaced by hydroelectric dams and colonial violence. In *Healing in Solar Storms*, there are many relations. It involves listening to the beating of the blood and viewing non-human consciousness. Such primitive forms of knowing assist Angel in building an identity that is fragmented as she becomes a scarred victim and a plant dreamer. The novel indicates that the psychological wholeness of Indigenous people is impossible without ecological health. By proving that knowledge of dreams and animal speech is possible, Hogan attacks Western paradigms of psychology. She proposes that intergenerational trauma can only be healed by returning to the sacred covenant between humans, animals, and the earth, revealing that the land itself is the medicine of the soul.

Keywords: Indigenous Epistemologies, Psychological Healing, Plant Dreaming, Animal Calling, Intergenerational Trauma, Eco-psychology.



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INTRODUCTION

The psychological trauma of Indigenous peoples is often inseparably tied to historical dispossessions, the eradication of cultures, and the breakage of ties to the land. Increasing social inequalities, biodiversity loss, and forced relocation are the accelerating effects of colonialism, which are indicative of a weakening ecological balance that has a direct effect on mental health. The core of this challenge is the notion of historical trauma, which is employed to refer to the intricate and multilayered connections between ecosystems of the planet, human processes, and the natural resources we use (Brave Heart 50). In the current research paper, the dynamics of psychological healing are proposed in the context of Indigenous epistemologies and how anthropogenic activity, such as dam building and resource removal, disturbs the fragile ecosystem and human psyche. Literature has become a prominent instrument for realising and creating awareness of these far-reaching effects. *Solar Storms*, the novel created by Linda Hogan, is one such literary work that combines the themes of trauma, ecology, and human experience in a very intricate way.

Specifically, in this paper, the author will concentrate on the role of *Solar Storms* in applying particular practices of epistemology, one of which is plant dreaming and animal calling as a key symbol to address issues of the ecological effects of environmental changes and ways to mend them. The novel depicts how the main character, Angel Jensen, overcomes her trauma and disconnection and recovers with the help of the rediscovery of ancestral knowledge. The text indicates that healing is not an internal and isolated process but a relational process that includes the land, ancestors, and non-human beings. The interruption of natural cycles, including the submerging of Adam Rib and the diversion of rivers, is a source of psychological trauma commonly mentioned in the book as soul loss (Hogan, 1995, Prologue). Characters such as Hannah Wing are violent and dissociated with the annihilation of their world, which shows how the imbalance of nature is reflected by the fragmentation within (Hogan, Chapter 7). This is in line with post-colonial psychological theories that postulate that when people lose land, they become severely spiritually and psychologically distressed (Duran and Duran, 19).

Plant dreaming and animal calling are used by Hogan to signify the healing of psychological completeness. The fact that Angel dreamt of certain plants that healed her grandmother, Agnes, confirms that Indigenous epistemology is an elaborate knowledge system (Hogan, 1995, Chapter 11). Similarly, the song of animal calling taught by Dora-Rouge educated Angel to build ties with the natural world, thereby overcoming the feelings of isolation experienced by trauma survivors (Hogan, Chapter 4). The argument presented in this paper is that *Solar Storms* substantiates the Indigenous ways of knowing as the key to comprehensive psychological restoration. The writings on *Solar Storms* show how profound the relationships between the land, spirit, and psychological well-being are. With this investigation, the paper will contribute to current debates concerning the dire necessity to acknowledge traditional knowledge as a valid and effective psychological intervention. The following sections will identify the epistemologies of Indigenous people and psychological trauma, consider the use of plant dreaming as a diagnostic method, consider the concept of animal calling and relational healing, examine land dispossession as psychological wounding, and conclude by discussing the role of ceremonial practices in identity recovery.

Research Focus

The main objective of this study is to examine how *Solar Storms* by Linda Hogan is an expression of psychological healing in the light of the traditional practices, with a view to deriving meaningful conclusions as to how individual identity is reinvented and the community restored. The article describes how Angel Jensen goes through the process of trauma to recovery through the reclamation of ancestral knowledge, with particular emphasis on epistemological models. Moreover, it explores the connections between land, spiritual practices, and psychology, and explores intergenerational trauma, soul loss, and human and non-human interconnections in depth. The study illuminates the ways in which Hogan employs traditional knowledge systems not only as cultural artefacts but also as therapeutic modalities to combat psychological destruction brought about by colonial displacement and environmental destruction; therefore, it provides a means through which mental health practices can be decolonised.

To conduct this research, the following questions were considered important:





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1. What does Hogan mean by referring to plant dreaming and animal calling to represent the psychological recovery process?
2. How do novel disturbances of natural cycles and ecological equilibrium function as means of psychological trauma?
3. How does the human experience, as depicted in *Solar Storms*, reflect the larger spiritual and environmental crisis indicated by the characters' relationship to the land?

Finally, the paper believes that solar storms confirm the validity of Indigenous ways of knowing as highly crucial in comprehensive psychological restoration. It places a value on shared responsibility and preserving cultural memory and nature, implying that no single person can change anything, but only by means of cooperation. This consequently highlights the urgent need to acknowledge traditional knowledge as a legitimate psychological intervention among Indigenous people and the general academic discourse and ultimate contemporary literary fields.

Indigenous Epistemologies and Psychological Trauma in *Solar Storms*

Indigenous psychology assumes that mental health is inherently connected with the continuity of culture and attachment to land in opposition to Western models of clinical paradigms. Maria Yellow Horse Brave Heart describes historical trauma as a generation-long emotive injury, which is expressed as soul-snatching among those communities experiencing spiritual disconnection, which results in psychological trauma (Brave Heart 89). This is portrayed in *Solar Storms* when Bush speaks of what happened to Hannah, not only as sick but as soul disintegration, where your soul crying out... was a cold wounding sound (Hogan, ch. Prologue). According to Duran and Duran, to heal, the mind has to be decolonised, and the connections that colonisation and forced assimilation have broken with Aboriginal epistemologies must be reconnected (Duran and Duran 48). This is supported by Linda Tuhiwai Smith, who states that the indigenisation of research and healing should take place to reinstate indigenous sovereignty in knowledge (Smith 69). Laurence Kirmayer also adds that Indigenous healthcare practices give less importance to individual pathology and more weight to community and land (Kirmayer 39). This is confirmed in the novel, which presents trauma not as an individual pathology but rather as a collective spiritual crisis based on the notion of dispossession and indicates that more traditional knowledge systems have answers to the problems that modern medicine is unable to offer.

Angel Jensen is a representation of this process of reestablishing the connection through her elders. First, she sees her physical scars as something shameful. She mentions that "scars had shaped my life... I was marked, and I knew the marks had something to do with my mother" (Hogan, ch. 1). It is through the experience of returning to Adam Ribs that she starts to recover, as knowledge of the ancestors serves as therapy. According to Paula Gunn Allen, Indigenous literature tends to reinstate the feminine and the sacred to heal the fractures in the community (Allen). It is through Dora-Rouge that Angel gets to understand that the process of healing is relational and is itself a part of the nature world; she is instructed that "plants began to cross my restless sleep in abundance... I was devoted to woods the wind walked through" (Hogan, ch. 11). Gerald Vizenor terms this as survivance, a presence rather than an absence so to speak (Vizenor). Through these traditions, Angel can feel the power of her pain, and she understands that "something wonderful lives inside me" (Hogan, ch. 21). Jace Weaver insists that the Native literature is devoted to the existence of the community, which is reflected in the recovery of identity by Angel (Weaver). Her plot structure shows that restoring indigenous knowledge is crucial to psychological strength and surpassing the tradition of abuse.

The reading also explains ecological exchange, in which the destruction of the environment directly affects mental sanity. To comprehend Hogan, Cheryle Glotfelty defines ecocriticism as the exploration of the correlation between literature and physical space (Glotfelty). The psychological disturbance of the characters is reflected in the construction of dams that break the natural cycles. When the rivers are diverted, the land suffers. The people project this agony: "the devastation and ruin that had fallen over the land fell over the people, too" (Hogan, ch. 15). The "



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hungry mouth of water " serves as a metaphor for consumption and loss, swallowing both animals and human history (Hogan, ch. 4). Finally, according to Hogan, the human psyche and landscape are united, and when the land is flooded, the people are similarly flooded internally. Land healing is therefore equivalent to self-healing, which confirms the indigenous worldview that ecological justice is also mental health justice. The novel contends that failure to pay attention to such connections is irreparably damaging to the soul, and that a complete view of survival requires treating the earth as an extension of the human soul.

Plant Dreaming as Diagnostic and Remedial Practice

In *Solar Storms*, Linda Hogan presents plant dreaming as a high-tech diagnostic device in Indigenous epistemology instead of a myth. Angel gathers important medical insight via the dreams instead of through medical analysis when Agnes becomes critically ill during the expedition towards the north. Angel describes how "inside my sleep that same night, a rust-colored root grew in a circle around itself" (Hogan, ch. 12). On awakening, Dora-Rouge recognizes the vision at once, and says, "Redroot. I believe that must be redroot... Wolfsbane, too" (Hogan, ch. 12). This dialogue legitimizes dream knowledge because it is as good as Western clinical diagnosis. Gregory Cajete further believes that Indigenous science is based on the intuitive connections with the natural world, where knowledge is acquired by taking part instead of observing it (Cajete 75). In contrast to Western medicine, where the practitioner and the patient are usually separated, Hogan's narrative indicates that healing is social and spiritual. According to Eduardo and Bonnie Duran, postcolonial psychology should be able to resolve the spiritual disintegration brought about by the effects of colonisation that are usually overlooked by Western clinics (Duran and Duran 56).

This intuitive knowledge is contrasted with the inertness of Western institutions in the north, as seen in the novel. When Agnes deteriorates, it is the case that Bush observes that "the doctor here won't help her... I'm getting you out of here" (Hogan, ch. 19). This is indicative of the shortcomings of enforced medical systems in remote Indigenous communities. Paula Gunn Allen highlights the fact that Native literature focuses on the restoration of feminine power and ancestral reverence as the key to healing (Allen 23). Plant healing is directly connected with lineage, as Angel has the capacity to dream of plants. Dora-Rouge explains, "I knew there'd be another plant dreamer in my family someday... I got it from blood, she said" (Hogan, ch. 17). This spiritual and biological transmission emphasizes the message that Linda Tuhiwai Smith is consistent in her claims of decolonising methodologies by reconstructing the indigenous knowledge systems that were once shunned (Smith 36). The learning cannot be abstract; it needs to be performed with physical activities and reverence. Angel has to go to locate the plants, observing, "I carefully moved earth aside and dug out some of the roots, thanking them" (Hogan, ch. 13).

This corporeal interaction is in line with Melissa Nelson, who considers the idea of original instructions when human beings actively engage in keeping life going by engaging in a respectful relationship with plants (Nelson 102). Community witness and survival are also parts of the healing process. Laurence Kirmayer emphasises the fact that the quality of healing practices among Aboriginal people is not focused on individual pathology but on communal and land-based healing (Kirmayer 198). The journey of the medicine that Angel undertakes is communitarianism, and Weaver refers to such literature as literature dedicated to community survival (Weaver 203). Finally, Hogan recommends that psychological wholeness be restored by reconnecting to ancestry through activities such as dreaming of plants. The text counters the superiority of knowledge that places Western science over Indigenous wisdom by confirming these dreams. What is being cured in the remedial practice is not only Agnes but also the disconnection between the people and the land. Hogan proves that health depends on the correct relations with the natural world and respect toward the gifts given by the generations through Angel's activities.

Animal Calling and Relational Healing

Solar Storms views healing as a relational process that extends beyond human beings to encompass the natural world. Dora-Rouge quotes an animal-calling song to Angel as she prepares her trip to Fur Island and claims the song, saying, "I know an animal-calling song... I will train you on it" (Hogan, ch. 4). This ritual confirms the epistemologies of the Indians who hold that communication with non-humans is essential to survival and psychological well-being.



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According to Thomas King, the identity of the Indigenous people is determined by stories and the relationships with land, and because of destroying the connection, people experience spiritual distress (King 29). She is attentive to the land, and when "wolves in the distance were singing, and their voices made a sound that seemed to lie upon the land" (Hogan, ch. 15). Specifically, Vine Deloria Jr. underlines that the Indigenous faiths lay stress on place and association with other living things rather than on abstract theology which supports the idea of healing presented in the novel which is associated with the connection (Deloria 67). The skill of Bush to move over the land is dependent on this kind of symbiotic relationship, where animals are not merchandise but family.

The bear coat is a physical transitional object that helps to bridge the gap between the contrasting past and present. Agnes wears a coat of glacier bear, which she killed, to free herself from suffering and state, "When I wear this coat, Angel, I see the old forests" (Hogan, ch. 2). The fur is a reminiscence of the memory and comfort, a carrier of ancestors. Once, Bush tells Agnes, "This coat is singing," indicating the spiritual vitality contained within the object (Hogan, Prologue). Shawn Wilson argues that Indigenous research and healing are ceremonial, with objects having a relational responsibility (Wilson 85). The coat is not merely a piece of clothing; it is also a place of history and sorrow that provides Agnes with a kind of psychologically confined space. Winona LaDuke has talked about the preservation of culture through traditional objects, even when there is dispossession, and that material culture provides spiritual strength (LaDuke 112). When Angel wraps herself in the coat, she inherits this covert heritage, implying that material things can ground the psyche when it is displaced and emotionally disintegrated.

The acknowledgement of animal signs enables the community to cope with loss and threat together. Following the death of Hannah, the villagers noticed that "There are even wolverine tracks all around Hannah's house" (Hogan, ch. 16). These songs mark spiritual bearing and collective trauma into ecological occurrence. Jo-Ann Archibald argues that the word Indigenous storywork entails listening to the messages of the land where animals serve as witnesses to what humans do (Archibald 54). The recognition of these signs in the community helps in shared grieving, and the burden of loss is shared. According to Kyle Powys Whyte, Indigenous climate justice models are based on collective responsibility and tracking environmental changes as social health indicators (Whyte 12). The wolverine songs are not premonitions but affirmations of the spiritual gravity held by society. Grande, Sandy, goes on to mention that Indigenous pedagogy demands that we learn to recognize these land-based indicators to decolonize the psyche, and a call to change individual pathology to collective ecological consciousness (Grande 45). This shared witnessing helps to ensure that trauma does not remain individual but is merely a constituent of a larger relational structure that requires communal healing reactions.

Land Dispossession as Psychological Wounding

Environmental justice theory examines the ecological degradation affecting marginalised communities unequally, depending on race, class, and socioeconomic status. According to Rob Nixon, slow violence refers to violence that occurs slowly and unobservably. In most cases, vulnerable populations are forced to go elsewhere without direct attention, leading to a crisis of representation (Nixon 2). In *Solar Storms*, the interference of dams with the natural processes is an analogy for the psychological interference of the characters. When the rivers are turned off, it hurts the land, and the people express it: "the devastation and ruin that had fallen over the land fell over the people, too" (Hogan 15). Robert Bullard points out that ecological equity demands that ecological advantages and disadvantages are evenly shared among societies, which would be difficult to achieve based on the historical exploitative ways (Bullard 15). Such an ecological imbalance implies that the safeguarding of the earth is the same as that of the human soul, since the drowning of the cultural memory when the government chooses to flood the Adam Rib is the drowning of the human soul "construct several dams" without consent (Hogan 3). Displacement is spiritual as well as physical, by breaking the connection between people and place.

The article also demonstrates the loss of the soul, in which the destruction of the environment has a direct effect on the stability of the mind. According to Val Plumwood, the mastery of nature tends to dominate groups of people who



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are allied to nature, resulting in a dualistic order (Plumwood 45). Hannah Wing is destructively violent and dissociative due to the annihilation of her world, which points to the reflection of ecological disproportion of the internal fragmentation. Bush does not just refer to the condition of Hannah as sickness but outlines it as a spiritual fragmentation where "your soul crying out... was a chilling sound" (Hogan Prologue). Vandana Shiva claims that women and nature are interrelated and that this process has been used by colonial development, thus resulting in mutual destruction (Shiva 22). In the case of flooding, Hannah is turned into an indifferent thing, and cold demonstrates how dispossession freezes the human heart (Hogan 9). Lee Maracle observes that Indigenous women tend to be exposed to the greatest effects of colonial trauma because they represent the sufferings of their peoples without collapsing (Maracle 67). This is confirmed by the novel in the way it frames an individual pathology as a collective spiritual crisis grounded in dispossession.

Finally, according to Hogan, the human psyche and landscape are united, and in the case of a submerged land, an internal flood of people occurs. Healing the land, therefore, becomes equivalent to healing the self, which confirms the indigenous worldview of ecological justice as mental health justice. Beth Brant points out that Indigenous peoples survive through the act of writing and witnessing to reclaim their narratives (Brant 10). The villagers' reaction to the flooding can be viewed as a group psychological means of overcoming feelings of despair. Bush makes a mourning feast in which she "put a piece of each of the different foods in her blue bowl for the spirits" (Hogan Prologue). Daniel Heath Justice points out that the Indigenous literatures are more concerned with community survival and continuation rather than with personal benefit (Justice 88). The novel states that neglect of these relationships results in permanent spiritual harm and calls on people to think holistically about survival so that saving the earth is also equivalent to saving the human soul.

Reclaiming Identity through Ceremonial Practice

The healing of solar storms requires ceremonial intervention to bring about psychological balance and deal with historical fragmentation. To move on with the loss of Angel, Bush throws a grieving feast, cooking music such as hominy and wild rice in dedication to the spirit and the child who has been taken away (Hogan, Prologue). Shawn Wilson claims that the Indigenous research and healing is a ceremonial activity, in which objects and actions present relational responsibility within a community (Wilson 85). This restoration is further consolidated by the giveaway after the feast, as Bush shares her worldly possessions, quilts, fishing poles, and other items with the people who attended the feast (Hogan, Prologue). According to Gerald Vizenor, this active engagement is what he refers to as survivance, which serves as an antidote to tragedy in the presence of the community, instead of as a victim (Vizenor 15). Eating together is raised to the status of a sacrament of togetherness that unites the people involved in a common responsibility. Therefore, the ritual serves as a mental box of mourning, reforming reality with the help of a ritual.

Community witnessing can enable the community to share the burden of trauma, so that no one is left alone. In the feast, people literally take away a piece of the sorrow of Bush and make personal grief a collective ecological and social ceremony (Hogan, Prologue). Melissa Nelson speaks about so-called original instructions, in which people contribute their active part to supporting life based on a respectful attitude to plants and animals (Nelson 12). The recognition of the community helps in grieving together so that the trauma is not seen as an isolated trend but rather a trend that belongs to a larger relational network needing communal healing reactions. Gregory Cajete states that Indigenous science is based on intuitive relations with the natural world, and knowledge is achieved through being involved and respectful (Cajete 45). Laurence Kirmayer points out that Aboriginal curing practices put more emphasis on community and land rather than individual pathology, and this underscores the importance of collective care (Kirmayer 22). Such witnessing compels the pain of displacement to be in the hands of many, not just a few.

Finally, the survival of Angel and the way in which she took care of her sister Aurora depict the passing of curing modalities to the future generation. Angel also gives the infant a name, Aurora, meaning new skin and mystery, and makes a direct breach of the cycle of abuse between the generations (Hogan, ch. 16). Linda Tuhiwai Smith demands that knowledge and future stories have to be decolonized to allow Indigenous sovereignty to take up its own





knowledge and history (Smith 12). Angel realises "something wonderful lives inside me," denoting internal healing with the help of ancestral belonging and internalised affection (Hogan, ch. 21). Paula Gunn Allen underlines that the ability to heal the Native literature and community survival depends on the restoration of feminine power and connection with the ancestors (Allen 50). This storyline shows that recovering indigenous knowledge is important in psychological resilience to ensure that the coming generation will inherit not the shatteredness that Hannah underwent. This new identity and hope are delivered through Aurora.

CONCLUSION

Solar Storms by Linda Hogan confirms the fact that Indigenous means of knowing are crucial to complete psychological healing. The novel shows that plant dreaming and animal calling are not symbolic but working therapeutic modalities through the experience of plant dreaming by Angel Jensen. They assist in regaining identity and healing intergenerational trauma because they help people reconnect with their ancestry and nature. Healing is described as a social activity that includes land, spirits, and the community rather than a solitary process that occurs internally. The storyline is evidence of the importance of restoring Indigenous knowledge to both mental strength and the ability to come to terms with a history of abuse. Moreover, the text provides an analysis of the future of Indigenous populations that are endangered by colonisation and ecological disharmony. The internal flooding of trauma of the ancestral lands is reflected by the flooding of the ancestral ones, implying that environmental justice is always mental health justice. Natural cycles destruction contributes to social disparities, and there is a need to understand that ecological destruction affects vulnerable populations unequally. The novel shows that ecological imbalances are elements of a greater, worldwide problem of human and non-human existence. Finally, a sustainable future is possible only when the entire population is more responsible for preserving cultural memory and the natural world. This paper highlights the fact that traditional knowledge should be considered a valid psychological intervention in various fields of study. By incorporating this ancient knowledge into contemporary settings, society will be able to solve the tremendous spiritual destruction of dispossession. Solar Storms is a call to readers to think about the possible long-term impacts of neglecting traditional knowledge and promotes the idea of a holistic approach to the world, in which the protection of the earth is the same as the protection of the human soul.

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RESEARCH ARTICLE

Soft Skills and the Memory – Emotion Nexus – A Study of Soft Skills and Memory in Preeti Shenoy's Fictions

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ABSTRACT

This paper examines the intersection of soft skills, memory, emotion and identity reconstruction in Preeti Shenoy's novels *The Secret Wish List* (2012) and *Wake Up, Life Is Calling* (2019). Moving beyond the conventional understanding of soft skills as merely professional competencies, this analysis positions them as fundamental human capacities, which are essential for survival, meaning-making, and self-renewal. Through a close reading of the protagonists Diksha in *The Secret Wish List* (2012) and Ankita in *Wake Up, Life Is Calling* (2019), the study demonstrates how emotional intelligence, problem-solving, adaptability, and resilience function as mechanisms for confronting and reinterpreting traumatic memories. Drawing insights from memory studies, the paper argues that the characters' journeys involve a critical rewriting of "memory scripts"—unconscious patterns from the past—to construct healthier, self-defined identities. Diksha employs assertiveness and decision-making to dismantle patriarchal constraints, while Ankita leverages emotional regulation and resilience to overcome the cognitive challenges of mental illness. By engaging in reflective memory work and cultivating emotional regulation, both protagonists overstep patriarchal oppression and mental illness by transforming their pain into agency. Ultimately, the paper underscores how Shenoy's narratives illustrate soft skills' role in healing, identity formation, and empowerment, offering broader insights into human potential for self-renewal.

Keywords: Emotion, Identity Reconstruction, Memory Studies, Preeti Shenoy, Resilience, Soft Skills



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INTRODUCTION

Soft Skills are not just skills for employment but for character building. The soft skills determine the character of a person which affects his or her way of life too. The decision one makes or the response of a person at a particular situation portrays that person's character. Soft skills play an important role in the race- 'Survival of the Fittest'. The study employs an interdisciplinary analysis connecting literature, memory studies, and cultural studies. In literary analysis, this study re-contextualizes memory, not just as storage of past but blueprint for future and soft skills not merely as workplace assets but as mechanisms of emotional self-regulation, adaptive coping, and interpersonal negotiation. Through qualitative literary analysis the character formation through memory and soft skills is identified. The proper handling of soft skills and memory makes the characters in the novel as round characters.

The contemporary novels became not just for reading but teach the life lessons and the importance of soft skills in difficult situations. In short, they formed a new genre named 'Soft skill literature'. Preeti Shenoy's novels are perfect examples for this. The story of the characters in her novel is not just mere stories but life teaching lessons. Being a popular Indian author, she focuses on coming of age stories and round characters, who are timid or innocent in the beginning and brave or cynical at the climax. Preeti Shenoy is known for her books that feature post-modern female characters. She is a Best-selling Author, Artist specializing in pencil portraits, Poet, Ex-basketball player, Blogger, TED x speaker and a Mother. She is specialized in portraiture and illustrated journaling and also conducts workshops related to it. ("Official Author Biography")

This study examines the significance of soft skills and memory as crucial tools of emotional survival and identity formation in the selected works of Preeti Shenoy. The study explores the soft skills such as; Problem-solving, Resilience, and Self-awareness, which empower characters to confront trauma, societal constraints, and emotional disruptions using memory as a helping hand for them. The novels analyzed include *The Secret Wish List* (2012) and *Wake Up, Life Is Calling* (2019). Both novels illustrate how the characters' emotional evolution is resulted by the development and application of soft skills and memory, and ultimately leading to self-realization and empowerment. The study limits itself to soft skills as internalized traits and not professional competencies and it does not explore all the novels of Shenoy due to **conceptual shift** in some of her works.

Problems-Solving and Self-Healing

Problem-solving skill enables different characters to transcend trauma and internal conflict in the story. This soft skill confronts and reinterprets the pasts of the characters like Ankita and Diksha in Shenoy's stories. In *The Secret Wish List* (2012), Diksha solves her central conflict of loveless marriage, by conscious evaluation of her desires and the systemic structures which were suppressing her. Diksha's past memory of being punished for kissing a boy becomes the emotional core of her present rebellion. This guilt was broken when she rethought her memory and this led to self-healing. This can be seen when Diksha explains her situation at the climax to her parents. "No, Ma. It was not a "physical relationship" as you say. I use air quotes to emphasize my point. 'It was just a kiss, and it wasn't the crime that you made it out to be. Had you left it, it would have probably died down on its own. It wasn't a big deal really. But the way you people twisted it, pulled me out of school, treated me like a leper, and the way you made it hang over my whole life, like the sword of Damocles, the way you never really listened to what I wanted, that was what has brought all this about.'" (SWL 250-251)

In this novel, *Wake Up, Life Is Calling* (2019), Ankita's fragmented and painful memories are not just flashbacks but active agents influencing her present decisions. Ankita's recovery from bipolar disorder is a cognitive-emotional process. She solves the "problem" of her past traumas by reframing them from negative to positive. The prequel of this book *Life Is What You Make It* (2011) portrays her struggle and overcoming process with the bipolar disorder which was gained as a result of her guilt provided by her memory of Abhishek's death (one-side love). As a sequel, in *Wake Up, Life Is Calling* (2019), Ankita starts a happy life, making new friends and doing new courses and living in an entirely different atmosphere. Everything was fine until a person from the past interrupts in her new normal life.



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Vaibhav, school love of Ankita, came back to her life. When Vaibhav came to know half –truth about Abhishek, he broke her with his words. This problem was solved when she confessed past to him in a new perspective. From a memory studies viewpoint, this suggests a rewriting of "memory scripts"—the unconscious behavioral patterns drawn from past experiences. For instance, Ankita avoided repeating the romantic entanglements in the college that had previously led her into emotional chaos. Also on listening to the story of Mrs Hayden, Professor of Ankita, her loss of father, husband and son, Ankita felt empathy for her. The guilt of Abhi's death vanished when Hayden told Ankita that they were not responsible for others' decisions and shouldn't worry about it. It was a time of enlightenment for her.

"For the first time I decided that what was important was my well-being. I would fight. I would not let my thoughts take over. If Mrs. Hayden could embrace life and go on even after all her losses, I could too. I would grab life and I would live it." (WULC 227)

Shenoy's characters reconstruct their fragmented memories as part of their problem-solving journeys. Both Diksha and Ankita solved their conflicts through their past memory. Here the memory which was once a weapon changed into medicine for the wound it created. Their problem-solving skills evolve through reflective memory work, which allowed them to respond rather than react.

Adaptability and Identity Reconstruction

Memory is not static. The past is continuously revised to serve present needs. Shenoy's characters exhibit adaptability by revisiting painful memories and integrating them into healthier identities.

The memory, which was very hard to digest for Diksha in *The Secret Wish List* (2012), once became nothing when she reinterpreted it. This reinterpretation healed Diksha, and her parents made peace with her. Diksha's adaptation is not just social but emotional. She learns to live outside the patriarchal constraints that once shaped her memories and suppressed her desires. Against her husband's wish, she started to learn salsa, drink alcohol, went on a vacation to the Maldives with Ankit and even made love with him. She got a fulfillment that she can do things for herself. From being a chicken who felt that she did not have an identity other than house wife, she became a fearless lioness who created her own identity by instituting a dance studio and becoming financially and emotionally independent. Finally, Diksha adapts to her new identity as an independent woman.

Ankita's identity is reconstructed not by erasing her past but by engaging with it through the lens of experience. After recovering from bipolar disorder, Ankita showed a green flag to her second battle by believing her negative thoughts. She self-doubted herself in most of the circumstances. Eventually, she overcame that, and reconstructed her new identity. Ankita's reinvention as a confident writer and speaker is made possible because of her flexibility in accommodating her past with her present. Memory studies propose that identity is an evolving construct, influenced by what we choose to remember and what we suppress or reinterpret. Ankita's identity in *Wake Up, Life Is Calling* (2019) is not merely a continuation of her former self but a newly formed self. She consciously constructed her new identity through selective remembrance. Ankita chose to remember her past failures not with shame, but as stepping stones towards success.

The new identities of Diksha and Ankita are more focused on self-defined worth rather than social validation. Empathy, resilience, and mindfulness are pivotal in their new transformation. These reshaped identities of Diksha and Ankita which are the byproducts of both memory and soft skills are more compassionate, confident, and emotionally intelligent.

Resilience: The Cornerstone of Emotional Survival

Resilience is considered as the outcome of emotional and cognitive soft skills. It is a defining feature across all protagonists of Shenoy's works. Whether it's Ankita's struggle with mental illness in *Wake Up, Life Is Calling* (2019) or Diksha's escape from a loveless marriage in *The Secret Wish List* (2012), all characters show the ability to bounce back from major life challenges.



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The capacity to rise above adversity, to find strength in memory without becoming trapped by it is called resilience in Shenoy's both the mentioned novels. Shenoy's fiction offers precisely this arc: survival through memory, mediated by soft skills. Though Diksha was trapped by patriarchal pressure, she broke it with the help of her soft skills, like being emotionally intelligent, confident in decision making and her problem-solving skills. Her powerful soft skills made her hard life soft and blossom again as it once was.

"As I take the tea to the drawing room, I have made up my mind. I cannot be a silent martyr anymore. I have been treated like a football all along—kicked first by my parents to Sandeep's court, and then kicked around by Sandeep all my married life. Now that I have finally found my voice and my grounding, it has created a furor.... I know now, so very clearly what I want and where I want to be. My parents have no choice but to accept. This is my life and I am determined now to really live it, to follow my heart's urging which I have ignored and tried to suppress for so long." (SWL 249)

Soft skills such as EI, confident communication, adaptability, problem solving and decision making created a new identity as a resilient self to Diksha. The fifteen years of bitter memories are now nothing to her. When she forgot her past and entered to present, she was born again to achieve success.

Ankita in *Wake Up, Life Is Calling* (2019), begins the novel feeling lost and struggling with self-doubt. She faces several obstacles in the upcoming phases of her life. The very own mind of Ankita was her great enemy. Everyone has their own inner voice, which supports guides and criticizes them. In Ankita's case, her inner voice is a symbol of pessimism. It never encouraged her and guided her on the right path. The inner voice of Ankita always showed her insecurities and highlighted her negatives. Not only her inner voice, but also the people and their words led her to depression again. Despite her bad thoughts, she overcame like a phoenix, coming out from the fire of pessimism and attacking the bad thoughts directly using affirmations and becoming a new normal Ankita mentally-well.

Ankita and Diksha, who once considered only their flaws and problems, shaped them later, with the help of supportive people and soft skills. Diksha's friends Gaurav and Tina, Diksha's mother-in-law and her son Abhay were very supportive of her in her resilient journey. In the climax, it was her mother-in-law who came as a savior from her parents' misunderstanding. She explained to them that the fault was on her son Sandeep, and not on her daughter-in-law. In the same way, for Ankita, her parents and Professor Hayden were very supportive in her journey towards resilience. Supportive people and their words can change the perception of the situation.

Resilience acts as both a psychological and narrative tool for rebirth and identity formation. The title of the novel, *Wake Up, Life Is Calling* (2019), is a symbolic representation of resilience. It calls the protagonist to wake up to reality and see the life that is waiting for her to crown. Life is not only about problems. It also holds beautiful pages that one should wake up and read. Ankita learnt to make clear decisions and understood that life is all about facing problems and solving, and learning from them. "Each of our mistakes makes us stronger. They are our life lessons. They make us grow. And I think that is the most important thing in life." (WULC 242)

Despite the overwhelming feelings of frustration and confusion, Ankita and Diksha didn't give up. Their willingness to confront their fears and insecurities is a manifestation of resilience. They learned to be affirmative, emotionally intelligent and confident, which led to resilience. From the lens of memory studies, Ankita's and Diksha's journeys are both healing and active identity formation through engagement of memory. Thus, both novels of Shenoy provide a powerful commentary on how soft skills function as deeply human capacities for survival, meaning-making, and self-renewal.





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SUMMATION

Soft skills can be called the basic human skills. Some may have a healthy level of soft skills, and some may have a low level of soft skills. The beautiful part of soft skills is they can be acquired at any time. It is not formed only at birth and only for some people. This study aims to show that soft skills and memory are essential even to normal people to undergo daily events and achieve success.

Now a days the meaning of past has connotatively changed into negative sense. People should use their past memory as a tool to build them in a constructive way. If one keep holding the bitter past, it will lead to an outpouring of emotions vigorously, and one may feel lost in the past itself. Allowing the past to let go and focusing on the present will lead to a bright future. The perception of the past can be shifted from negative to positive through soft skills. Soft skills help not only with perception shifting but also with emotional balance.

This is what happens for Ankita and Diksha in *Wake Up, Life Is Calling* (2019), and *The Secret Wish List* (2012). At first, they were trapped by the memory of past bitter events. This led to the arousal of self-doubts and other negative emotions. But they handled them with care with the help of Soft Skills and supportive people around them.

In *Wake Up, Life Is Calling* (2019), Preeti Shenoy portrays a protagonist who transforms remembered trauma into emotional strength through the cultivation of soft skills. Preeti Shenoy artfully blends memory and emotion, illustrating how soft skills serve as survival tools and identity-building mechanisms in the aftermath of trauma. Through introspection, emotional regulation, communication, and decision-making, Ankita reclaims authorship over her own story.

In *The Secret Wish List* (2012), Shenoy portrays a homemaker who finds herself in a dilemma whether she wants to live her life on her own or to satisfy the societal needs. Urged by a twist of events, a wish list is born, and this list changed her life entirely. On accomplishing those wishes, she found herself. Like Ankita, Diksha claimed authority over her story at the end by getting out of the patriarchal constructions. She determined to live a life she wished.

By combining Soft Skills and memory studies the study reflects the complexities of identity formation and emotional survival of the characters in Shenoy's selected novels. This framework enables a nuanced reading of Shenoy's work that avoids simplistic interpretations and instead highlights the emotional sophistication of her storytelling. Soft skills are thus treated not just as functional traits but as critical lenses through which readers can explore resilience, trauma, and transformation in contemporary Indian fiction

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RESEARCH ARTICLE

Reimagining Reality through Digital Science: A Critical Reading of Liu Cixin's *Ball Lightning*

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ABSTRACT

The shift from pen to thumb and paper to screen can be viewed as both a boon and bane in disguise. With the constant changing ideologies, can culture be preserved through the base of digital humanities? Though human beings are trying to adapt to the digital era, the process is challenging. Over the period of time, literature has been reflecting the realities of life. The genre of Speculative fiction provides an unblemished assessment of how literature gains the importance of discerning forward. This ultramodern perception is necessary to understand the environs in a humane outlook. *Ball Lightning* by Liu Cixin is a Chinese Science Fiction work which reflects the themes of memory, knowledge and ephemerality in terms of maintaining the line between technology and culture. The chief characters and trivial characters of the novel have equivalent reputation in developing the notions of digitalization. The weapons used in today's world for combats and other battles are replicated in the novel through the feature of ball lightning. The paper aims to bring the elements of digital trauma, conservancy of acquaintance, and traditional artifacts which the characters face in their lives as a form of acclimatizing to the veracities of life under the title, "Reimagining Reality through Digital Science: A Critical Reading of Liu Cixin's *Ball Lightning*".

Keywords: Digital Culture, Neutrality, Science Fiction, Strategies, and Social Concern



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INTRODUCTION

The world in a deep sense is a beautiful place to live in unless and until the synonym for beautiful is in an optimistic notion. Glorious changes which happen every day, every minute and every second may or may not be the same for all human beings. Some are too joyful about the events which happen in their life whereas the others are completely devastated by the incidents which take tremendous turns. Fighting for individual rights, human qualities, emotional needs, space for feelings, money and a stand for oneself, human beings look like puppets in the hands of its creator. Literature has been one of the most astounding genres which can imagine the unimaginable and create a world which was not even visualized as a fancy by the previous generations. From just being a genre of producing poems and plays to becoming one of the most realistic plotlines of the present, literature has come a far way.

The twenty-first century which is pragmatically called the 'digital age' with its inventions in artificial intelligence, cyborgs, robots and high-five technologies was once a matter of just imaginations by few writers in the past. People who criticized literature to just be stories are now witnessing it to be a seed for all the beginnings of productive things happening around the world. Anna Menyhért in her article, "Digital Trauma Processing in Social Media Groups: Transgenerational Holocaust Trauma on Facebook" comments on the process of trauma in digital age as, "In contrast with the earlier conception of trauma as fixed in time and space, unspeakable, and beyond representation and mediation, trauma in the digital age is considered multiply configured and represented, multidimensional, diverse, and shared in the digital space" (357).

The aim of the paper is to bring of the fact that how people are defeated by digital trauma which they can later defend through their education in the society and culture. The objective of taking Liu Cixin's novel *Ball Lightning* is to emphasize on the recent hard science fiction where the characters and their life are embedded with cultural trauma in the digital age.

The digital age refers to the fragmented changes which happen the society which was initially created for the betterment of the people. But as days pass by, just like the human beings who pay less attention for the negative sides of a creation, the digital age also witnessed few backdrops. The shift from paper to keyboards are akin to the shift from gasoline to stove and telephones to cellphones. Even though it looks like there is a wonderful improvement which is made convenient for the individual, its consequences are brought out much later in life. For instance, cellphones can be carried anywhere and everywhere for the purpose of an individual but its consequences are that the private life can be more dangerous. Human beings are not let in peace to enjoy their privacy and they are traumatized to be more available in both their professional and personal life. The so called 'digital trauma' began long ago when human beings were trying to figure out what it was to live in a world where machines have equal power as human beings. Ekaterina Haskins in his article "Between Archive and Participation: Public Memory in a Digital Age" says:

The intersection of contemporary remembrance culture and new media technologies presents a mixed bag of promises and problems. Storage and sorting capacities of the internet are certainly helpful in preserving, organizing, and linking vast amounts of data. Everyone can now engage in a free search for one's past and identity, becoming her own historian. Thanks to interactivity, virtually everyone can also leave an imprint on the fabric of public memory by sharing images and stories with millions of other users. (408)

Just like a coin which has two sides, the digital age also has two sides which are used as per conveniences. For instance, the creation of artificial intelligence, cloud computing, algorithm-based networks, cyberwarfare and cryptocurrency have made life more interesting and vibrant. The communication process is made easy, human beings can provide a life which they require and improve the standards of their life. But on the other hand, there are also few disadvantages which can be termed as privacy loss, too much of technical ideologies, risk of losing jobs for



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human beings due to robots. All these are the physical turmoil's which human beings face in reality. What really matters the most is the trauma which individuals façade due to the digitalization in and around the world. Adapting to certain changes in the world in terms of job is acceptable but adapting day-to-day life scenarios has become more challenging and risk-taking.

Liu Cixin's *Ball Lightning* explores into the juncture of scientific inquisitiveness, fascination, and the ethical uncertainty of technical encroachment. The novel commences with an intensely individual disaster, where the adolescent protagonist Chen viewing his parents demises by the enigmatic occurrence of ball lightning, which drives him into an enduring expedition to comprehend it. Liu usage of this foundation to discover how disturbance can fuel an unremitting quest of information, often at the charge of mortal construction and moral lucidity. The novel masterfully interlaces hard science with theoretical philosophies, bestowing a near-future biosphere were quantum model and martial determination strike in volatile and habitually distressing behaviors. Stanley Singer in his article "Ball Lightning-The Scientific Effort" defines the terms as "Ball lightning is a luminous globe observed in nature, most often in warm months when thunderstorms are frequent. The fiery ball may appear after lightning, either near the impact or at some distance from it. In main origin of the ball and its disappearance are not observed because of its most globe floats with a moderate speed sometimes compared with that of a walking. It occasionally enters dwellings by way of a chimney or through or window, passing near startled" (5).

As the story discloses, Chen intersects a concealed investigation program, and the tale swings from private tragedy to universal insinuations. Liu analyses the weapon of knowledge and the emotionless fairness with which logical detection can be designated for annihilation. Other minor characters like Lin Yun, a merciless military physicist, symbolize the novel's stiffness between understanding and power, emphasizing the significances of appreciating development over mortality. Eventually, *Ball Lightning* advances disturbing interrogations about the restrictions of scientific consideration and whether the hunt of truth vindicates its cost, proposing an intensely philosophical replication entrenched within a fast-paced and ardently reverberating chronicle.

Ball Lightning discovers the connection of unconventional physics and anthropological emotion which climaxes how extremely technology can ensnare the situation with distress. However presumably an effort of hard speculative fiction entered around the secretive spectacle of ball lightning, the description is essentially focused by a peculiar tragedy. The harm of the protagonist's parentages in a lightning assault on his birthday. Pierre Nora observed, "Modern memory is, above all, archival. It relies entirely on the materiality of the trace, the immediacy of the recording, the visibility of the image" (13). This instant is not only a chronicle reagent but also a demonstration of anything can be implicit as digital or scientifically interceded strain. The human mind is clear and altered by the intellectual services of knowledge and the emotionless logic of scientific evolvement.

The impression of digital trauma in this framework is not about the web or social medias, rather about the technique of progressive discipline and technology, predominantly numeral and quantum-level singularities that interconnect with psychosomatic experiences. Chen observes the eradication of his parents by a ball lightning occasion, and the revulsion of this happening becomes a benevolence of programmed trauma, manipulating each judgement and eventually motivating him to bestow his life to the education of ball lightning. As Chen explains the state as, "This time, though, the arc came in through the wall, emerging like a spirit from an oil painting of a carnival of the Greek gods. It was about the size of a basketball... its flight path was erratic" (BL 4). This result is symbolic of how trauma can get entangled with a procedure of technical fascination. He does not lament in an outmoded sense, nor prepares for therapy and expressive termination. As an alternative, he affects the incident as a thoughtful problem to be cracked, a riddle encrypted in the linguistic of physics and electromagnetism. Trauma becomes not only an individual damage but a systematic and unidentified to be unravelled. By doing so, Liu Cixin imperceptibly converts emotional anguish into scientific inquest.

The idea which Liu exemplifies through Chen is a philosophical disaffection from conventional demonstrative dispensation. The character's sensitive world is sieved through the lens of equipment and physics, to the amount that



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even his reminiscences of his parentages become the theme of technical clarification. The ball lightning that executed them is not extended simply as a climate event but a mysterious phenomenon to be replicated and understood. This technical reframing becomes a surviving instrument, and also partially dehumanizing. As the novel advances, Chen gradually drops trace with the mortal measurement of his expedition. As he cites his father's words as, "The key to a wonderful life is a fascination with something" (BL 13). His emotional trauma is digitized, emblematically twisted into data opinions, investigation objectives, and martial submissions. There is no accident that abundant incidents of the novel takes residence in top-secret investigation amenities and armed labs, places that arrange rationalism and efficacy over mortal sensitivity. These surroundings are in consequence the allowances of Chen's own consciousness, sterilized and hyper-rational, where sentiment is either repressed or deciphered into unlawful cleverness.

Liu's interpretation of digital trauma becomes supplementary multifaceted with the overview of Lin Yun, a warrior who also has her personal stressful history and an equally compulsive search of weapon-zing normal singularities. She and Chen are echoes of each other, both preoccupied by previous procedures and both discovering comfort, or minimum determination, in the balanced examination and mistreatment of disparaging forces. Lin's trauma, like Chen's, is not straight articulated in demonstrative relationships but is instead channelled into a military philosophy that clinches eradication and cold effectiveness. Her trauma is explained as, "I'll admit that weapons do possess an indiscernible allure, but it's built on top of murder" (BL 85). This common agenda generates a frightening interaction between the characters and replicates a wider traditional explanation on how systematic growth, particularly in grounds with armed impending, can both disguise and amplify the belongings of individual trauma.

The factors emerged in these characters is a kind of response circle between trauma and technology. The more they try to comprehend or connect ball lightning, the more they become inaccessible, expressively undersized, and disconnected from any expressive human joining. Their trauma is not rehabilitated but as a replacement becomes a proposal for the missiles they benefit to generate. As he states, "For the first time since deciding to devote my entire life to this thing, I felt like the world was paying attention, too" (BL 28). The ball lightning scheme, which originally assures accepting and termination, eventually leads to the growth of quantum artilleries proficient of removing the substance in itself. The termination of Chen's expedition is not explanation or reconciliation but the comprehension that his technical effort has been designated by a reason of devastation, a judgement instinctive from his personal distressed essence but exaggerated by national supremacy and technical determination.

This conversion replicates a noticeably contemporary form of disturbance, one which is not merely psychosomatic but universal. It is suffering that has been integrated into the equipment of technical expansion, where the demonstrative ancestries are elapsed or overwritten by mechanical linguistic and administrative areas. As the narrator says, "People like him are suited only to the sort of work that will be done entirely by machines in the future" (BL 32). Liu does not unambiguously sermonize this process, but the insinuations are strong. The novel finishes with Chen inquisitorial of the track he has taken, comprehending that in demanding to comprehend the strength that murdered his parents, he has donated to roughly far more hazardous and uncontainable. This is the core of digital trauma, the renovation of individual agony into data and efficacy, and the forfeiture of expressive preparation in the appearance of intellectual authority.

Additionally, Liu Cixin's narrative style underlines this leitmotif. His style is frequently experimental, occupied with comprehensive explanations of experimentations, equivalences, and martial procedures. This style generates a hostility consequence, illustrating the reader into the identical rationalist background that traps the characters. Expressive scenes are offered with nominal feeling, as if even the chronicle itself is stressed to coherent sorrow in a world subjugated by systematic judgment. The consequence is a novel that senses expressively unsympathetic yet intensely disconcerting. The trauma is contemporaneous, but it is diverted through a numerical lens, concentrated lucid only over science, and exposed of its emotional nearness.

Additional imperative coating to deliberate is the traditional background in which Liu is writing. In post-Mao period of China, prompt transformation and scientific progression have repeatedly come at the charge of individual



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detriment and demonstrative subjugation. In this framework, *Ball Lightning* can be delivered as an assessment of how state-sponsored technical drives captivate individual pain, revolving secluded anguish into public convenience. The novel's representation of investigation organizations and martial labs, along with the characters peculiar conversions, advocates an observation on the method individual trauma is collectivized under the tremendous improvement. Chen describes the quality of Lin Yun as, "It gave me a funny feeling that the first woman I felt something for talked so calmly of bloodshed and death like other women her age talked of makeup" (BL 84). Trauma does not evaporate rather it is repurposed for the situation, digitized according to the morals, and weaponized in army forces.

Ball Lightning about enigmatic corporeal phenomena is a consideration on the customs that trauma can be determined in technical investigation and technical improvement. Liu Cixin boons a visualization of digital trauma in which emotive pain is deciphered into the etymology of statistics and algorithms, unvarnished of its mortality, and regenerated as an instrument of supremacy. Through the attractiveness of Chen and his expedition from peculiar loss to technical fascination to principled reckoning, the novel arranges unadorned emotional costs of such an alteration. Though the narrator comments on Chen as, "He said he could devote a lifetime to its study...People are like that—they sometimes become fascinated with something without knowing it and are unable to get rid of it their entire life" (BL 46). It is a poignant examination of what transpires when the mortal soul is endangered to the cold examination of the digital contemplation, and it requests whether considerate through knowledge can ever truthfully brand us complete.

In Liu Cixin's *Ball Lightning*, traditional artifacts perform faintly yet eloquently throughout the story, performing as inaudible spectators to the clang between the antique and the recent, the individual and the technical, the social and the scientific. Although the novel is essentially an effort of tough science fiction absorbed on progressive physics and investigational weaponry, it is not empty of national commemoration or representative remnants of ritual. These artifacts, whether bodily objects, recollected ceremonies, or indirect standards, aid to pounded the section in an endurance that lengths outside the atmosphere's distinct pursuits. The most straightaway reverberating outmoded artifact in the section is the birthdate cake Chen obtains on the evening of the catastrophe that defines his life. Though ostensibly unexciting, the cake is not just a Western convention implemented in modern China but also a representation of family, festivity, and life's growth. Its unexpected obliteration during the ball lightning attack becomes a distressing disagreement, suggesting not only the ferocious interruption of changeable natural armies but also the disturbance of a national and domestic ritual.

This instant severs Chen from the customary world of household and emotion, pushing him into an innovative world administrated by knowledge, judgement, and generalization. Yet, the remembrance of that second relics anchored in the artifact of the cake, an ordinary item that loiters in his thoughts extended after his parents are gone and that signifies a misplaced demonstrative and cultural solidity. As Chen says, "The table that had the birthday cake was still there...Exhausted, I sat down on the sofa" (BL 15). Another significant layer of traditional occurrence can be found in the divergence between the disinfected scientific situations and the more meek backgrounds Chen encounters. Initially in the novel, passages that take dwell in his hometown, designated with orientations to usual life in a Chinese township or city neighbourhood, transport with them the consistency of traditional life. However Liu Cixin does not lodge on these settings, the dissimilarities with the unfriendly, untried spaces of workshops and martial connections intensifies their cultural cost.

The implements, cabinets, and even the elder people who colonize Chen's initial memories symbolize a lower steadiness that is at probabilities with the troublesome countryside of the ball lightning singularity. These artifacts of ordinary outdated life, from timber furniture to handwritten minutes to acquainted foods, are dominated by the unindustrialized supremacy of microelectronic apparatuses and hypothetical replicas, but they are not completely removed. "The mirror should not have been that clean...The water from the iron tap should have been rusty, but what flowed out was perfectly clear" (BL 16). Their occurrence, even if it is insignificant, edges the broader renovation that Chen endures as he travels away from a life entrenched in traditional collective constructions into one subjugated by science and martial judgment. In many of Liu's metaphors of scientific research accommodations,



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there is an inherent dissimilarity between the contemporary and the traditional. The deficiency of traditional Chinese building, art, or viewpoint in these settings is not unintentional, it highlights how technical advancement in the novel is manifested by a detachment of the old. The cultural simplicity of these cosmoeses, conquered by unsoiled lines, brass surfaces, and numerical screens, purposes as a type of anti-artifact space.

It is not an objective place where customary artifacts are misplaced, it is a residence where their absenteeism is symbolic of a greater philosophical shift. In this background, the infrequent seconds when traditional artifacts do perform like as a teacup, a canvas, or even the method a character reminisces an ancient sonnet or story becomes extremely exciting with significance. As Chen says, "Once again I sat in that house until dawn on a stormy night, and once again I numbly left home" (BL 21). They perform as inaudible prompts of what has been left after in the hunt of information and control over environment. Lin Yun's charisma also offers a lens through which the tightness between convention and modernism is discovered. Though she is a creation of the military-industrial compound, accomplished to think in relationships of approach and annihilation, her private history mentions at a supplementary intricate connection with the past. Her name itself is customarily Chinese, and however the novel offers rare realistic facts, the endurance and chastisement she displays resonance Confucian ethics of duty and detriment. In this sense, her physique and behaviour become existing artifacts of an elder principled organization, even as she contributes in the most progressive and hazardous systematic investigation.

The fight inside her, between a sympathetic of hereditary ethical cypher and an afresh obligatory logic of technical ruthlessness emulates the wider conflict among outdated values and scientific determination that runs complete the novel. Even in linguistic it assists as a kind of artifact in Liu Cixin's work. Though interpreted into English, the innovative Chinese prose hires a terminology that often lures from conventional foundations. Liu's selection of names, symbols, and imageries sometimes resounds with antique Chinese fictional and philosophical civilizations, implanting coatings of denotation that faintly permeate the chronicle with an intellect of cultural complexity. This etymological dimension supports the knowledge that even in a forthcoming subjugated science and technological world, the heaviness of past and custom is not completely discarded. It remains in how characters communicate, how they recall, and how they make wisdom of their understandings.

One of the supreme and effective instants where customary artifacts allegorically re-emerge is near the end of the novel when Chen commences to inquire the ethical significances of his work. "I realized that beauty for most people is characterised by fragility and powerlessness. True beauty needs to be supported by internal strength" (BL 449). The interior fight he experiences, his abrupt requirement to imitate on truth and false, on the denotation of lifetime and demise can be understood as a re-emergence of customary logical apprehensions. These are not interrogations that knowledge alone can react, and in rotating to the innermost, Chen re-engages with a method of self-examination that is intensely entrenched in Chinese metaphysical civilizations such as Daoism and Confucianism. However he never openly quotes these schemes, the plain act of replication in the expression of technical power establishes a reappearance to an elder method of intellectual thinking. It is more like the artifacts of custom, however not actually existent, restate themselves over thought and integrity.

Liu Cixin's treatment of traditional artifacts is consequently not unconcealed or sentimental. He does not overemphasize the ancient or forefront customary cyphers in the way some writers might. As a substitute, he permits them to happen at the side-line of his tale, entrenched in reminiscences, indirect in behaviours, or juxtaposed in contradiction of the hyper-modern surroundings of his section. Their inconspicuous company marks their representative meaning even extra commanding. They characterize a cultural remembrance that trashes to be entirely exterminated, a generous of ethical scope or demonstrative newscaster that continues even when flabbergasted by the flow of technological shrewdness. This stiffness between the ancient and the present is not determined by the conclusion of the novel.

Chen is jammed in a liminal universe, designed by a disturbance born from environment but inspected through discipline and progressively preoccupied by moral enquiries that knowledge alone cannot report. Traditional



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artifacts, aid not as apparatuses or substances but as delicate notices controlling the reader to appreciate what is on hold in Liu's dream of advancement. They prompt us that after every technical discovery lies a human being moulded by past, philosophy, and reminiscence, and that the forthcoming that is shaped cannot discharge the shades of the history, even by the weapons and digital history of the world. As Susan and Myriam in their article "Awe and the Interconnected Self" says, "The current emphasis in society in on a separate, egoic self, consumed by the digital world. Culture has an influence where attention goes and may have undermined our relational connection to the outer world" (6). The idea of digitization in today's world has made human beings to choose wisely between the elements of life. Everything is becoming more technical, right from financial ideas to production and consumption. During these developments process, human beings are forced to submerge their emotional turmoils due to the fast-developing process. Just like all our memories having a place in hard disks and screens instead of books and albums, culture is also taking a place in closed digital world. It is necessary for human beings to state the differences in life and take a formulate step along with digitalization.

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RESEARCH ARTICLE

The Desert as a Sacred Landscape: Mysticism and the Hero's Spiritual Transformation in *The Alchemist*

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ABSTRACT

This research investigates the spiritual and mystical implications of the desert in Paulo Coelho's *The Alchemist*, contextualising the book within extensive theological, literary, and philosophical discussions of landscape and spirituality. Utilising Joseph Campbell's *The Hero with a Thousand Faces* and the mystical notions posited by scholars like Evelyn Underhill and Crossfield Happold, the study examines the desert's role as both a narrative impetus and a spiritual mentor in Santiago's transforming odyssey. Modernity often reduced the desert to a realm of invasion and imperial expansion; yet, the book reinstates its former religious significance as a locus of retreat, cleansing, and divine contact. The study traces Santiago's journey through the phases of Departure, Initiation, and Return, illustrating how the desert influences his psychological and spiritual development. Instead of being a hostile place, the desert is a loving yet challenging force that pushes the main character toward a mystical connection with the "Soul of the World". Through quiet, seclusion, and introspection, Santiago achieves self-realisation, reconciles with parental authority, and finds that genuine richness resides not just in financial prosperity but in spiritual enlightenment and inner change. In the end, the publication says that *The Alchemist* reaffirms the desert as a holy place that may bring back spiritual awareness in a time when people don't believe in God. Coelho contests postmodern disillusionment by portraying the phenomenal world as an expression of divine presence, so validating the persistent human need for transcendence, unification, and connection with the Absolute.

Keywords: Desert spirituality; Mysticism; Nature mysticism; Hero's journey; Spiritual quest; Landscape and identity; *The Alchemist*, Paulo Coelho.





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INTRODUCTION

The significance of the desert shifts from one period of time to another. After it has been praised as a place of spiritual and mystical experiences during the 3rd and 4th centuries, the desert lost such significance during the modern era when, says David Jasper (2004), it was considered as a mere test ground into which brave people enter to serve the different projects of the Western “Empire” (p. 56). However, he adds, the “desert wind is again blowing in the unlikely wastes of postmodernity” (P. 57). The reason for this revival, according to Lewis Mumford (1961), is that desert admirers wish to find a refuge from the religiously-alienated and spiritually-distanced societies and dystopian “cities of the dead” within which they live (p; 57-59). These desert lovers provide evidence that religious conviction which is rejected by critics, such as Zygmunt Bauman (1997), as being improper for the mobile contemporary society, can on the contrary, be achieved in mobility and wandering in secluded places such as the desert (p. 172).

Furthermore, having acknowledged the sublime importance of place in the lives of people, Belden Lane (1998) states that the place and the landscape where the individual lives define the way he envisions himself and the Divine. Besides, in “The Spirit of Place”, D. H Lawrence (1964) reveals the acute influences which accompany the man-environment relationships by insisting that place influences one’s ideas and consciousness (p. 15-17). Yet, Says Belden Lane, those who live in the post-enlightenment society, can hardly “grasp” the correlation between spirituality and landscape essentially because these individuals are more concerned with movement than they are “bereft of rituals of entry that allow us to participate fully in the places we inhabit,” and because the individual freedom led progressively to the loss of any heed to spiritual traditions and the way of seeing the world (Lane, 1998, p. 10). In due course, Lane (1998) expresses a sense of anxiety toward the idea that nowadays spirituality is becoming sterile and non-existent nearly in every place in the world (p. 10). Henceforth, critics and theologians explain that experiences in the desert landscape can provide a remedy for the spiritual loss within the human soul (Lane, 1998, p. 20).

In addition to these theologians, contemporary literary figures such as Paulo Coelho, seek to inform that contrary to the prevailing secular beliefs during the contemporary age, God exists in every space and has a word to say in the life of every individual. Many of his works tend to pass the message that man needs to work, displace, contemplate, and search ceaselessly to re-establish belief and harmony with God. Hence, in *The Alchemist*, Coelho illustrates that the desert landscape can afford a valuable help for the one who looks for a mystical apprehension of the Ultimate God.

The hero’s Transcendent Journey Through The desert

In *The Alchemist*, Paulo Coelho’s desert setting facilitates and enriches the protagonist’s journey. Due to the desert experience, the youth’s journey culminates not only in a material reward, but also in a spiritual growth. Following Joseph Campbell’s model of the quest pattern which he depicts in *The Hero with a Thousand Faces*, this chapter foregrounds the important role that the desert plays in every phase of his journey. In addition, it draws inspiration from the theory of mysticism in order to read the desert as a land which enhances spiritual awareness. With particular focus put on “nature mysticism,” which is characterized by a sense of the “immanence of the Other or God or soul in nature,” (Happold, 1970, p. 43) the study will reveal the way the serenity of the land, its silence and peace push the individual to ponder upon the reality of the human self and the universe, seeking higher states of being. By so doing, it will show that the Desert Fathers’ account of the desert as a holy place where one can reach beyond the world of the senses and feel the presence of the transcendent still intrigues contemporary authors such as Paulo Coelho.

Taking into consideration the world-view of *The Alchemist*, one may argue that the author’s representation of the desert and his appeal for spiritual experiences parodies the ongoing process of secularization which is prevalent in contemporary literature, culture and theory. Coelho’s narrative is about Santiago, an Andalusian boy who embarks on an archetypal journey of quest to the Egyptian Pyramids to find a hidden treasure. His journey solicits sweet encounters with people from various races and backgrounds. He meets a gypsy woman, a king disguised in the form



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of an ordinary citizen, a thief who steals all his earnings, an English man who enlightens him with valuable ideas of alchemy, the old wise alchemist, and most important of all, Fatima, the beautiful desert woman with whom he falls in love. Along his path, Santiago is robbed three times, he is captured by a desert tribe and receives many threats of death. Yet, eventually he succeeds to communicate with the universe, to turn himself into wind and to be more powerful than he has ever been before.

During all these experiences, the desert stands as a supporter and a recorder of how he changes from a naïve person to a wise one. Far from being an enslaving power, the desert heightens awareness of the greatness of the world. Basically, it is filled with God's presence and is ready to satisfy the heart which believes and reads all its signs, recalling the experiences lived by the Christian monks during the Monastic Movements when they retreated "to wild and undeveloped landscape, seeking new meaning along the outer margins of familiarity" (Lane, 1998, p. 147).

Basing his argument on the different world myths, Joseph Campbell (1968) shows the physical, psychological and even the spiritual importance of the heroic journey taken away from one's home and family; a journey during which the adventurer grows more self-aware. Campbell divides the quest pattern into three major phases; Departure, Initiation and Return. In fact, this pattern is adequate to discuss the role of the desert in *The Alchemist*, knowing that its land acts as an agent that defines the course of the events.

At the beginning of the novel, the boy is portrayed as a simple shepherd whose father wants him to become a priest. Yet when he receives the dreams about the treasure, his heart is filled with new ambitions leading him to seek their realization. These recurrent dreams are the "Call to Adventure" which comes from the Soul of the World. According to Campbell (1968), when the call is launched, "the familiar life horizon has been outgrown; the old concepts, ideals, and emotional patterns no longer fit; the time for the passing of a threshold is at hand" (p. 51). So, because the destiny "has summoned the hero and transferred his spiritual center of gravity from within the pale of his society to a zone unknown," Santiago decides to take a different move in his life and go in search of his treasure and destiny, defying the will of his father (p. 58).

Before he is ready to cross the "First Threshold" away from Spain into the unknown tracks of the African desert, the boy falls into hesitation and indecisiveness.

Eventually, he tells his father that his dream lies in travel and not in becoming a priest. The father agrees immediately because he wants him to become more than these priests who "come in search of new things, but when they leave they are basically the same people they were when they arrived" (Campbell, 1968, p. 9). Pertinent to this, Paulo Coelho in an interview in 1998 states that:

"At the threshold of our quest, the fear of stepping into an unknown world and the desire to stay at home lie in wait for us, it is a crucial moment of initiation. But we cannot stand on the threshold forever. We must dare to move; only corpses do not move. Life is movement." (1998, p. 35)

Hence, when Santiago commits himself and gets ready for the new challenges, crossing the "First Threshold" and leaving behind the safety of home, he is helped by few persons. That help is not supernatural and can be recapitulated in the few pieces of advice he receives from the Gypsy woman who urges him not to give up because "dreams are the language of God" (p. 56), and Melchizedek, the disguised man who claims to be the King of Salem who persuades him that "when you want something, all the universe conspires in helping you to achieve it" (p. 23). This advice spreads hope in the boy's heart because he feels that wherever he goes the universe will take care of him. Gradually, he enters the "Initiation Phase" which Campbell (1968) considers, as an important phase during which the adventurer is put into various tests and undergoes "difficult tasks" before he is forged as a powerful hero (p. 97). The adventurer, during this phase, needs to wrestle against the fiends of hesitation, fear and indecision. The first obstacle he confronts during "The Road of Trials" is in Tangier, the crowded city where he is robbed by a thief (Coelho, 1992, p. 40). That accident leaves him desperate and heartbroken: "he was in a different country, a stranger in a strange land, where he couldn't even speak the language... he had nothing, not even the money to turn and start everything





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over" (p. 41). Hence, he finds himself obliged to accept a job which he does not like in the crystal merchant's shop. When he is kidnapped with the alchemist by tribesmen who ask him to turn himself into a wind or face death, Santiago faces a new obstacle. It is at this point that he gets supernatural aid from the desert, its sand, sun and wind to transform into Simum wind (p. 156). The last trial he faces is when he arrives at the Pyramids where he is beaten and once more robbed of his gold by two men (P.170). Interestingly, none of these troubles brings him down or prevents him from hearing that strong voice telling him that trials and errors are part of the process of becoming stronger. To borrow from Campbell (1986) : "the original departure into the land of trials represent[s]only the long and really perilous path of initiatory conquests and moments of illumination"(p. 17). For this reason, Santiago moves on and never gives up.

To become a true hero, to fulfill his dream of an unforgettable legend, the archetypal hero needs to complete all the stages of the "Initiation Phase" because the different tests and trials through which he will pass challenge him deeply before he begins his transformation "slaying" all the handicapping hindrances on his road (Campbell, 1968, p. 97). Hence, in addition to the abovementioned difficulties, the desert tests the boy's maturity and his degree of determination to achieve his goal. Yet, the alchemist ensures him that the desert does not do so with a bad intention, rather, for the sake of training him. For this reason, the desert landscape is never demonized or looked at as an antagonistic space. On the contrary, the alchemist tells him that the Soul of the World is manifested in the desert and before his dream is realized, it tests everything that was learned along the way. It does this not because it is evil, but so that we can, in addition to realizing our dreams, master the lessons we've learned as we've moved toward that dream. That's the point at which people give up. It's the point at which, as we say in the language of the desert, "one dies of thirst just when the palm trees have appeared on the horizon... Every search begins with beginner's luck. And every search ends with the victor's being severely tested. (Campbell, 1968, p. 139)

Paulo Coelho (1992) passes the message that every personal legend is full of tests and obstacles. Yet, every test is an important step in the spiritual growth. Pertinent to this, the boy states that "when I have been searching for my treasure, every day has been luminous... I have discovered things along the way that I never would have seen had I not had the courage to try things that seemed impossible for a shepherd to achieve" (p. 137).

By choosing to become a travelling shepherd pursuing a personal destiny, the boy has to separate from his father at an early age. However, during his journey, he meets the alchemist, the man with whom he reconciles his needs for a constructive father in a step which Joseph Campbell (1968) names "Atonement with the Father" (126). Significantly, then, meeting with the alchemist is one of the blessed gifts of the desert for the boy because since their encounter, he acts out as a caring father and teacher for him. He teaches him to understand many realities of the world and how to inspire power from the inward to understand the realities about the existence of the Ultimate Being. Duly, says Campbell (1968):

"The problem of the hero going to meet the father is to open his soul beyond terror to such a degree that he will be ripe to understand how the sickening and insane tragedies of this vast and ruthless cosmos are completely validated in the majesty of Being. The hero transcends life with its peculiar blind spot and for a moment rises to a glimpse of the source." (p. 147)

The alchemist, who learns how to communicate with the desert natural environment and masters how to transform metal into gold, plays a great role in helping him focus more on his objective. In discussing the elements of magical realism in *The Alchemist*, Stephen M. Hart (2004) considers that the character of the alchemist is reminiscent of Melquiades in Gabriel Garcia Marquez's *One Hundred Year of Solitude*, in the sense that he is "the sage man who knows the answer to all of life's questions" (p. 305). As an example of his support, when the boy is about to give up on his quest in favor of stability with Fatima, the alchemist interferes and convinces him that she is a woman of the desert and will await his return because true "love never keeps man from pursuing his destiny. If he abandons that pursuit, it's because it wasn't true love... the love that speaks the Language of the World" (Coelho, 1992, p. 126). When the two are having their trip through the desert toward the pyramids, the alchemist teaches the boy to mediate on the mystery of the desert in silence and read its omens. This echoes Joe Guse's (2007) proclamation that "until we



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make peace with our parents we are unable to move forward into the next more rewarding periods of our lives" (p. 13-14).

Due to the presence of the alchemist, the sustenance of the desert, and the feelings of love which he carries in his heart, the boy's journey ends up in blessedness, rupture and contentment with the self which realizes its goal. This becomes clear when he reaches the pyramids and kneels down to thank God for "leading him to meet a king, a merchant, an Englishman, and an alchemist. And above all for his having met a woman of the desert..." (Coelho, 1992, p. 169). The boy acknowledges that the other true treasure which his journey grants him is knowledge. This knowledge and wisdom are the "Ultimate Boon" of his trip and his weapons in facing the hostile forces of life.

So, it can be said that the boy's heroic journey through the desert is very particular because it culminates with more than one reward. In other words, Santiago does not only find the hidden treasure of gold, but also a more precious one, which is knowledge of the divine spark which lays dormant in him. In this context, C. Happold (1970) says "it is the chief end of man's earthly existence to discover and identify himself with his true self. By so doing, he will come to an intuitive knowledge of the Divine Ground and so apprehend Truth as it really is, and not as to our limited human perceptions it appears to be" (p. 143). In that sense, the desert becomes a location which evokes "retreat and spiritual growth," when wandering its tracks, the boy enters into a state to mystical enlightenment and illumination (p. 143).

About the "Ultimate Boon," Joseph Campbell (1968) adds that after all the experiences through which the hero goes: "the stature of the divinity that summons to his highest wish increases, until it subsumes the cosmos. Finally the mind breaks the bounding sphere of the cosmos to realization transcending all experiences..." (p. 190). Similarly, in *The Alchemist*, the journey through the desert teaches Santiago to understand the language of the world in the mere time he spends contemplating its mysterious tracks. After that, he can turn to his family and natal home well-equipped with knowledge and wisdom about life and the Ultimate Creator.

In fact Santiago's spiritual experience can best be understood through explanation of mystical insights. Edward Mercer (2008) admits that the definition of mysticism is by no means an easy task. Yet to achieve a close clarification of its significance, Mercer pinpoints that a true mystic is the one who aspires to unite with the "Real," "super-sensuous," "super-rational" and "unconditional Absolute" (p. 8). To be more precise, a true mystic does not mistake the possibility of sensing the Absolute's presence in nature with the idea that every natural element in it is endowed with a spirit, which is basically a primitive "shaman" belief and a dysfunctional use of mysticism (Bharati, 1976, p. 15). Rather, a mystic man believes that the phenomenal can serve to experience the transcendental.

Evelyn Underhill (2002) notes that mystics, whom she considers the pioneers of the spiritual world, have succeeded in what all others failed and established "immediate communication between the spirit of man, entangled as they declare amongst material things, and that only Reality that immaterial and final being, which theologians call God" (p. 4). Mysticism, does not only prove the existence of the Absolute but advances the belief that "knowing and finally attaining it" because knowledge is not limited to sense impression (Underhill, 2002, p. 23). When exercise of "pure reason" could not offer a great knowledge of this world, knowledge-seekers started to use "natural mysticism" as an instinct for the Absolute "latent in man" (p. 13). In fact, ideas akin to the mystic ones have principally been initiated by the theory of Platonic Idealism which acknowledges the existence of a supreme perfect realm of knowledge. One of the basic tenets of this tradition passed down by Plato, the father of Western philosophy, is to save the phenomenal, "to discover the eternal in the temporal, to know the truth hidden within the apparent, to glimpse the absolute Ideas that reign supreme behind and within the empirical world" (Tarnas, 1996, p. 53).

Written in the 1980s, Coelho's *The Alchemist* is surrounded by the atmosphere of secularism and diminishment of religious beliefs which characterized the post Second World War Era (Hungerford, 2010, p. 6). As a result, the human soul is sidelined in favor of the material gains and worldly matters. The logical consequences of the loss of faith in



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God are the prevalence of nothingness, meaninglessness and disillusionment with and fear from the limits imposed by being human.

Coelho (2005) himself has experienced a similar disillusionment and doubt in his life leading him to seek spiritual enlightenment on the road between France and Spain. He declared that "during the twentieth century we experienced the dictatorship of science, which tells us that the world consists only of scientifically provable things. Thus the amazement and surprise of experiencing our souls were lost to us" (p. 4). He assumed that one of the aims he wants to achieve through his mystic and spiritual tale, *The Alchemist*, is the restoration of belief in the goodness of the world and human essence (p. 4).

Writing out of this background, Coelho (2005) tries to rescue the importance of the spiritual and the metaphysical by portraying characters who are willing to establish contact with the Divine. These characters' long journey of search is only significant because, says the narrator: "every second of the search is a second's encounter with God and with eternity," their hearts do never enjoy happiness till they "have God within them" (p. 137). In this sense, the manifestation of the desert in *The Alchemist* mirrors David Jasper's (2004) hypothesis that "people sometimes go out into the desert to find new beginnings and a new place from which theological articulations can be found and recovered" (p. 4).

Jasper (2004) explains that mysticism is at the heart of the spiritual life of human beings. If they fail to hear its voice, then the life of the spirit is spoiled. Most importantly, he says, the magnitude of mysticism can be sensed only in the very particular spaces of the desert. Accordingly, every journey into the desert is motivated by the hope to "recover" mystical experiences because it is a place "outside the law where nothing superficial can be tolerated" (p. 5). In relation to this, *The Alchemist* is more than a mere story of a boy wandering in the desert looking to find the treasure of his dream as it reenacts the need of the contemporary individual to reestablish the lost sense of religion and spirituality.

Leading a heroic journey through the desert, Santiago learns to enter into a harmonious communion with its paraphernalia. During this process, he finds out that the world can "conspire" to make realize one's dreams, and that a human possesses stunning inner capacities and abilities which remained hidden and unknown to him. When he is obliged to turn himself into wind, the boy reveals that it is his heart which teaches him how to speak the language of the desert and the wind (Coelho, 1992, p. 140). In this context, Edward Mercer (2008) observes that the accurate capacity to unite with nature that certain persons may develop is not only a mere "source of the purest pleasure" but "a subtle and powerful agent in aiding men to realize some of the noblest potentialities of their being" (p. 4).

Having reached that high level of consciousness, Santiago is more willing to benefit from all his talents. He longs "to blow away the sands" and to carry the voice of his beloved Fatima (Coelho, 1992, p. 154). The encounter with the desert geography stirs unwavering reliance on his skills. There, in the vastness of the land, Santiago displays significant efforts to liberate himself from the shortcomings of being human. His insistence is fruitful by the end as he comes to recognize that self and nature move in harmony with each other and that man has inside of him "the winds, the deserts, the oceans, the stars, and everything created in the universe" (p. 154).

The isolation of the desert is given positive effects on the spirits of Santiago and the alchemist. For instance, as they approach the places which are disturbed by violent battles between the tribes, Santiago becomes very sensitive toward the landscapes which grant him the feeling at home (p. 135-6). The reason, says David Mercer (2008), is that the more salient feature of the desert has always "arrested attention and stimulated the mystic sense" (p. 242). As such, the solitude of the desert is romanticized by Coelho as pivotal for the tranquility of human beings.

Belden Lane (1998) praises the silence of the desert and strongly links it to the human self which is "an inner desert of its own, stripped of worldly care, is delighted in silence...to become an inner desert is to abandon the rampant race of thoughts, feelings, and worries that continually distract the soul from attentiveness to God" (p. 13). Assumedly, a self





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perceived as an inner desert is a self cleaned up from all the unquittous and evil preoccupation which distracts the individual from devoting his soul to belief in God. The goal of a journey through the desert, such as the one initiated by Coelho's protagonist, can be turned by the desert's silence into a spiritual quest for the Divine.

THE DESERT AS A SPIRITUAL GUIDE

A short time before his journey ends, Santiago experiences a high level of self-realization, individuation and self-balance (Coelho, 1992, p. 136). Progressively, he and the alchemist become "content simply to contemplate the desert, and to drink ...from the Soul of the World. The boy and his heart had become friends and neither was capable now of betraying the other" (p. 141). In the same context, Carl Jung (1964) considers that man's personality appears at first as "an inborn possibility," it may emerge very "slightly, or it may develop very relatively completely during one's lifetime" till one becomes a complete human being, aware of all his hidden aspects (p. 162). The process is completed when the boy turns himself into wind; an act which the chief of the Twariq tribe respectfully believes to show the greatness of Allah (Coelho, 1992, p. 156).

Interestingly, Santiago interacts with nature as a living being which can feel his joy and misery. For example, shortly after he enters the African desert, he meets the crystal merchant; the boy is so optimistic and offers to work for a whole day to earn money for the travel. But, the merchant encounters him with the harsh reality that even a whole year of work will not suffice to gain enough money. At that time, a kind of despair and sadness enters the boy's heart and the whole world of the desert falls sad "it was as if the world had fallen silent because the boy's soul had" (Coelho, 1992, p. 49). This shows the fusion between the inner state of the boy's heart and that of the surrounding nature. By so doing, Coelho zooms on the self as a part joined strongly to the desert natural space rather than something alien and outside its realm.

In the desert of *The Alchemist*, there is an ambiguous power which may satisfy one's longing for spiritual knowledge. Few days after his meeting with Fatima, the boy sits in the desert thinking about many questions related to man and his existence. Suddenly, he "felt an urge to go out into the desert, to see if its silence held the answers to his questions" (p. 104). In this sense, the desert is a land which forges a mystic individual who believes that its natural world holds super sensual abilities and is "a genuine primary manifestation of the ultimate Ground" which can please one's hunger for comprehensions (Mercer, 2008, p. 27). For this reason, the desert becomes the friendly companion and the trustful teacher for the characters who acknowledge that by saying: "Everything we know was taught to us by the desert" (Coelho, 1992, p. 113).

The alchemist who lived the two hundred years of his life in the desert, has developed a Platonic sense of belief in the reality of the world and its Creator. In typical Platonic words, he restates that:

"This natural world is only an image and a copy of paradise. The existence of this world is simply a guarantee that there exists a world that is perfect. God created the world so that, through its visible objects, man could understand his spiritual teachings and the marvels of his wisdom." (Coelho, 1992, p. 133)

He believes that being pure, clean and vast, the desert can substitute for all other places on earth and provide a best example for the manifestation of the divine spark in nature. Thus, he simply advises the boy to embrace its purity by telling him: "so immerse yourself in it. The desert will give you an understanding of the world... all you have to do is contemplate a simple grain of sand, and you will see in it all the marvels of creation" (p. 134). In this passage, the desert is seen as a medium of knowledge.

The mystical union with the soul of the world

The protagonist of *The Alchemist* walks away from the city of Andalusia and that of Tangier and heads toward the unknown mysterious desert where he will seek and find spiritual perception. After some months of wandering in its geography, contemplating and touching everything on its surface, he gains satisfaction. In contrast, the city, which is demographically crowded, constitutes a source of melancholy and depression for those who experience peace in the desert (Coelho, 1992, p. 56).





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Paulo Coelho represents the desert as a buoyant space which strengthens one's self confidence and leads one to understand that he is himself "vital—a free centre of energy;" a being who can move to higher levels, to greater realities and self-fulfillments (Underhill, 2002, p. 31). Helped by the desert omens, the boy becomes conscious of many secrets that rule the world. He understands that man can be the master of the world because he is endowed with an inner power that can change the way the universe responds to his dreams and wishes. So, his heart tells him that "most people see the world as a threatening place, and, because they do, the world turns out, indeed, to be a threatening place"(Coelho, 1992, p. 138). That is to say, the way we perceive things has its power and influence on the whole world.

Santiago's journey is led basically by a revealed intention to find out a hidden treasure. However, in its symbolic implication, it is a journey of quest for absolute truths about the whole existence in the physical terrain of the desert. Measured by mystical standards, says Evelyn Underhill (2002), "hidden truth is the object of man's craving"(p. 4). The boy, the Englishman, and the alchemist, are all after one unified objective which is the reality of the universe, its soul and Creator. As far as the boy is concerned, his utmost perception is noticed when in the silence of the desert he "reached through to the Soul of the World, and saw that it was a part of the Soul of God. And he saw that the Soul of God was his own soul. And that he, a boy, could perform miracles" (Coelho, 1992, p. 160).

Near the end of his journey, the boy has to climb some heights to reach the destined pyramids. This climbing is very much symbolic of the spiritual ascent he is about to accomplish and the discovery of reality to which he is heading: "when he reached the top of the dune, his heart leapt" (p. 168). Underhill (2002) affirms that "inside your spirit there is a little door, so high up that only by hard climbing can you reach it" (p. 43). Hence, he climbs the heights to reach the spiritual within himself. Before that, when he is wandering in the desert's magnificent landscapes, the boy applies the entire mystic pieces of advice which can be summed up in Underhill's (2002) words: "trust your deep instincts: use your latent powers. Appropriate that divine, creative life which is the very substance of your being. Remake yourself in its interest, if you would know its beauty and its truth"(p. 15). By so doing, the boy gets a double treasure because his self is completely freed from the imprisonment of the mere senses. By being able to turn himself into wind, which is basically an ability consecrated to the Divinity, Coelho advances the belief that

"Mysticism is essentially a movement of the heart, seeking to transcend the limitations of the individual standpoint and to surrender itself to ultimate Reality; for no personal gain, to satisfy the transcendental curiosity, to obtain no other worldly joys, but purely from an instinct of love." (Underhill, 2002, p. 7)

It is clear that in Coelho's narrative a harmonious relationship is established between human beings and the desert geography. They coexist in peace without trying to monopolize each other. The desert landscape in this text is highly alluring, for it stimulates encounter with that reliable human faculty which grants the individual the capability of discerning spiritual truth. A similar account of the desert experiences appears in the Judao-Christian writings of Philo and Clement who see the desert as the most suitable place for decency. In this land all the conditions conduct to contemplation, detachment from the amoralities of the crowd and focus on the inner self in a search for tranquility and peace of mind.

In the same token, the desert allows the boy to reach beyond the known phenomenal world to acknowledge that all things are one. Step by step, his journey becomes a mythic one, unlimited by the confinements of space and time. In the magical scene when he talks to the sun, he says: "I know the Soul of the World, because we have talked at great length to each other during this endless trip through the universe" (Coelho, 1992, p. 157). As such, his journey is also one of descent into the soul of man and that of the universe.

Having immersed himself in the quietness of the desert and its majestic emptiness, the boy is granted the chance to communicate with his heart and listen to its advice and enjoy tranquility. His heart transmits to him that it receives a revelation from The Soul of the World, saying that: "everyone on earth has a treasure, that awaits him... we people's hearts, seldom say much about those treasures, because people no longer want to go in search of them. We speak of





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them only to children" (Coelho, 1992, p. 138). Therefore, the suggestion that his heart has already told him about the treasure means that he still possesses the innocence which can nurture his faith.

According to Crossfiled Happold (1970) explains that there are two urges in life; one toward selfhood, individualization, and separation; the other is toward "escape from the loneliness of the self into something bigger than self," this is the mysticism of knowledge, of finding the secret of the universe and how to make it work on one's behalf (p. 40). Accordingly, as he spends a longer time in the desert, Santiago's understanding of the mystic forces that permeate every element in it becomes larger. There, in the open serenity of the land, he communicates with his horse, the flying birds, the wind, the grains of sand, the sun, and, above all, with the Soul of the World, which speaks to him through dreams and visions. David Klemm (2004) maintains that:

"the experience of the desert is an experience of the overturning of human finitude, the opening of human being to the mystical basis of its identity. This place is where the divine as "God" empties itself into finite human being and where finite human being discovers its own deep participation in transcendence." (p. xii- xiii)

Significantly, reading in the history of the word "mysticism," Happold (1970) states that the word has its origins in the Greek mysteries when a mystic man was understood to be the person endowed and given access to the knowledge of these mysteries, allowing rebirth into eternity (p. 18). In this sense, after his achievements during the journey, the boy could become a mystic person who creates a long-lasting legend for himself. For instance, when he succeeds to turn himself into a Simum wind, he became a legend (Coelho, 1992, p. 161). Though people's reactions were varied, those who considered it as a sign of God's glory do showed ecstasy.³ Turning one's self from one state of being into another is stunningly a divine activity, and when he does it successfully, the boy confirms one of the basic tenets of mysticism which is the belief that "man is in some way a sharer in the divine life" (Happold, 1970, p. 44).

Far from the mystical manifestations of the desert, this land is loaded with other positive images. On the one hand, the boy looks at it with longing; with hope for coming back, and with desire for finding a treasure. On the other hand, for Fatima, the desert represents a "hope for return" because she waits for the man who wanders its tracks and endures all its obligations. In Coelho's narrative, just as we see it in The Odyssey and Ulysses' journey, the motif of "going back" is apparent because true treasure is to be found in one's home.

The treasure Santiago was looking for lays buried under the sycamore tree in Spain where he sees the dream for the first time. This consolidates the belief that the intended goal of the journey is, in addition to material gains, to test one's determination, inner strength and endurance. Above all, it makes one understand that the true treasure is in discovering the energy within, finding a home and in having a family to care and to commit one's self to. Departing from Campbell's quest pattern,

Coelho's protagonist does not encounter any trouble in his way back home and there is no "Refusal of the Return" in his journey (Campbell, 1968, p. 193). This shows that when home summons, the individual shall answer the call because it is a blessed act.

The journey motif and the appearance of a Ulysses, who embarks on a journey looking for Penelope, appear in other works by Coelho, such as The Zahir. However, according to Mansour Wissam (2006), while Ulysses undergoes all the physical and spiritual difficulties to reach Ithaca and restore his position by force, Coelho's protagonist in *The Alchemist* is a "postmodern European subject with mystical tendencies that mediate and soften any possibility toward aggression" (p. 93). Hence, when the majority of Campbell's heroes have destructive forces with which they crush their enemies, a hero by Coelho, adds Wissam Mansour (2006), "arms himself with sensitivity, sensibility [and] a passionate heart" (p. 93).





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CONCLUSION

Paulo Coelho's representation of the desert is colored by the spiritual tendencies to which he becomes a devotee after a trip of enlightenment along the medieval pilgrims' route between Spain and France in the late 1970s. The spiritual awakening that he achieved prompts his writings and personal perception of the natural sceneries, starting from his books *The Pilgrimage* and *The Alchemist*. Coelho is a writer who has faith that once one sets himself to his purpose and dreams, he can succeed and overcome all the obstacles that life puts in one's way. This becomes obvious in portraying the desert as a space which responds to the needs of the individual whose inner force is able to stimulate sustenance from nature. In *The Alchemist*, Santiago, the alchemist, and the Englishmen show a force of will which influences the course of the events and makes of the land a place of possibilities rather than a space of obstacles. Coelho teaches the lesson that once one believes in the magic of being human, positivity one will reign over his world; a doctrine which is best manifested in the constructive way the desert reacts toward the needs of man.

The reading of *The Alchemist* showed that the belief in the desert as a space of solace, rejuvenation and devotion did not end with the Desert Fathers. In this narrative, the desert empty space and its silence sustain Santiago by several illuminating mystical experiences which increase his awareness of the world beyond the physical and phenomenal one. The analogy between Coelho's representation of the desert and that of the Desert Fathers appears clearly in this narrative where the phenomenal and the transcendental realms coexist. The world of the senses is redeemed by believing that it holds a spark of the Ideal one.

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RESEARCH ARTICLE

Psychoanalytic Trauma and the Afterlives of Childhood Abuse: A Freudian Reading of Anna Quinn's *The Night Child*

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ABSTRACT

This study examines Anna Quinn's *The Night Child* (2018) through the combined frameworks of Freudian psychoanalysis and contemporary trauma theory, highlighting how childhood abuse is inscribed upon memory, identity, and the unconscious. The novel portrays the protagonist, Nora Brown, whose experiences of physical violence, emotional denigration, and sexual violation are not only remembered but are compulsively relived through symptoms such as dissociation, panic attacks, and intrusive recollections. Drawing on Freud's concepts of repression, the return of the repressed, and the compulsion to repeat, the analysis demonstrates how traumatic experiences persist in the unconscious, resurfacing belatedly in fragmented memory and bodily responses. The study shows how abuse within caregiving relationships produces enduring disruptions in selfhood, relational trust, and affective regulation. By engaging with psychoanalytic constructs such as betrayal trauma, confusion of tongues, superego formation, and identification with the aggressor, this study highlights how Quinn's novel stages the psychic and somatic aftermath of abuse. This study argues that *The Night Child* functions as a literary witness to the resistance of trauma to closure, underscoring the enduring dialogue between psychoanalysis, literature, and trauma studies.

Keywords: Freud; Trauma Theory; Childhood Abuse; Dissociation; Psychoanalysis.





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INTRODUCTION

The relationship between childhood trauma and its psychic afterlives has long occupied the attention of both psychoanalytic and literary scholarship. It offers profound insights into how early violations reverberate across time, shaping memories, identities, and the unconscious. Anna Quinn's *The Night Child* (2018) dramatizes this area with constant intensity. The novel traces the fragmented inner life of Nora Brown, a woman whose adult experience of dissociation, anxiety, and intrusive recollections bears witness to the lingering effects of childhood abuse. In Nora's past, physical violence, emotional degradation, and sexual violation intersected. The narrative emphasizes not merely the catalogue of abuses but their enduring psychic effects. It emphasizes how the body registers trauma that the mind cannot fully process and how memory returns belatedly, compulsively, and against the subject's will. As shown in Figure 1, childhood trauma often leads to defence mechanisms such as repression and dissociation. These defenses help the child survive at the time, but in adulthood, they can reappear as anxiety, flashbacks, dissociation, and panic attacks.

Freud's work, from *The Aetiology of Hysteria* (1896/1955) to *Beyond the Pleasure Principle* (1920/1955) and *Inhibitions, Symptoms and Anxiety* (1926/1959), persistently returns to the question of how unassimilated experiences inscribe themselves on the psyche. For Freud, early relational trauma, especially when inflicted by caregivers, is not simply stored in the conscious memory. It becomes lodged in the unconscious mind, shaping dreams, symptoms, and character, often surfacing indirectly through what he called the "return of the repressed" (Freud, 1917/1955). The child, lacking the cognitive and linguistic means to process overwhelming experiences, defends itself through repression, denial, and dissociation. These mechanisms also ensure that trauma returns, belatedly and repetitively, demanding psychic reckoning even decades later (Laplanche & Pontalis, 1988). In *The Night Child*, Nora's recurring visions, bodily tremors, and psychic splitting exemplify what Freud identified as the compulsion to repeat: "the paradoxical tendency of the traumatized subject to relive what has not yet been mastered, as if the psyche were seeking belated integration through repetition" (Freud, 1920/1955).

Trauma theory has deepened these psychoanalytic insights, drawing on neurobiology, attachment research, and literary studies to explore how overwhelming experiences exceed the mind's capacity for integration. Bessel van der Kolk (2014) observes that "the body keeps the score," with traumatic memory often encoded somatically rather than linguistically. According to the study, it reappears in flashbacks, startle responses, or visceral sensations rather than in narrative recall. Figure 2 shows how trauma affects the mind, body, and behavior. In the mind, it appears through repression and disturbing dreams; in the body, it leaves traces as muscle tension, visceral sensations, and somatic memory; and in behavior, it surfaces through panic attacks, sudden startle reactions, and flashbacks. This model illustrates van der Kolk's (2014) insight that the body holds on to what the mind cannot fully process, emphasizing that trauma is not only psychological but also deeply physical and behavioral.

Teicher and Samson (2016) documented the enduring neurobiological consequences of childhood maltreatment. This study linked early abuse to lasting alterations in stress response systems, affect regulation, and brain connectivity. Psychoanalysis offers something more than a clinical account. It highlights the subjective and symbolic dimensions of the trauma. It also traces how psychic life knits itself around absences, ruptures, and the enigmatic demands of the unconscious mind. As Laplanche and Pontalis (1988) note, the unconscious does not merely store memories like a passive archive; 'it translates, distorts, and disguises them, returning them to consciousness in dreams, symptoms, or uncanny repetitions whose meanings resist immediate deciphering.'

Childhood abuse, whether physical, emotional, or sexual, has deep and lasting effects on a person's development, sense of self, and capacity for healthy relationships. Studies have shown that when children experience multiple forms of abuse, the harm is compounded. It often leads to depression, low self-esteem, difficulties in social functioning, and even chronic health conditions in adulthood. Figure 3 illustrates the wide range of psychological



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consequences that abuse can leave behind. Each section highlights how trauma continues to shape the body, mind, and relationships long after the abuse has ended. In *The Night Child*, this framework helps clarify how Nora's experiences of being beaten, insulted, and sexually violated leave scars not only on her body and memory but also on her identity, self-worth, and ability to trust others. These themes resonate with central concerns in psychoanalysis and trauma theory, as seen in the writings of Freud, Ferenczi, and Herman, and are further supported by contemporary research (Zhang et al., 2025; Spinazzola et al., 2018).

The interplay between memory, repression, and the return of the repressed makes Freud's work indispensable for interpreting *The Child*. The novel's fragmented structure, shifting temporalities, and hallucinatory doublings formally enact traumatic memory dislocation. Scenes from Nora's childhood emerge unpredictably. It presents things in strange manners, such as a shattered rosary, a mother's slap, a father's whispered threat, and a Valentine's Day turned sinister. These images recur with the compulsive force Freud (1920/1955) describes in *Beyond the Pleasure Principle*, where he links traumatic repetition to the psyche's attempt to bind overwhelming stimuli into coherent meanings. As Freud suggested, such binding is never fully achieved. The trauma resists complete integration and remains partly unsymbolized, lodged in what Caruth (1996) terms "the unknown that one carries within." Nora's adult experiences, including her dissociation into the alter ego Margaret, her panic attacks, and her faltering speech before therapists, testify to this unassimilated kernel, the traumatic Real around which both psyche and narrative revolve.

This study interprets *The Night Child* not simply as a story of individual suffering. It is a literary exploration of how trauma shapes memory, language, and the unconscious by connecting Freud with contemporary trauma theory. The novel's broken timeline, jumps between past and present, and moments in which Nora seems to see herself twice reflect the confusion and disruption caused by traumatic memories. In the novel, scenes from Nora's childhood appear unpredictably and repeatedly. These repetitions reflect the compulsive return of traumatic experiences, as Freud (1920/1955) described, "in which the psyche struggles to integrate overwhelming events into coherent understanding." However, as Freud notes, this integration is never fully achieved. Trauma resists complete assimilation and remains partly unprocessed, which continues to affect the mind and body. Nora's adult experiences, which include her dissociation into the alter ego Margaret, her panic attacks, and her difficulty speaking in therapy, demonstrate the lasting effects of these unresolved traumas.

The novel also highlights how abuse within caregiving relationships blurs the boundaries between care and harm. The father's alternating gestures of tenderness and violation exemplify what Freyd (1996) calls betrayal trauma. This suggests that the person who is supposed to provide protection becomes the source of danger, destabilizing the child's sense of safety, trust, and self. Similarly, Ferenczi's (1949) concept of identification with the aggressor explains how a child may internalize the perspectives or desires of the perpetrator to survive. This can lead to patterns of self-blame, shame, and ambivalent attachment in the child's adulthood. *The Night Child* thus aligns with contemporary trauma theory in refusing neat closure or catharsis. By presenting childhood sexual, physical, and emotional abuse as ongoing influences rather than resolved events, the novel demonstrates how trauma persists across time and the psychic life, demanding ongoing attention and interpretation.

Theoretical Framework

This study situates *The Night Child* within a psychoanalytic and trauma theoretical framework. The aim is to examine how childhood abuse, including physical, emotional, and sexual abuse, leaves lasting marks on the psyche, memory, and bodily experience. Freud's early ideas, including the seduction theory, and later work by Ferenczi (1949), show that when caregivers become sources of harm, the child experiences a deep betrayal that shapes their sense of self. Herman (1992/2015) adds that such trauma damages not only the body and emotions but also trust, relationships, and identity, often leading to shame, self-splitting, and loneliness. As shown in Figure 3, childhood abuse creates wounds that later appear as dissociation, inner criticism, and bodily symptoms. The figure outlines the theoretical framework of this study.



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These dynamics are powerfully staged in *The Night Child*. The mother's swing between care and cruelty, the father's intrusion of sexual violence into moments of supposed tenderness, and the family's broader silences together create what Ferenczi (1949) called the "confusion of tongues." In such moments, the child is trapped in the caregiver's unspoken rage, desires, and anxieties, unable to tell love from harm or safety from threat. Freud's "Three Essays on the Theory of Sexuality" (1905/1953) helps clarify how childhood sexuality normally becomes ordered and repressed over time. Violent abuse interrupts this process. Adult desires are forced onto the child, producing what Laplanche (1988) terms "enigmatic messages." A signal that the child cannot interpret, but also cannot dismiss. In Nora's case, her father's whispered commands operate as such messages, driving repression while ensuring the return of trauma through nightmares, dissociation, and intrusive memories.

Freud's (1923) idea of the superego adds another layer to this discussion. Nora's mother's words, calling her a "liar" or "stupid girl", solidify into an inner voice of harsh judgment, mirroring Freud's description of the punishing parental authority that shapes the psyche. Contemporary research supports this view. Zhang et al. (2025) linked childhood maltreatment with long-lasting shame, while Spinazzola et al. (2018) showed that verbal abuse can harm as deeply as physical assault, corroding self-worth and reinforcing guilt. In this sense, the superego becomes an internal record of abuse, replaying and magnifying the original trauma in the child. Psychoanalytic theory helps to explain the ambivalence that survivors often feel toward abusive caregivers. Freud (1917/1955) described this as identification with the aggressor, wherein the child internalizes aspects of the abuser's perspective as a survival strategy. In Nora's case, this ambivalence surfaces as a tangled mix of fear, longing, and loyalty toward the very parents who harm her, resulting in dissociation and fragmentation in adulthood.

The temporal dimension of trauma further highlights Freud's framework of the unconscious. His concept of *Nachträglichkeit* (deferred action) emphasizes that experiences unprocessed in childhood often gain traumatic significance later, when subsequent events reactivate the memory (Freud, 1896/1955). *The Night Child* dramatizes this temporality through its nonlinear form, shifting between Nora's adult reflections and her fragmented childhood memories. Flashbacks of parental violence, sexualized encounters, or broken household objects return with a compulsive force. The novel suggests that trauma resists smooth integration into narrative. Instead, it re-emerges in fragments, bodily reactions, and dissociative episodes. As Caruth (1996) argues, trauma speaks through what cannot be fully known, revealing itself indirectly through repetition, silence, and disruption. As outlined in Figure 4, psychoanalytic concepts such as betrayal trauma, identification with the aggressor, and somatic memory provide a framework for understanding how abuse in Nora's childhood is written into her psychological, relational, and bodily life.

Freud's writings on childhood sexuality further illuminate the psychic consequences of incestuous sexual abuse. Ordinarily, the child's sexual drives are diffuse and socially unorganized, later shaped by Oedipal development and repression. In cases of abuse, this process is violently reversed. The child encounters adult sexualization before the ego can process it, producing confusion, guilt, and dissociation. In contrast, the psychoanalytic lens insists on the integration of bodily and psychic registers. Freud's early seduction theory identified the body as a site of trauma expression when the mind cannot contain it. Nora's trembling, pallor, and psychic numbing exemplify this embodiment. It shows that her body remembers what her conscious mind cannot fully process.

RESEARCH METHODOLOGY

This study employs a qualitative research methodology to investigate how *The Night Child* (Quinn, 2018) represents childhood trauma. It specifically examines how physical, emotional, and sexual abuse shape the protagonist's psychic life through the lens of Freudian psychoanalysis. As Taylor et al. (2016) note, qualitative research generates descriptive data that capture lived experiences in depth and complexity rather than reducing them to numerical patterns. Similarly, Ritchie and Lewis (2003) emphasized that qualitative inquiry aims to reveal phenomena as they emerge within natural contexts. In essence, the present study engages closely with *The Night Child's* language,



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imagery, and characterization to uncover how trauma inscribes itself on memory, identity, and the unconscious. This research follows a phenomenological orientation, as outlined by Creswell and Poth (2018), prioritizing the exploration of subjective experiences and meanings. The study highlights how traumatic childhood events are registered psychologically, expressed linguistically, and enacted behaviorally by focusing on the protagonist Nora Brown's inner life. Data collection proceeded through literary criticism methods, beginning with multiple close readings of the text to identify passages that depict abuse and dissociation. Quotations were extracted from narrative descriptions, dialogues, and interior monologues, where the imprint of trauma on the protagonist emerges explicitly or implicitly. Consistent with Yin's (2016) recommendations, source triangulation was employed by consulting theoretical, psychological, and literary scholarship to ensure interpretive rigor.

Data analysis followed Miles and Huberman's (2014) interactive model, encompassing data reduction, display, and conclusion drawing. Extracted passages were first categorized according to types of abuse and corresponding PTSD symptoms, then interpreted through Freudian psychoanalysis—particularly concepts such as repression, the return of the repressed, and repetition compulsion—and Herman's trauma framework. As Miles and Huberman (2014) note, literary analysis requires constructing a sustained argument grounded in textual evidence. Accordingly, this study integrates psychoanalytic theory and trauma studies to elucidate how *The Night Child* renders the psychological effects of childhood abuse.

Physical Child Abuse in the Novel

Freudian psychoanalysis posits that early relational trauma, especially physical abuse by caregivers, resides not only in explicit memory but also in the unconscious, shaping the psychic structure, generating defense mechanisms, and influencing symptom formation (Freud, 1910; Laplanche & Pontalis, 1988). In *The Night Child* (2018), Nora Brown's childhood is not merely endangered by physical violence—it is shaped and haunted again and again by it. Physical abuse operates as both a rupture and a repetition. It forms the rupture of maternal care, repetition of pain, repression, and the creation of internal fantasies. From a Freudian perspective, the body becomes a repository of unassimilated trauma, and the unconscious is a theatre in which the child's earliest experiences drive later dysfunction. The following argument locates instances of physical abuse in Quinn's text by examining Maeve's psychological state and Nora's responses.

Physical abuse in the text emerges through vivid imagery and tactile violence. Nora's narration recollects with painful specificity when she was with her therapist, Dr. David Forrester:

"that sometimes her mother would shriek at her and how if she tried to run her mother would grab her, throw her down, bring her hand hard across her cheek, how the force of the slap sent her reeling against walls and furniture, how sharp and shocking those things felt against her body. She should have told him how her mother pulled her hair out, how she had wanted her mother to die" (Quinn, p. 31).

Nora's mother, Maeve, not only physically assaults her through grabbing, throwing, and striking, but these actions also deeply affect Nora's sense of safety and control. Violence forces her into repeated cycles of fear and submission, highlighting that the abuse is not merely symbolic; it is intensely physical and sensory. Beyond the immediate physical pain, Nora's account reveals the emotional and psychological toll of abuse. She mentioned how she wanted her mother to die, reflecting deep feelings of anger, helplessness, and despair. These emotions are common among individuals who experience chronic abuse, leading to complex trauma. From a Freudian perspective, the physical assaults Nora endured become part of her unconscious mind, encoded in what Freud termed the "infantile scene." These repressed memories can resurface as dreams, hypervigilance, and bodily fear responses.

Maeve's physical violence is unpredictable and eruptive, often linked to tensions neither she nor Nora fully understands. A later memory intensifies this unpredictability when Nora misses the bus while helping Sister Rosa, who comes to drop her off later. Her mother asked:





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"What did you say to her?"

"Nothing." Nora steps back.

"You told her something."

Fear shakes Nora's body, and her skin pales. "No ... no ... Mommy."

"Didn't you?" Her mother says, coming closer.

Shivering all over.

Hard furious terrified woman hand bones against girlface-girlarm-girlback-girlbones. Again, and again and again.

"You stupid girl! You've shamed us! Shamed us!" She stops, gulps more gin and Nora crawls away fast and slips downstairs to her piano." (Quinn, p. 194-195)

The repetition in "again and again and again" echoes the Freudian concept of the compulsion to repeat, "where trauma that is not fully known or integrated resurfaces in recurring patterns, forcing the individual into psychic reliving" (Freud, 1920/1955). Nora's bodily reactions, paleness, trembling and shivering, illustrate how the body itself registers and responds to trauma. The narrative's detailed mapping of Maeve's hand and bones across Nora's face, arms, and back enacts a primal violation of personal boundaries. This grotesque merging of self and aggressor demonstrates how physical abuse can collapse distinctions between victim and perpetrator, leaving indelible marks on both body and psyche. The following diagram (figure 7) shows how Freud's idea of the trauma cycle appears in *The Night Child*. It illustrates how moments of physical abuse create fear and cause Nora to split her feelings, how the unconscious hides these experiences through repression, and how the trauma later returns as symptoms and repeated behaviours, shaping both her emotions and her body.

Freud's early theorizing (e.g., his seduction theory) posited that childhood sexual trauma could be etiological for neuroses. In the case of physical trauma, while less foregrounded, it similarly disrupts psychic development (Freud, 1896/1955). He also emphasized repression. The infant or small child lacks the capacity to fully represent the traumatic event in language or conscious memory. As a substitute, the trauma returns in symptoms, in the body, in odd fears, in fragmented recollection. Nora's inability to recall exactly "when" Maeve stopped wearing lipstick, or what shift took place as she mentions, "I don't remember exactly when. I only remember that her lips tightened into a hard line, and she stopped wearing lipstick. And she had a shot or two of gin every day around three (Quinn, p. 30)." The shift here is gradual yet marked. Maeve's own identity becomes frayed, and through her, Nora's sense of the dissolution of maternal safety. The lipstick, a cosmetic boundary between self-presentation and social face, disappears. The gin becomes Maeve's regular companion in mid-afternoon, perhaps a means to deaden anxiety or shame. Such disintegration in the mother's ego capacities, Freud would say, weakens the holding environment for the child. When a caregiver is unable to maintain psychic equilibrium, objects meant to comfort instead erratically turn cruel.

In Freudian terms, Maeve's stress, her alcohol consumption, and her racial anxieties are psychic loads that are repressed and perhaps disowned. These inner conflicts need an outlet, and often the child becomes the target where these feelings are shifted. In this scenario, the physical abuse can be understood not just as cruelty, but as the mother's unacknowledged inner pain expressed outwardly. The violence may arise when Maeve's defences, such as splitting, projection, and denial, are overwhelmed. The attack on Nora's body is also an attempt to control a world that the mother perceives as threatening. Nora's mother always wanted to control the social mobility, racial otherness and identity anxiety. The home, meant to be safe, becomes a stage for conflicts between conscious aspiration (fitting in, achieving respectability) and unconscious fear (marginalization, shame).

Freud's theories of anxiety and the ego provide a useful lens for understanding Nora's experience. Her bodily trembling and fear can be read as anxiety produced by an internal conflict. On one side, her need for safety and protection, and on the other, the painful reality that the very person who should provide care, the mother, becomes the source of threat. In Freudian terms, the ego is caught between the punishing demands of the superego, which insists on conformity, propriety, and social acceptance, and the disruptive forces embodied in Maeve's rage, alcohol



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dependence, and position as an outsider. This fragile balance creates psychic strain that the ego can only manage through defence mechanisms. When the slap is too violent, Nora dissociates. When she longs for maternal affection but sees only an angry, rigid face, denial operates to soften the blow of psychic pain. In this way, the novel dramatizes how repression, dissociation, and denial function not as abstract theories but as lived survival strategies under conditions of trauma.

The consequences of physical abuse unfold gradually and leave lasting marks. They may take the form of body memories, recurrent nightmares, hyperarousal, mistrust of others, and a sense of shame that settles into bodily posture and flesh. Freud suggested that early traumas inscribe themselves through what he termed “‘somatic seduction’, not limited to sexual violation, but encompassing any intrusive experience in which the child’s body becomes the site of overwhelming penetration, leaving behind both psychic and symptomatic traces”. In *The Night Child*, Nora’s bodily reactions, her paleness, trembling, and constant vigilance, reflect these imprints. Such symptoms strongly resemble the physiological markers of trauma frequently observed in clinical populations, including panic disorders and dissociative episodes. Although Quinn’s novel avoids medicalized terminology, its portrayal of Nora’s responses resonates with well-documented findings in both psychoanalytic theory and contemporary neuroscience, which confirm the body’s role as a repository of traumatic memory (Samson, Newkirk, & Teicher, 2024)."

Recent psychoanalytic psychotherapy research shows that adults with histories of childhood abuse, whether physical, sexual, or emotional, tend to experience more severe depression, persistent interpersonal difficulties, and greater challenges in forming a secure therapeutic alliance (Krakau, Ernst, Hautzinger, Beutel, & Leuzinger-Bohleber, 2024). Notably, participants in long-term psychoanalytic therapy who had experienced childhood trauma showed greater symptom reduction, suggesting that addressing early relational wounds can lead to deeper psychological repair. This research provides a useful framework for understanding Nora’s narrative. Nora’s recounting of her abuse, the repeated reliving of painful experiences, and her difficulty in articulating the unspeakable mirror the psychoanalytic therapeutic process. The process where the repressed memories emerge, internal retransference unfolds, and even internal witnessing provides the first steps toward healing. In other words, only by bringing these traumatic experiences into conscious awareness and safely processing them can meaningful repair and integration take place, highlighting the therapeutic potential of narrative engagement with past trauma.

Freud’s concept of transference also helps elucidate Nora’s relationship with her mother, both in memory and in her adult self-understanding. The mother’s figure in Nora’s unconscious is both object of longing (for protection) and terror, which is suggested through Nora’s fear, anticipation of violence, even when silent and her bodily reactions when Maeve is near. The mother becomes a phobic object for the child. This duality is central to Freudian object relations, later developed by Klein, Fairbairn, and others. However, the foundational structure—the ambivalence between love and hate, safety and danger—is already Freudian.

Emotional Child Abuse in the Novel

Emotional abuse in *The Night Child* does not emerge through physical violence alone but through insidious, recurrent assaults on Nora Brown’s sense of self, security, and belonging. Freud’s early theorization of trauma as “‘Nachträglichkeit’, a belated action where the full impact of an earlier experience is realized only in later moments of psychic crisis” (Freud, 1910) is especially useful here for several reasons. For Nora, childhood events do not simply recede into the past. They linger in her life as they are sedimented in memory, returning in adulthood as symptoms, flashbacks, and feelings of dissociation. Emotional abuse, unlike physical abuse, which leaves visible scars, often inhabits the realm of language, silence, and psychic threat. It operates through humiliation, belittling, and repeated erosion of a child’s self-worth.

One of the novel’s most powerful scenes occurs when six-year-old Nora is accused of lying, and her mother’s rage explodes in both a verbal assault and the destruction of a sacred object.





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"Liar!" her mother shouted, snatching the rosary from Nora's six-year-old hand. "Where did you get this?" "S-s-sister Rosa gave it to me." "Liar!" Her mother's red hands shake the rosary close to Nora's face. "P-p-please Mommy, give it back." You want it back? Here!" And then her mother's angry fingers wrenching the rosary apart until SNAP! The white thread breaks, and all fifty-nine blue beads pop into the air and clatter to the floor. Her mother leaving her there then, in the sudden silence of it all, Nora smearing tears off her cheeks and scrambling to find each precious bead" (Quinn, P. 98-99).

Here, the repeated accusation, "Liar!" becomes more than just a moment of anger. It takes root in formative psychological wounds. From a Freudian perspective, this moment illustrates the internalization of the parental voice as a superego. Freud (1923) explains that the superego emerges from the authority of parental figures, often through prohibition and punishment, becoming a harsh and punitive inner voice. Nora's mother's voice echoes in her psyche, condemning not just her actions but her very sense of self.

The destruction of the rosary intensifies this moment in the film. As a sacred object, the rosary symbolizes faith and comfort, but in Maeve's hands, it is turned into a weapon of shame. The scattering of blue beads across the floor is a striking image of fragmentation. It represents the shattering of Nora's trust, her sense of safety, and her spiritual grounding in her marriage. Trauma research shows that such early experiences of humiliation and violence can crystallize into deep-seated shame, leaving long-term effects on self-concept and emotional regulation (Zhang et al., 2025).

From a psychoanalytic perspective, such verbal assaults exceed mere "discipline." The mother neither inquires into the child's motives nor allows her a voice. Instead, she imposes a unilateral judgment. Freud (1923) suggested that a caregiver's aggression overwhelms the child's ego defenses. Children often internalize aggression, turning it inward as self-reproach, guilt, or compulsive obedience. For Nora, being called a liar repeatedly and violently instills a sense of moral failure in her unconscious, even when none exists. The result is not moral guidance but a psychic injury. Moreover, psychoanalytic scholars argue that repeated accusations of lying in childhood often lead to what Ferenczi (1949) called "confusion of tongues". According to this idea, the child internalizes the aggressor's interpretation and becomes alienated from her own memory and truth. This is reflected in Nora's subsequent confusion. She recalls the accusations but not their reasons. She remembers "the missing cookies, the church confessional, or praying to St. Margaret" (Quinn, p. 98), but cannot find the exact reason. Her memory is fractured, pointing towards the idea of trauma's paradox (Caruth, 1996), which is both unforgettable and unassimilable, returning in fragments rather than a coherent narrative.

Moreover, the novel's temporal structure underscores the persistence of these childhood scenes into Nora's adulthood. Lying awake at night, she remembers "these things", the mother's accusations, the sharp voice, the shattering beads. The return of these memories in adulthood exemplifies Freud's notion of the return of the repressed: "what the child cannot fully process in the moment resurfaces later, often with intensified affect" (Freud, 1910). Emotional abuse thus operates across time, with its traumatic force accumulating in the psyche until it manifests as anxiety, depression, or dissociation.

Emotional violence in the novel extends beyond accusations of lying to episodes of overt humiliation and verbal assault. One such moment occurs when Nora's mother, drinking gin, lashes out at Nora:

"Nora follows her mother through the doorway, and the door clunks closed. Her mother walks to the coffee table and picks up her glass of gin, takes a drink, the green olive touching her lips, then floating around the clear liquid again. She slams the glass back down. "What did you say to her?"

"Nothing." Nora steps back.

"You told her something." Fear shakes Nora's body, and her skin pales. "No ... no ... Mommy."

.....





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“You stupid girl! You’ve shamed us! Shamed us!” She stops, gulps more gin and Nora crawls away fast and slips downstairs to her piano” (Quinn, p. 194-195).

Here, the mother’s words “You stupid girl! You’ve shamed us!” show how Nora becomes the target of her mother’s anxieties about respectability and social standing. The rage is disproportionate, and its true source is likely her mother’s own inner turmoil, which is displaced onto the child. In psychoanalytic terms, this is a type of projection. The “aggressor disowns feelings of shame or inadequacy and attributes them to another, who is then punished for them” (Laplanche & Pontalis, 1988). Too young to recognize this psychic mechanism, Nora absorbs these accusations as truths. This shapes her ego, marked by guilt and low self-worth. The following illustration (figure 8) shows how repeated verbal assaults, such as accusations of lying and calling her stupid, penetrate Nora’s psyche. It also shapes Nora’s superego through parental aggression. These experiences generate shame and anxiety, which are then repressed, producing psychic splitting and later symptoms, such as dissociation and identity fragmentation.

Research on emotional abuse confirms these dynamics of power and control. Studies indicate that verbal denigration and humiliation are among the most damaging forms of childhood maltreatment, often leaving scars that persist into adulthood (Spinazzola et al., 2018). Emotional abuse undermines a child’s emerging sense of self, creating chronic patterns of shame and self-doubt. As Herman (1992/2015) observes, repeated abuse in childhood often leads to complex posttraumatic stress disorder (PTSD), characterized not only by intrusive memories but also by relational distrust, identity disturbance, and feelings of worthlessness. This dynamic is intensified when the abuser is also a caregiver. Freud (1925/1961) described such situations as traumatic because the child cannot escape the source of the threat. To survive, “the psyche may split, repress painful experiences, or even adopt the aggressor’s perspective to preserve a fragile bond” (Ferenczi, 1949). In Nora’s case, humiliation becomes internalized, fusing maternal rage with her own sense of self and leaving her vulnerable to cycles of guilt and psychic fragmentation.

The father’s role deepens the cycle of abuse, reinforcing the fear and secrecy. A particularly chilling memory captures how the threats of isolation and disbelief silence Nora:

“Her father had taken this picture the day she’d received the Valentine’s dress from her grandmother. Taken the picture a week before he ruined the dress. Taken the picture when she’d been a good girl. And now—her father’s mouth, breathing heavy in her ear, whispering ‘If you tell you will be alone. All alone. No one will believe you. If you tell, no one will ever believe you.’” (Quinn, 2018, p. 192).

Here, the father’s whispered threats enforce silence through the primal fear of being abandoned. Freud (1925/1961) suggested that threats of loss or isolation create overwhelming anxiety in children because attachment figures are essential for survival. The father ensures Nora’s obedience and secrecy by weaponizing her dependency. This form of emotional abuse extends beyond the immediate encounter, leaving enduring imprints on Nora’s capacity for trust, speech, and self-assertion.

Contemporary research has confirmed these consequences. Teicher and Samson (2016) noted that repeated emotional abuse in childhood is strongly associated with adult psychopathology, including depression, anxiety, and posttraumatic stress disorder. In *The Night Child*, Nora’s dissociation and psychic fragmentation are manifested in the figure of Margaret. This can be understood as a delayed response to these assaults. When a child cannot protest, flee, or seek comfort, the psyche often survives through dissociation, partitioning intolerable memories and emotions into separate compartments (van der Kolk, 2014).

From a Freudian perspective, emotional abuse in *The Night Child* functions through language, threat, and humiliation, inscribing wounds not on the body but in the unconscious mind. Such experiences become the latent material of Nora’s later symptoms, the repressed kernels around which anxiety, shame, and dissociation coalesce. However, the novel does not present emotional abuse in isolation. Rather, it depicts a continuum in which physical violence, sexual threats, and neglect intertwine, each magnifying the other’s trauma. In this way, emotional abuse





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provides the psychic groundwork upon which subsequent violations are inscribed, shaping the complex texture of Nora's trauma and the clinical picture of PTSD that emerges in her adulthood.

Sexual Child Abuse in the Novel

The novel portrays sexual abuse not as a single event but as part of a broader continuum of violence shaped by emotional neglect, maternal hostility, and paternal violations. Nora's father, Karl, enters this fractured family space not only as the incestuous aggressor but also as the figure who appears to offer comfort in the midst of maternal rage and parental conflict. As Herman (1981) argues in *Father-Daughter Incest*, such dynamics are tragically common in our society. She states that, "when mothers are abusive, absent, or emotionally unavailable, daughters often turn to their fathers for protection, only to have this dependency exploited". In Nora's case, the father presents himself as a confidant and caretaker, but this protective role collapses into incestuous violation, leaving the child caught between love and terror. A recent psychological study by Tekin (2025) found that young women with histories of paternal neglect and abuse showed that their early relationships with their fathers significantly influenced their later romantic relationships and partner choices.

The novel stages this collapse through fragmented memories in which moments of parental fighting, the father's apparent tenderness, and the child's confused emotional responses are interwoven. Freud's theory of infantile sexuality (1905/1953) highlights "how parental figures, meant to establish boundaries, instead blur them, leaving traces that return as symptoms in adulthood." As Caruth (1996) and later trauma theorists note, this repetition of fragmented memory and affect underscores how "trauma resists straightforward narration, surfacing instead in disjointed recollections, bodily reactions, and conflicted emotions".

The narrative presents Nora's sexual abuse as a profoundly disturbing convergence of affection and violations. In one of the most harrowing scenes, Nora's father approaches her with a seemingly benign Valentine's greeting:

"Behind her a man says, 'Nora?' She turns and looks.

'Daddy!' she jumps up, so happy to see him! ... 'Happy Valentine's Day, Princess,' he says.

He sits on the bed, takes her hand ... 'Say it,' he says. 'Kiss me,' she says, barely a whisper, and he leans in and kisses her softly on the lips. And he pops the candy in her mouth his hand on her leg, stroking stroking stroking ... 'Say it again,' her daddy whispers, now moving her back and forth back and forth slow back and forth fast on his lap ... 'Say it. Say. "Kiss me, kiss me,"' (Quinn, p. 152-54).

Here, the father's language, referencing fairy tales, princesses, and romantic fantasy, disturbingly aestheticizes the act, masking the incestuous violation within a lexicon of affection. This strategy simultaneously confuses a child's emerging understanding of intimacy, pleasure, and bodily autonomy. The scene exemplifies how adult sexual desire is imposed on a child's body, creating a traumatic entanglement of care, fantasy, and abuse.

Freud's *Three Essays on the Theory of Sexuality* (1905/1953) provides a crucial framework for understanding this dynamic relationship. Freud theorized that children possess infantile sexuality, which precedes the structured organization of adult sexual drives and is normally subject to repression as the child matures. In incestuous abuse, however, the adult enforces premature sexualization, bypassing developmental boundaries and introducing erotic experiences in a coercive, unilateral manner (Freud, 1905/1953). This premature imposition produces a paradoxical response: the child experiences sexual sensations along with fear, confusion, and guilt. Laplanche and Pontalis's (1988) concept of the "enigmatic signifier" further illuminates this psychic mechanism. Adults communicate messages charged with affect and desire that exceed the child's cognitive and emotional capacity to decode, embedding sexual meaning into their unconscious. Nora's whispered compliance—"Kiss me"—does not signify volitional consent but reflects her psychic entanglement in this unassimilable communication.

The narrative repeatedly highlights Nora's inability to comprehend or articulate the wrongness of the acts perpetrated against her as a child. In one scene, she and her brother James attempt to shield themselves from the



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chaos of parental conflict: “In her mind, she is seven, hiding in the bathroom with James, her hands pressed over his ears, trying to block out the voices of their parents fighting and slamming doors, slamming each other. Bang, bang, bang.” (p. 37) Here, the child’s world is already saturated with violence, verbal aggression, and unpredictability. The domestic space, which should provide protection and stability, becomes a site of fear and hypervigilance. Into this fraught environment enters the father, whose apparently caring gestures, such as drying her after baths, giving her candy, and complimenting her appearance, gradually serve to mask the intrusion of sexualized acts. The juxtaposition of nurturing behavior with sexual violation exemplifies what Ferenczi (1949) termed the “confusion of tongues,” in which the child’s legitimate needs for care and affection are exploited to facilitate abuse. This early disruption of boundaries and trust contributes to lasting psychological consequences, as the child cannot fully recognize, protest, or process the abuse, leaving the experience encoded in their unconscious (Freud, 1905/1953).

One of Nora’s most harrowing memories recounts, “Her father’s voice whispering, ‘Our secret, our secret, our secret,’ the hands rubbing between her legs, hard and fast” (Quinn, p. 181). The repetition of “our secret” functions at multiple levels. On the surface, it enforces the silence characteristic of sexual abuse, isolating the child through threats and demands for complicity. This echoes the earlier warnings, “her father’s mouth, breathing heavy in her ear, whispering, “If you tell, you will be alone. All alone. No one will believe you. If you tell, no one will ever believe you!” (p. 192). At a deeper psychoanalytic level, the injunction installs a repression. The child is compelled to bury the event in the unconscious, where it persists as an unassimilated fragment of experience. Freud (1920/1955), in *Beyond the Pleasure Principle*, linked trauma to the compulsion to repeat, suggesting that unprocessed experiences return through dreams, symptoms, and neurotic patterns precisely because they were never fully integrated into conscious memory.

Nora’s adult life, marked by intrusive recollections, dissociation, and psychic fragmentation, exemplifies the return of the repressed. The father’s whispered injunction, “Our secret,” resonates across time, producing what Caruth (1996) terms the “belatedness” of trauma. It is the delayed emergence of traumatic impact, generating symptoms that testify to experiences simultaneously lived and unassimilated. Moreover, the father’s oscillation between tenderness and violence erodes the child’s ability to distinguish care from harm, producing what contemporary trauma theory identifies as betrayal trauma (Freyd, 1996). The child experiences not only sexual violation but also a profound ontological rupture because the perpetrator is both an attachment figure and a threat. The diagram below (figure 9) illustrates how parental care and abuse converge to collapse emotional security, forcing the child into dependence on the abuser, silencing disclosure, and producing long-term psychological fragmentation.

The text emphasizes this through scenes of physical passivity. For example, “her hands stiff at her side. She is him. Her eyes closing” (Quinn, p. 181), indicating the child’s retreat into psychic numbing, a splitting of consciousness that allows survival amid inescapable violation. Ferenczi (1949) termed this identification with the aggressor. The child is unable to resist or flee, which internalizes the perpetrator’s desires and perspective. It forms as a dynamic that re-emerges in adulthood as self-blame, shame, and ambivalent attachment patterns. The father’s command, “No one will believe you,” further silences the child. The traumatic experience becomes unspeakable, lodged in what Caruth (1996) describes as “the unclaimed experience,” “returning only through flashbacks, nightmares, or compulsive repetition rather than coherent narrative memory”.

The long-term effects of Nora’s childhood sexual trauma, as the narrative suggests, include dissociation, guilt, and difficulties in forming and sustaining adult relationships, consistent with clinical accounts of survivors of childhood sexual abuse (Herman, 1992). However, the text resists providing full psychological closure. Memories appear in fragments, sensory flashbacks, and dreams rather than in a linear narrative form, reflecting trauma’s inherent resistance to integration. As Caruth (1996) emphasizes, trauma is communicated indirectly through gaps, repetitions, and disruptions rather than through coherent storytelling. Nora’s recollections of bathroom scenes, Valentine’s dresses, and whispered secrets function as screen memories (Freud, 1917/1955), which are vivid but displaced images that simultaneously reveal and conceal the traumatic core.



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The representation of sexual abuse in the novel intertwines Freudian notions of repression, the uncanny return of the repressed, and the traumatic collapse of family and psychic boundaries. The father's acts exemplify what Kristeva (1982) terms abjection, "a breakdown of the distinctions between love and violence, self and other, parent and lover, that ordinarily stabilizes subjectivity". The narrative deliberately leaves these dynamics unresolved. It signals that the aftereffects of trauma, including its repetitions in adult relationships and its inscription in memory and language, require further examination.

CONCLUSION

The analysis of *The Night Child* through Freudian psychoanalysis reveals how physical, emotional, and sexual abuse inscribe themselves upon the child's psyche, body, and language, shaping identity and symptom formation long after the events have passed. As Freud (1910, 1920/1955, 1923) observed, early relational trauma rarely disappears. It persists in the unconscious, returning as dissociation, anxiety, and compulsive repetition. Nora Brown's fragmented memories, bodily reactions, and psychic splitting illustrate Caruth's (1996) notion of trauma as both unforgettable and unassimilable, lived yet unspeakable.

Physical abuse marks the child through violence and fear, producing what Freud termed the "compulsion to repeat," where repressed experiences return through nightmares, bodily symptoms, and hypervigilance. Emotional abuse, expressed through humiliation, threats, and the maternal voice of condemnation, creates what Ferenczi (1949) calls the "confusion of tongues," in which the child internalizes the aggressor's voice, carrying shame and guilt into adulthood. Sexual abuse, enacted by the father under the guise of care, collapses distinctions between love and terror, tenderness and domination, imposing repression and secrecy while shaping Nora's psychic life through silence, ambivalence, and fragmentation.

Freud's concepts of repression, identification with the aggressor, and the return of the repressed illuminate Nora's dissociation, her creation of Margaret, and her difficulties with memory and speech. Contemporary trauma research (Herman, 1992/2015; van der Kolk, 2014; Teicher & Samson, 2016) confirms these depictions, linking early abuse to lasting psychological effects, including PTSD, identity disturbance, and relational difficulties. Yet the novel also emphasizes trauma's resistance to closure: memories surface in fragments, sensory flashes, and dreams rather than in coherent narratives, reflecting the psychoanalytic view that trauma exceeds representation and demands prolonged "working through" (Freud, 1920/1955).

In the study, *The Night Child* demonstrates that childhood abuse constitutes not only physical and emotional harm but a profound reconfiguration of the inner world. The maternal slap, the paternal whisper, and the verbal humiliation become what Laplanche and Pontalis (1988) term "enigmatic signifiers," messages charged with violence and desire that shape unconscious life long after the original events. By bringing together literature, psychoanalysis, and trauma theory, this study shows how narrative bears witness to trauma's persistence while leaving open the possibility of re-narration, therapeutic engagement, and psychic repair.





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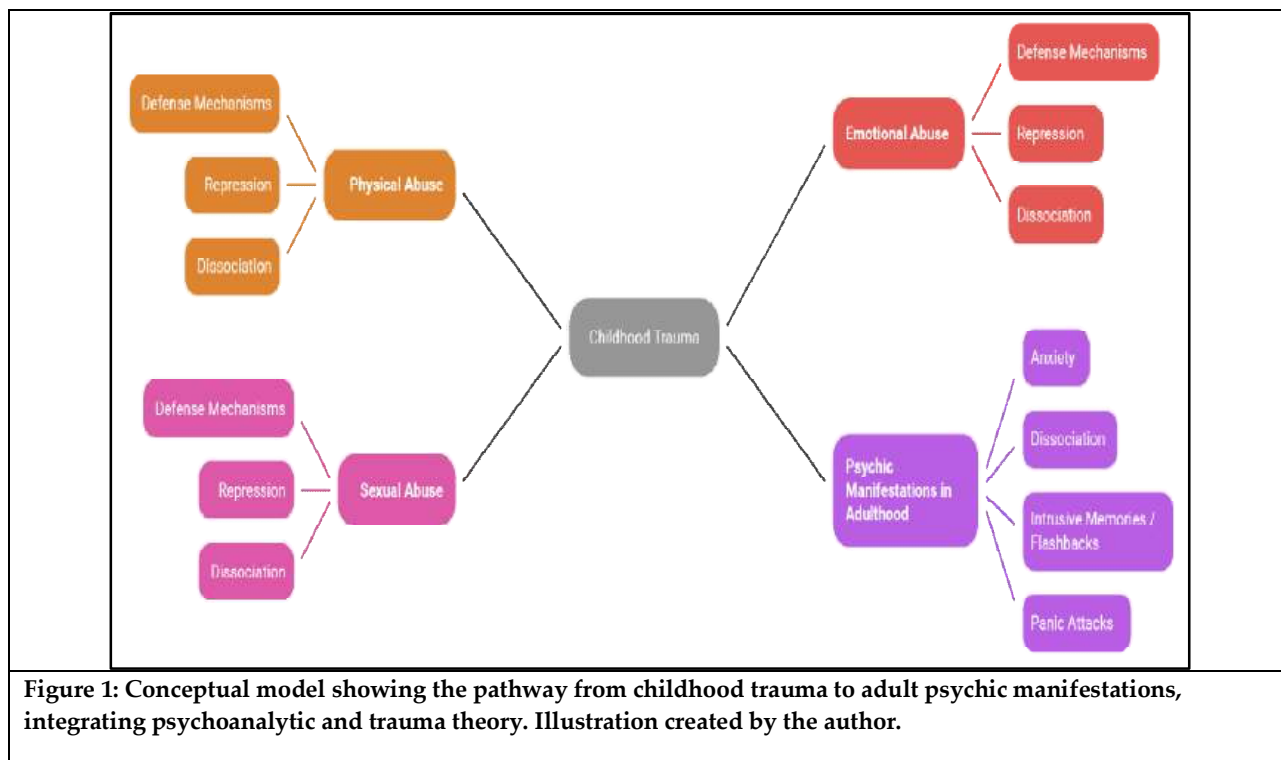


Figure 1: Conceptual model showing the pathway from childhood trauma to adult psychic manifestations, integrating psychoanalytic and trauma theory. Illustration created by the author.





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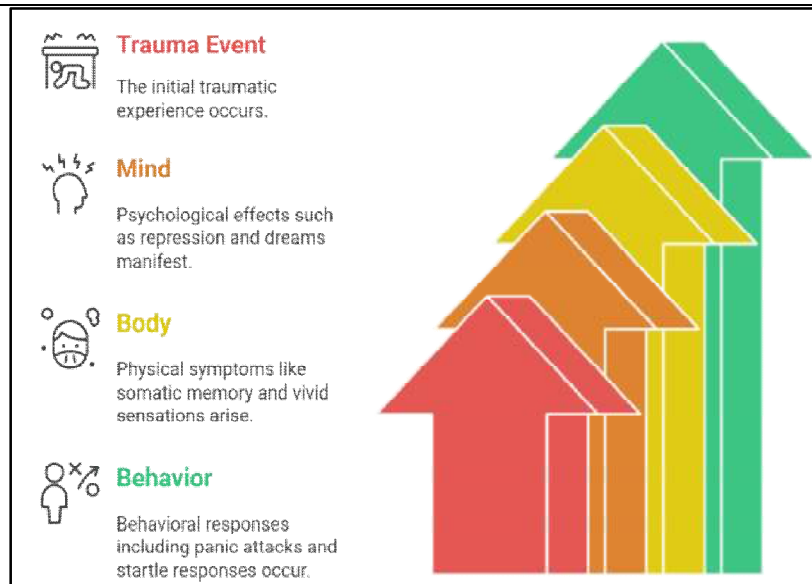


Figure 2: Mind-Body-Behavior Model of Trauma. Traumatic events manifest across mental, bodily, and behavioral domains, illustrating van der Kolk's (2014) insight that the body retains what the mind cannot process. Illustration created by the author.

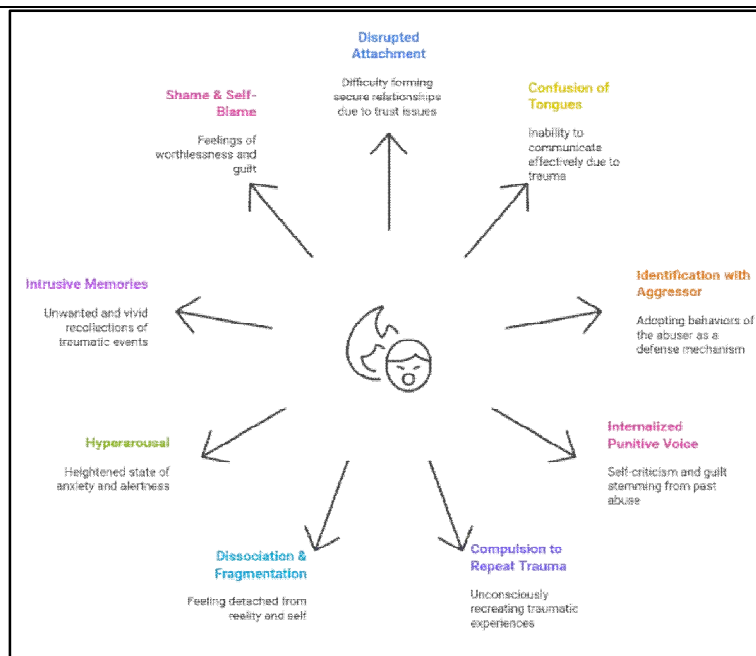


Figure 3: Effects of Childhood Abuse: A psychoanalytic-trauma model showing how abuse leads to lasting effects on relationships, the mind and the body. Illustration created by the author.





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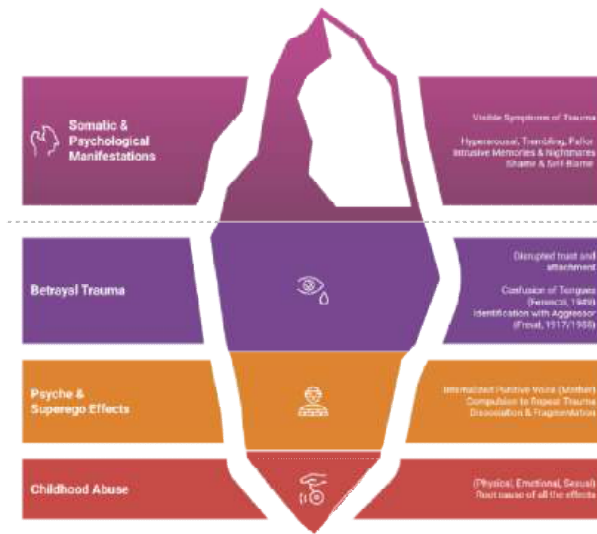


Figure 4: Conceptual Diagram of Psychoanalytic-Trauma Dynamics in Childhood Abuse. Illustration created by the author.

Concept & Theorist	Focus / Theme	Application to Nora
Betrayal Trauma – Freyd (1996)	Abuse by caregivers disrupts trust and attachment	Mother's care/abuse oscillation creates fear and confusion
Confusion of Tongues – Ferenczi (1949)	Child cannot decode caregiver's desires	Father's sexualized intrusion blurs protection and threat
Identification with Aggressor – Freud (1917/1955)	Child internalizes abuser's perspective for survival	Nora feels loyalty mixed with fear, causing fragmentation
Superego Formation – Freud (1923)	Internalized parental authority shapes self-judgment	Mother's criticisms become Nora's internalized guilt
Nachträglichkeit – Freud (1896/1955)	Trauma acquires meaning later in life	Flashbacks and fragmented memories emerge in adulthood
Somatic Memory – van der Kolk (2014); Samson et al., 2024	Trauma manifests in body and mind	Trembling, pallor, and psychic numbing reflect embodied trauma

Figure 5: Key Psychoanalytic Concepts and Their Application to The Night Child. This table outlines the central psychoanalytic theories of trauma and shows how they help explain Nora's experiences of abuse, her dissociative coping, and the persistence of trauma in bodily memory. Table created by the author.





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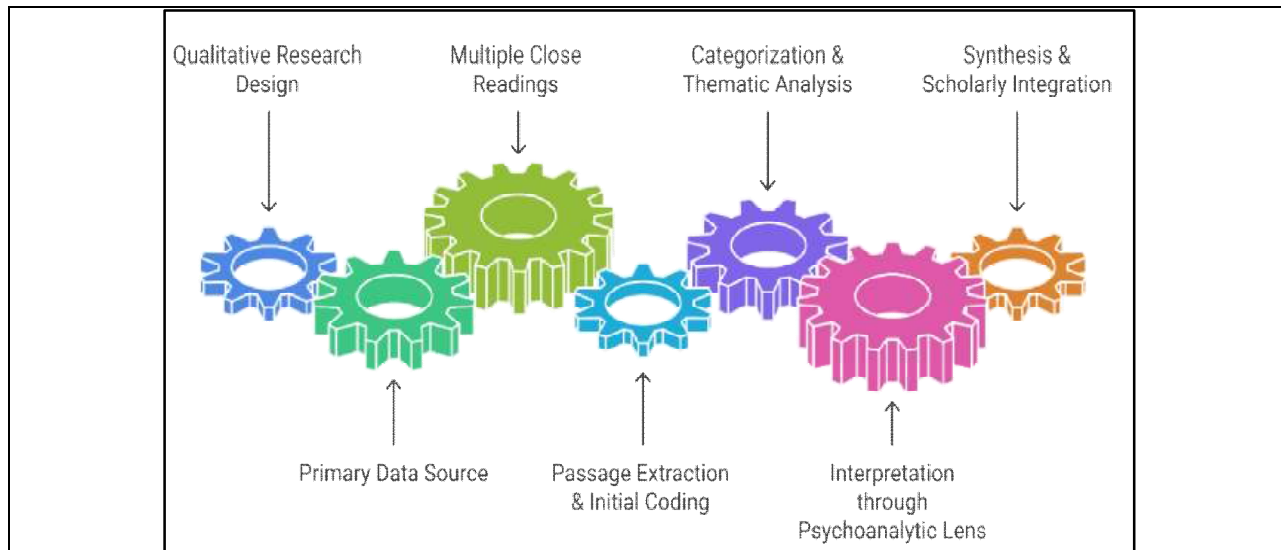


Figure 6: Visual representation of the Research Methodology applied in this study.

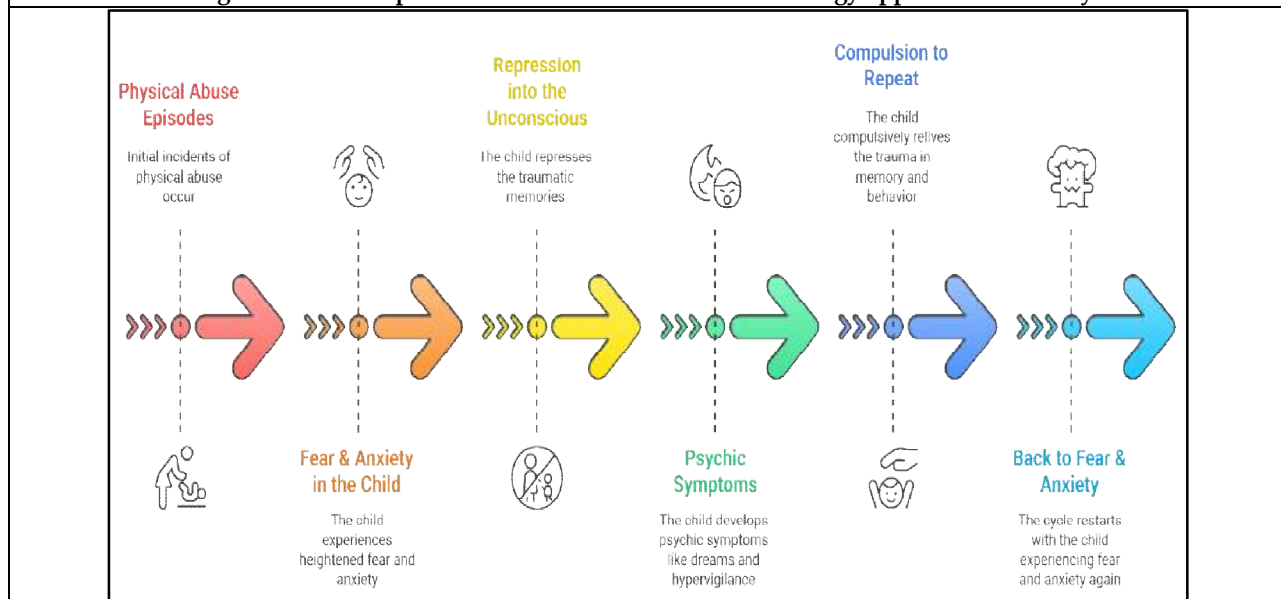


Figure 7: Psychoanalytic Trauma Cycle caused due to the physical abuse in The Night Child. Illustration created by the author.





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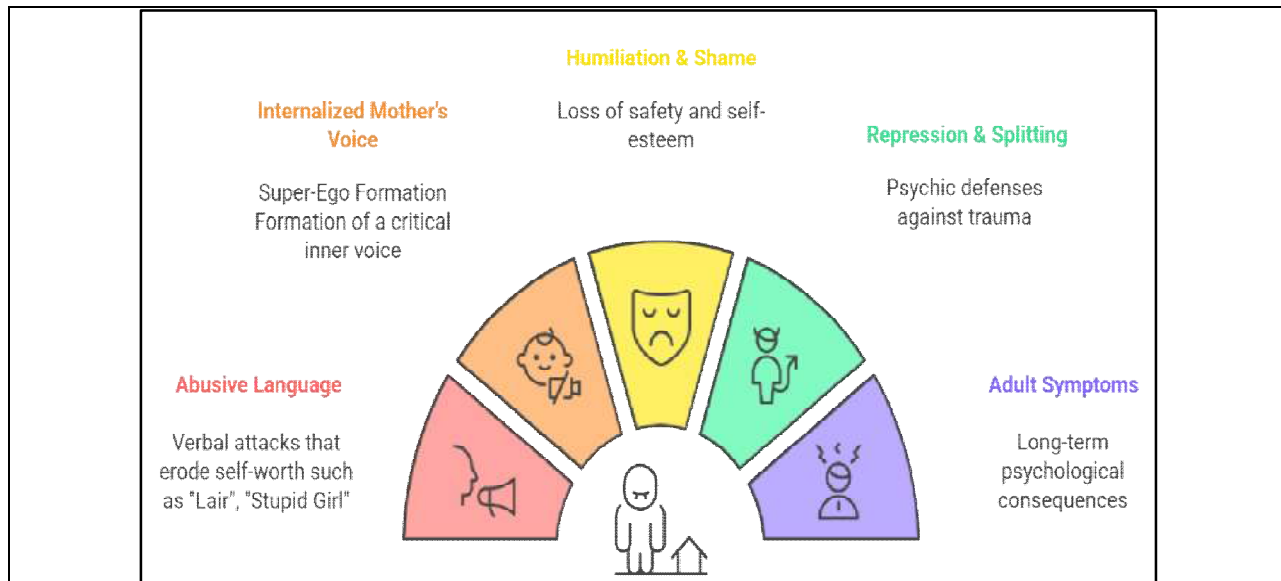


Figure 8: Flowchart illustrating the trajectory of emotional abuse in The Night Child.

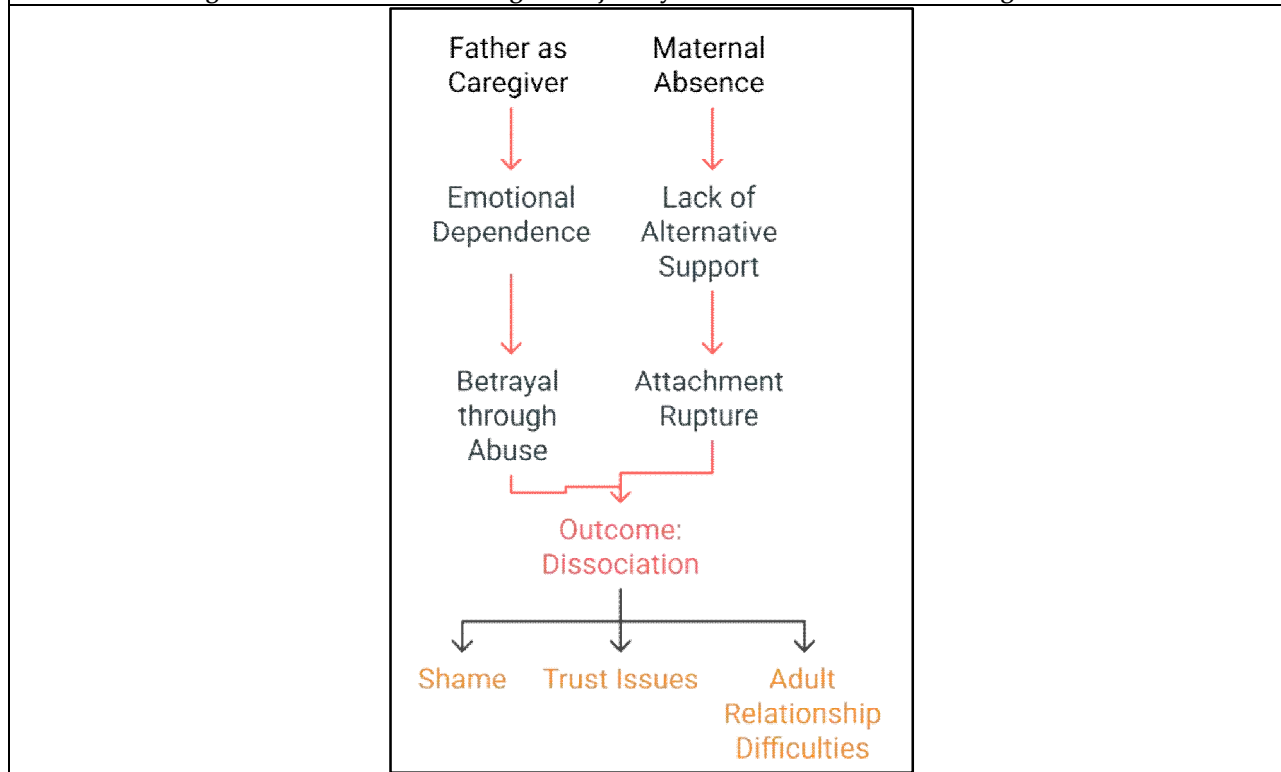


Figure 9: Betrayal Trauma and Attachment Rupture in The Night Child. Illustration created by the author.

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RESEARCH ARTICLE

Truth and Fabrication: Narrative Multiplicity in Philip Roth's *Deception*James Raaj^{1*} and M. Renuga²

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ABSTRACT

This paper aims to present an interpretation of Philip Roth's work "Deception," by scrutinizing the unique narrative approach the author employs. Roth engages in a sort of linguistic "wordplay" that draws the reader into both the structure and essence of the novel, often without their awareness. The frequent and chaotic dialogues create a whirlpool of conversations, both significant and seemingly trivial, that have the capacity to deceive – hence the title of the novel. This deception extends beyond mere marital infidelity; it intertwines with the art of storytelling and the way our lives are shaped by our own falsehoods and those of others. Interestingly, a protagonist named Philip and his female counterpart enact the tale of betrayal, employing dialogue tactics reminiscent of dramatic strategies. Their conversations seem to mirror a theatrical dialogue, with the ultimate goal of convincing the reader of the fusion between fiction and reality through ceaseless verbal circularity. Concurrently, the narrative's metanarrative essence appears to illuminate Roth's skepticism regarding the existence of a genuine truth in human relationships.

Keywords: Metafiction, betrayal, metanarrative, Philip Roth

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INTRODUCTION

Within Philip Roth's extensive body of work, "Deception" distinguishes itself through two significant aspects that characterize both its structure and content. The first aspect revolves around the cyclic nature of its narrative discourse, where tense, overlapping, and recurring dialogues engender a palpable psychological intensity within each character's situation. This divergence from the conventional plot progression seen in Roth's other novels like "American Pastoral," "The Plot against America," or "The Dying Animal" is evident. In these novels, a logical-temporal sequence of events unfolds, reflecting intricate contexts and relationships. "Deception," however, employs a unique narrative technique. It does not rely on a narrator to arrange the narrative flow. Instead, each moment unravels organically, with pertinent and seemingly insignificant words strategically intertwined, creating a swirling sensation where everything finds its place, albeit partially confounded. The innovation of "Deception" lies in its title, which serves as a framework for both the story's commencement and conclusion. This framework is populated with words that lend semantic depth to the apparent void enveloping the narrative. This results in a sort of literary playfulness, culminating in a text handed over to the reader who becomes partly immersed in the construction of the novel's verbal ambiguities.

The second significant aspect pertains to the deeply metanarrative essence of the text. This quality becomes apparent as all of the author's decisions contribute to constructing a narrative framework where Philip Roth, as the narrative voice, refrains from explicitly outlining the characters' roles and their interpersonal dynamics. As Claudia Roth Pierpont astutely observes, "the issue of intent – whether we accept his authorial explanations, whether the women are intended to be genuine – imparts a sensation akin to one of Escher's paradoxical creations" (Roth Pierpont 2014, p. 168). Maurits Cornelis Escher's etchings are famous for their utilization of geometric distortions. These distortions create paradoxical visual effects that almost contradict the very essence of what they portray. This results in a continuous redefinition of space. Similarly, in this specific novel by Roth, there is a resemblance to Escher's approach. Roth skillfully shuffles the narrative cards, providing both the reader and the characters themselves with a sense of bewildering interaction. The characters appear to navigate their lives in a state of dialogic confusion, societal instability, and existential uncertainty. This fluidity, central to the metatextual aspect of the novel "Deception," is made even more compelling by the introduction of a narrator named Philip, mirroring the name of the actual narrator. This narrative device serves a dual purpose. On one hand, it alludes to the cyclical nature often found in novels, and on the other hand, it directly ties into the inception of the metanarrative. This prompts us to ponder what storytelling truly is, if not a form of 'deception' in its essence. Fundamentally, the composition is shaped within the realm of ambiguity, a concept epitomized by Barthes in his piece "Writing Degree Zero." Published in 1953, this work thoroughly explores the examination of writing and language, delving into the intricate interplay between the writer and society. Furthermore, it delves into the intricacies of the creative process within the backdrop of societal expectations.

In this manner, Roth positions himself outside the confines of conventional literature, aligning with the realm of uncertain decisions that, as Barthes notes, align with "the requisites of an autonomously generated language." From this perspective, the notion of deception extends beyond the mere pattern of relentless unfaithfulness that defines the central character, someone consistently primed to embark on new liaisons while maintaining an air of innocence in the face of the theme of adultery. The core deception within the novel distinctly revolves around the domain of narrative craftsmanship. This is underscored by the fact that Roth employs writing as the platform where he intricately stretches the interplay between fiction and reality, a dichotomy that can be identified as the clash between authenticity and falsehood, to its utmost ramifications. In many respects, the author presents a narrative composition that, albeit indirectly, brims with a succession of inquiries: How profoundly are our everyday lives shaped by both our own lies and those propagated by others? To what extent does infidelity symbolize a narrative construct that we transmit to the person who has been betrayed, a kind of fictional storytelling? And above all, a question of paramount narratological significance: Why is "Deception" structured in a manner that persuades the reader of the





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seamless fusion of narrative fiction and actuality? In essence, the overtly autobiographical elements provide the cornerstone for this novel, which essentially recounts an act of betrayal. Within this context, literary fabrication metamorphoses into the tale of an autobiographical fabrication, wherein the reader is granted insight into how the protagonist Philip Roth (a figure expected to be genuine but necessarily adheres to literary conventions) delineates his personal variant of deceit. This deceit, within the context of the story, materializes as adultery and, consequentially, the breach of trust directed at his spouse. Indeed, we are stepping into the realm of metafiction here. However, underlying the tension of metanarrative lies something more intricate than a mere plot involving characters betraying their partners. As pointed out by Margaret A. Rose, parody and metafiction inherently challenge "an attack (implicitly or explicitly) on theoretical oppositions between reality and unreality in the artwork or as given in the canons of literary criticism" (Rose 1979, p. 150). Ultimately, Roth's aim is to expand the horizons of his creative writing by employing a tactic that, in terms of pleasurable reading, dismantles all the elements stipulated by the narrative pact. This approach is intended to furnish the reader with a dynamic text that, above all, serves as an experiment and, we would venture to add, as an intense self-portrayal in the guise of autobiography through profound dialogue. We refrain from using the term "pseudo-autobiography," though it might appear more accurate, because an entirely candid and truthful autobiography is a notion that doesn't truly exist. All autobiographies present a perspective on life wherein order supplants disorder, the linear arrangement of events takes the place of the chaos of everyday existence, and the artifice of reconstruction supersedes the objective truth of occurrences. In essence, there is a point where autobiography and fiction merge.

Furthermore, we can also contemplate a Victorian autobiography like Trollope's, among various others. "Deception" is fundamentally constructed upon this very type of ambiguity, although it employs dialogue as its predominant mode to establish greater credibility for autobiographical fabrication. In this context, Searles has astutely observed: "True to its title, Deception is deceiving. Despite the erotic hard sell of the dust jacket, there are no graphic descriptions of sex – or of anything else. The novel is pure dialogue, without a phrase of exposition or attribution, without asingle 'he said' or 'she said' – just bare-naked talk" (Searles 1992, p. 254). This dialogue, which is rendered without the inclusion of descriptive instances or linguistic markers that typically indicate the speaker ("he said," "she said," and the like), constructs a version of events with the intent of imparting an impression of authenticity. It has been duly noted earlier that the narrator is acutely aware of the ruse being played. Yet, he finds himself unable to evade his own belief in it, entrusting his words—which, much like any written expression within a narrative creation—necessarily operate within a backdrop that is not truly real. Needless to say, this suspension of disbelief on his part becomes equally shared by the reader.

The convergence of reality and fiction initiates at the very crossroads of character nomenclature. At the diegetic layer, this marks the primary hint that the discourse seemingly alludes to autobiography—an initial-person recollection of a personal ordeal centered around betrayal. However, beyond merely hinting at betrayal, the use of the name "Philip" for the protagonist serves as a pivotal element in the overarching strategy of ambiguity. From the standpoint of the novel's construction, this element assumes the role of a pivotal structural component. Simultaneously, it is crucial to emphasize that "Deception" does not adopt the format of a personal journal or a textual confession: it is, in essence, a work of fiction, not a replication of something anchored in reality. In this regard, the significance of the protagonist's name "Philip" holds no interpretive weight. What remains evident is that the authentic Philip Roth is credited above the title, signifying his ownership of the copyright for "Deception." Meanwhile, the character within the narrative emerges as a creation stemming from the author's imaginative prowess:

Most of Deception consists of precoital and postcoital conversations between adulterous lovers: an unnamed literary Englishwoman and a Jewish-American novelist named Philip, who is living in London. Roth, too, is a Jewish-American novelist who has lived in London, but insists that Deception is fiction, not autobiography. The novel's protagonist offers the same argument to his shocked wife after she discovers a notebook recording his conversations with his mistress. He tells her that he made the whole thing up, that she has been taken in by a trick of literary ventriloquism. (Johnson 1990, p. 66)



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From a semiotic standpoint, Roth's inclination to amplify the potential of narrative generates a sense of alienation within the reader. In numerous respects, those engaging with "Deception" will discover themselves, to borrow Wolfgang Iser's expression, within "a kind of uncharted territory of implicit connections, and it's precisely these connections that actively engage the reader within the novel" (Iser 1990, p. 136). While the critic's allusion pertains to Faulkner's masterwork "The Sound and the Fury" (1929), it is fitting to extend the same assessment to Roth's approach, one that, as observable in his other literary works, draws explicitly from his personal existence. Indeed, in the realm of literature, personal everyday encounters serve as a pivotal catalyst for igniting the flames of creative imagination. Hemingway, for instance, could not have vividly depicted Africa and the pursuit of game without firsthand experience. Faulkner could not have woven a tapestry of Southern American cotton planters and the African American community without having directly observed these characters. Similarly, John Fante consistently drew from his own life, yet he was acutely aware that his self-expression through writing took on a form distinct from strict autobiography.

In a similar vein, Roth possesses a keen awareness of the intimate connection between the various junctures of his own experiences as an American Jew and his literary craft. However, he is equally conscious that the art of storytelling is distinct from life itself, recognizing that when personal experiences transition into the realm of fiction, they cease to remain strictly autobiographical. Roth deftly navigates this terrain, as highlighted by Gooblar, always adhering to "a refusal to impose a restrictive and reductive vision upon a reliably complex and unknowable world" (Gooblar 2011, p. 155). In numerous respects, the novel delves into this intricate and enigmatic reality, employing a technique that, in its linguistic execution, evolves into a narrative of equal intricacy and opacity.

It is important to emphasize that the novel's framework emulates a theatrical enactment, predominantly centered on the exchanges transpiring between the protagonist, Philip, and his female conversational counterparts. Within this context, "Deception" markedly diverges from Roth's other literary creations, as it adopts a presentation that closely resembles the dialogues of a stage play. In different words, this work cannot be strictly classified as a conventional novel, as its composition mirrors the intensity and tempo of a theatrical performance, wherein voices take turns within the same space, seemingly revolving around themes of love and the various manifestations of betrayal, whether they are of a psychological nature or confined to the physical realm.

The hybrid nature of the work also entails a blending of language, which deliberately employs a destabilizing effect on the reader to closely mimic real-life occurrences. From a narratological vantage point, it seems that Roth has taken Henry James's notion of characters living more through actions than explanations to its utmost consequences: the narrator's role is to demonstrate how characters move and converse, avoiding external descriptions or explicit declarations of their morality, whether they are virtuous or flawed, unfaithful or loyal, honest or deceitful. In "Deception," Roth refrains from being judgmental or categorical; he solely presents the dialogues exchanged among characters, abstaining from adopting the perspective of an intrusive narrator. While this technique indeed thrives within the realm of theater (where characters are identified by their appearance, attire, and vocal inflections), its efficacy is somewhat diminished when transposed onto the printed page. Beneath the dramatized situations crafted exclusively through dialogue, there unmistakably resides a strategy that draws parallels to psychoanalytic therapy. Here, words metamorphose into the foundation upon which a remedy for the struggles of existence is erected, transitioning from gratification to dissatisfaction. Nevertheless, it holds true that "Deception" represents therapy in a negative or even disdainful light. This aspect becomes particularly evident through the words of Philip's lover: "Actually, I think they're all quite creepy [...] I didn't think I'd heard anything that I hadn't thought a million, million times before" (Roth 2006, pp. 144-145). As noted by Mauren Scheurer, "While therapeutic talk is disparaged [...] the entire novel is written in dialogue and has the quality and intimacy of a therapeutic exchange" (Scheurer 2015, p. 42).

Consequently, prior to embarking on an analysis of the text as metatext, it is crucial to underline this characteristic which, in numerous aspects, not only challenges the conventional structure of the novel but also profoundly impacts the reader's process of interpretation. Consequently, a heightened level of ambiguity emerges, casting a shadow over the discourse itself and engendering ontological uncertainties (often encapsulated by the female characters





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questioning "what am I doing here?") as well as psychological divisions (the genuine author himself seems torn between embodying the character and embodying the implied author who narrates said character). As is a common occurrence within Roth's literary works, the opening words not only unveil the theme that will be explored but also provide insight into the author's approach to unfolding the narrative and the manner in which he employs various techniques and rhetorical methods. In the instance of "Deception," a meticulous examination of the initial page exposes the precise thematic and narratological parameters that distinguish the narrative.

'I'll write them down. You begin'.

'What's it called?'

'I don't know. What do we call it?'

'The Dreaming-About-Running-Away-Together-Questionnaire.'

'The Lovers-Dreaming-About-Running-Away-Together-Questionnaire.'

'The Middle-Aged-Lovers-Dreaming-About-Running-Away-Together-Questionnaire.'

'You're not middle-aged.'

'I certainly am.'

'You seem young to me.'

'Yes? Well, that shall certainly have to come up in the questionnaire. Everything to be answered by both applicants.'

(Roth 2006, p. 7)

Evidently, a dialogic framework emerges that forgoes the customary constituents found within a narrative composition. The initial portion makes it evident that there exists an "I" and a "you," simultaneously alluding to the central activity: writing. Simultaneously, the declarative tone of "You begin" implies a metanarrative and almost redundant manner of commencing: the first-person narrator informs us that someone is initiating a discussion about themselves, immediately ushering us into a psychological and existential realm. However, this self-focused approach is somewhat counterbalanced by the subsequent statements. Indeed, his response to her inquiry signifies that the title of the piece will be "The Dreaming-About-Running-Away-Together-Questionnaire." However, once the title is introduced, it also sparks an imagery of a reciprocal linguistic skirmish. The woman inserts the term "lovers," thus altering the title. This alteration prompts Philip to respond with a touch of self-deprecating humor, appending "middle-aged." The initial exchanges predominantly revolve around the questionnaire, which, in a sense, they immediately proceed to fill out, effectively rendering the words the reader has encountered so far as a preamble. This is so pronounced that the initial phrase commencing the subsequent section (post-preamble) is precisely "Begin," the very word that inaugurates the novel. The initial reflections prompted within us, the readers, pertain to a sense of disorientation precisely because our anticipations are unfulfilled. On the contrary, they generate a form of psychological dissatisfaction.

Certainly, it is difficult to overlook the fact that Roth is demanding a form of narratological exposure within his narrative text, an aspect that resonates in the minimal presence of contextual cues (such as spatial and temporal indications). The level of information presented is notably reduced compared to what one would typically encounter in a twentieth-century play, where even if briefly, the spatial context is depicted and the characters' names are conventionally included in the written text alongside their dialogue lines. Consequently, the pursuit of this intentional silence regarding the characters and the context of the unfolding events scarcely inhibits us from contemplation. Rather, it propels us to consider that Roth, the author, aims to construct a scenario where textual austerity acts as a conduit for the internal vulnerability of the characters:

'Begin.'

'What's the first thing that would get on your nerves about me?'

'When you are at your worst, what is your worst?'

'Are you really this lively? Do our energy levels correspond?'

'Are you a well-balanced and charming extrovert, or are you a neurotic recluse?'

'How long before you'd be attracted to another woman?'



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'Or man.' (Roth 2006, p. 8)

As previously highlighted, the second use of the word "begin" serves as a verb that, within the narrative framework, appears to nullify the impact of the initial "begin," which effectively functioned as a false start. This initial deviation perhaps aimed to momentarily divert the reader's focus as they grapple with comprehending the dialogical structure Roth has crafted. Up until this point, the narrative's primary focus has been centered around the concept of a questionnaire, which, in various ways, conveys the notion of a psychoanalytic session rather than a dialogue rooted in reciprocal exchange of information. Notably, an evident sense of circularity is established in the questions, especially in the initial pages. Whenever she poses a question ("What's the first thing that would get on your nerves about me?"), Philip consistently counters with another question ("When you are at your worst, what is your worst?"), strategically prompting her to elaborate further rather than providing direct answers. In essence, these questions evolve into not only a questionnaire but also a form of self-examination bordering on obsession. Subsequent sessions witness a progression of these somewhat assertive queries, akin to the expansion of concentric circles. Indeed, Philip inquires about her personality ("Are you a well-balanced and charming extrovert, or are you a neurotic recluse?"), and her response takes the form of a very personal question directed back at him ("How long before you'd be attracted to another woman?"), a query that deftly shifts the discourse toward matters of sexual ambiguity ("Or man"). Consequently, the outcome of this exchange isn't just an ambiguous questionnaire, but rather its antithesis—a form of dialogue that can be aptly characterized as an "anti-questionnaire."

The novel's concluding pages firmly establish that the dialogue revolving around the questionnaire bears no correlation to the narrative or the portrayal of betrayal. Beneath the structure of rapid exchanges and the utilization of a realistic and seemingly transparent language, lies the actual essence of "Deception," which centers around the question, "Should I write it?" The true inquiry delves into contemplations on the narrative approach and the discourse that may or may not be transcribed. Were narrative creations to encompass every notion traversing an author's mind, chasms would open up, into which the very act of writing, distinct from reality, would plummet. To narrate entails an engagement with the realm of falsehoods, for writing is fundamentally an artifice. It isn't truth that is recounted, but rather artful deceptions, sleights of hand, and facades of the self—akin to the manifold masks that every individual dons, much like the characters within "Deception." As the novel culminates, the ultimate extended conversation with his past lover shifts once more toward discussions of books rather than individuals. The central concern pivots more towards the methodology of narration rather than the content to be narrated, focusing on identifying authentic characters and distinguishing between reality and fiction. This sentiment is encapsulated by the phrase: "However visible you may be feeling, you weren't identified in that book or made overtly identifiable."

However much you may have served as a model, the great British public happens to be ignorant of it and you only have not to tell them for them to remain ignorant" (Roth 2006, p. 201). Consequently, a recurring theme emerges once more, echoing the inception of the narrative, juxtaposing actual and fictional occurrences. Evidently, for a writer akin to the one portrayed by Roth, his creative fiction holds greater value than the tangible reality that merely serves as a wellspring of inspiration. This sentiment is perfectly exemplified by the tale that has just been penned: the utmost priority is to obscure any trace of the source material's identity. It is not coincidental that his lover draws conclusions aligning precisely with the real-life state of affairs, indicating that the writer's preoccupation is predominantly centered around his craft: "What it comes down to is that a woman comes to a man to chat a little, and all the man is really thinking about is his typewriter. You love your typewriter more than you could ever love any woman" (Roth 2006, p. 201, my emphasis). The narrator-protagonist's retort holds significance, as from a narratological standpoint, he confuses the fabrication of fiction (embodied by the typewriter) with the actuality of the model that has spurred him. Characteristically, Philip's existence is woven from a tapestry of written books and those yet to be penned. This is why, within their final extensive telephone exchange, the woman underscores the fact that his book would unfold in an alternative manner, elucidating their emotions with greater clarity: "And it—my book—is all about kissing and telling because if I were to write this book, I would be doing that" (Roth 2006, p. 201, emphasis in the text). In response, Philip suggests that she should endeavor to compose a novel, recounting her own perspective on the events:





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'Should I write it?'

'I'm not the one to say no, especially as I may do another about you.'

'You wouldn't. You're not. You aren't, are you?'

Laughing. 'Yes, of course I will. This'll be part of it.'

'Well, I'd be amazed. I would call that scraping the barrel, really.'

'Don't underestimate yourself. You're a great barrel. For me you were.'

'Was I? Oh, I felt so angry. I was angry for months. Although I was very torn, really, because as soon as I read it, I also couldn't be angry.'

'Why was that?'

'Because it was so, so tender... I think. Unless I got it wrong.'

'No. I thought there were some things you'd like. Things I planted just for you to be amused by.'

'Oh, there were. I didn't miss them. It was very strange reading it, absolutely strange. Because I was in no doubt which of it was addressed to me. I may have been wrong but I felt no doubt. And which bits of it were not, particularly.'

'I'm sure you didn't miss any of it. But that was our life, I thought, as it might have been. Our life also.'

'I saw. I saw. It's such a strange story.'

'I know. No one would believe it. (Roth 2006, pp. 201-202)

The epilogue revisits the notion of the book and its creation, stating, "It was very strange reading it, absolutely strange." In this manner, the writer—distinct from the Philip within the narrative—conveys that his novel might not yet encompass the entirety of his imagination's constructs around a love story conveyed through the lens of betrayal. Indeed, the phrase "I may do another [book] about you" also communicates to the reader that, from a narrator's perspective, imagination possesses an almost boundless quality. The writer's task involves transforming seemingly trivial details into substantial narratives, thereby opening the door to an unending continuum, utilizing the same event as a foundation. This isn't a matter of "scraping the barrel," but rather, initiating the narrative machinery anew. When Philip tells the woman, "You're a great barrel. For me you were," he's essentially confessing that, for a narrator, there is never an exhaustion of material. Reality is an infinite expanse from which an endless stream of stories can be drawn, an idea eloquently expressed by Maurice Blanchot.

To prevent any potential misinterpretations, the closing lines of "Deception" unequivocally convey that novels are crafted to be read and to convey the enigmatic journey of human existence: "It was very strange reading it, absolutely strange." Undoubtedly, the woman's words serve as an insightful revelation, akin to an epiphany of reading. The strangeness she alludes to is intricately linked with the capricious escapades of human life, the intricate formation and dissolution of relationships, and the intricate "particular web" that embodies our interactions with others and society at large. Indeed, we coexist in a state of simultaneous isolation and companionship, possessing both autonomy and freedom while being tethered and somewhat confined by emotions, routines, and familial bonds. Philip Roth's brilliance within this specific novel lies in his masterful staging of these facets. He achieves this by magnifying the spectrum of possibilities presented by the art of narration, along with its artifices and conventions. For this very reason, "Deception" can rightfully be regarded, within its metanarrative scope, as one of the most profound embodiments of Roth's experimentalism.

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RESEARCH ARTICLE

Narratives of Introspective Peregrination and Emotional Transformation in Amulya A Malladi's *A House for Happy Mothers*

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ABSTRACT

Life is a journey which is not only physical, but also emotional. Literally the former journey involves body movements navigating through geographical space, the later journey denotes self-reflection. This article explores the concept of introspective peregrination in Amulya Malladi's *A House for Happy Mothers* by focusing the central characters particularly Priya and Asha, who undergo profound inward voyages, eventually often shaped by life experiences, sterility, economic vulnerability, and societal expectations. These experiences inaugurate a process of introspection which directs the characters to resist feelings of guilt, displacement, moral conflict, and emotional uncertainty. Though the novel primarily spotlights the practice of transnational surrogacy, simultaneously it portrays a profound inward journey experienced by women navigating motherhood, identity, and agency within multifaceted socio-cultural frameworks. Through moments of reflection, struggle, and interpersonal interaction, the narrative illustrates how these women gradually move toward resilience, emotional awareness, and redefined identities. The article views how the characters endure profound emotional conflicts, introspection, and gradual transformation as they combat sterility, economic hardships, and societal expectations. Furthermore the article highlights introspective peregrination as a narrative framework which cultivates emotional transformation, enabling them to reconstruct their sense of subjective identity while navigating the intricacies of motherhood and belonging in a globalized world.

Keywords: surrogacy, motherhood, psychological renaissance, Carl Rogers' humanistic theory, emotional transformation.





INTRODUCTION

Narratives of Introspective Peregrination and Emotional Transformation in Amulya Malladi's *A House for Happy Mothers*.

"Life is a journey that must be traveled no matter how bad the roads and accommodations."

Oliver Goldsmith.

The concept of journey is the center of ancient, modern, and of all literature, in the world. The word peregrination literally means a long journey, often across borders, or unfamiliar geographical space. It represents vivid images of wandering, exploring new identities and transformative movement. In literary contexts, the term introspection denotes a process of self-scrutiny through which an individual examines personal emotions, motivations, and identity. Life is a journey which is not only physical, but also emotional. Literally physical journey involves body movements navigating through geographical space. An emotional peregrination denotes an inward voyage through psychological, moral, or spiritual landscapes. Emotional peregrination simply signifies, moving through distinct emotional states, eventually often shaped by life experiences, growth, loss, self-discovery, and transformation. We meet different persons with distinct characteristics in different environments. Each individual gives us different experiences and teaches us lessons that reflect in reconstructing our identity. The present research study analyses the inward peregrination and emotional transformation of Amulya Malladi's women characters in the novel *A House for Happy Mothers*.

Amulya Malladi's *A House for Happy Mothers* is not just a novel about poverty and surrogacy but it is solely an intensive exploration of introspective peregrination - the inward odyssey of self-discovery, autonomy, motherhood, and moral responsibility within unequal social structures.

Physical Journey

"The experience of motherhood is a complex and multifaceted one, and it cannot be reduced to simplistic or romanticized notions." (Rich 67). While society often associates women's identity to motherhood, a woman's sense of self surpasses beyond this single dimensional role. The central character from this novel, Priyasha, the protagonist, an Indian-American affluent woman, is not blessed with a child. She becomes completely upset, after three miscarriages. Jane comments, "A woman is a giver of life, a means of moving forward and perpetuating the human race, at the same time the cruel onslaughts of fate lead to her despondency and withdrawal" (4). Priya's fondness for motherhood leads her to undertake a journey from Silicon Valley to a small village in Southern India to pursue surrogacy, is a literal displacement.

"The idea that poverty leads to victimization through systematic exclusion" is rooted in Social Exclusion theory (Silver 542). Asha, another protagonist, a poor Indian woman, driven by economic necessity, moves to the 'Happy Mothers House' in Hyderabad, leaving behind her family and rural geographical space. In this perspective, the novel's narration itself is a peregrination - a crossing of geographical and social frontiers that elevates both women to confront realities beyond their familiar worlds.

Inward peregrination of the protagonists

A character becomes introspective when he/she reflects deeply about their choices and actions, reexamine his/her identity, values, personal beliefs, and analyse and interpret their emotional experiences. Priyasha's journey is not only determined by physical voyage but also by profound internal peregrination- a psychological, emotional, and ethical transformation shaped by sterility, surrogacy, diasporic identity, and ethical conundrum. Priyasha's sterility becomes a conundrum that has shaken not only her identity but also her conjugality with husband Madhu. Both are disappointed due to their previous miscarriage pregnancies.





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Priyasha tries to hide her pregnancy, so she expresses the following, “Depression was hell on the libido” (Malladi 104) to her husband Madhu. She remains silent for six weeks, after that discloses her pregnancy to Madhu who finds her untrustworthy and shouts at her “I’m scared of losing the baby, too. We could’ve been scared together. But I think you should be scared alone this time. I’m done worrying about this shit” (Malladi 106). The ultrasound identifies that the fetus has no heart beat, hence that pregnancy also ends in DNC. Though she deeply anticipates her husband’s gentle hugs and shoulders for support, she doesn’t call him. Because she knows pretty well that it wounds their conjugality. Madhu leaves the house with a broken heart by taking all of his things when he comes to know about the DNC for the third time. Though she in the initial phase of pregnancy “wanted to be alone; it hurt too much—her body, her heart, everything and it hurt more to have a witness to her pain, her grief, her ultimate inadequacy as a woman.” (Malladi 106). The three weeks of loneliness torments her day and night constantly and “she was alone...She lost weight, nearly eight pounds in two weeks. She couldn’t eat, couldn’t sleep, couldn’t feel” (Malladi 110). Priyasha experiences isolation during the DNC and the following three weeks without her spouse. The pain she experiences is both physical and an internalized grief as well. Madhu’s absentia makes Priyasha feel emotionally detached, and induces her fear that sterility is her burden alone. Madhu’s inability to comfort her causes the separation of the couple which vividly pictures the unspoken anxiety and conflicts in their marriage.

Priya’s inward peregrination can be comprehensively inspected through feminist lens, which illustrates how gender, power, globalization, and inequality shape her experience. Priyasha experiences anxiety to fit in the society to evade social ostracism. After a long search, Priyasha landed into a surrogacy clinic in India. As Priyasha travels through the complexities of surrogacy, she encounters judgment, criticism, and even hostility from those around her, including her own family and community. “I felt like I was drowning in a sea of expectations, my own and everyone else’s” (Malladi 63) shedding lights on Priyasha’s emotional suffocation and overwhelm. As a result, she stands as a shattered persona due to paternal society’s expectations. The inability to fulfill the basic anticipation imposed by patriarchy provokes a condition of significant emotional strain of a woman. Priya expresses, “I felt like I was losing myself, bit by bit, with each passing day” (Malladi 228). It evokes Priya’s conflicts with her own identity and sense of self. It is evident that Priya’s persona is fractured and she misses herself badly. But she doesn’t allow it towards destruction; rather reconstruction through enduring transformation. She reconstructs herself by stepping forward to choose a surrogate mother, Asha. Hence, from a feminist perspective, Priya’s sterility reveals how patriarchal norms equate womanhood with motherhood. The Society concerns the dignity of a woman through reproductive ability. Priyasha initiates, to hire a surrogate mother, truly challenging patriarchal definitions of motherhood.

Subsequent to numerous interactions between Priyasha and husband Madhu, they meet Dr. Swati Gudla who arranges the surrogate mother Asha for them. Asha, the second protagonist, a married woman with two children Manoj and Mohini, contemplates providing better education for her children regardless of her penury. The subsequent articulation of Asha, “I was just a vessel, a container for this tiny human being, but what about my own desires, my own dreams?” (Malladi 130) accentuates her conflicts with her own identity and intense aspirations as a mother. The following discourse, “I had never felt so alone, so scared, and so unsure of what the future held for me and my child” (Malladi 244) spotlights her dreads, instability and conflicted emotions about decisions or the future as a mother. The inability to fulfill the basic needs of a family constitutes a condition of significant emotional strain of an individual. The conflict between Asha and her husband Pratap with regard to surrogacy fetches out the profound emotional peregrination and the struggle of a surrogate mother. Asha shouts, “Maybe if I died while giving birth, no one would care...I’m stuck here with someone else’s baby in my stomach because you can’t support us” (Malladi 120).

Asha initiates her decision to become a surrogate mother, because she aspires to secure a prosperous future for her son Manoj by facilitating him to become an engineer in a reputed company in America. However, her impoverished circumstances drive her to assume the role of a surrogate by carrying the child of Madhu and Priyasha, individuals who are entirely unfamiliar to her. Her life exemplifies the painful realities of an uneducated, and economically deprived woman in Indian society, who endure adversities at every stage of her existence. The following utterance of Asha “I was a vessel, a container, I’m a womb . . . a belly. If tomorrow, they could save me or the baby, who would





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they save, you think?" (Malladi 165) illustrates her emotional exhaustion and thereby challenges poverty, patriarchal constructions of womanhood and motherhood. Being a surrogate, Asha faces a lot of emotional conflicts. She grows emotionally attached with the child in the womb and isn't ready to give up the baby to its biological parents. Even though she carries the child for money, her motherly emotions, care and sacrifices are true. This is comprehensible from her interaction "You wouldn't believe the thoughts I've had about her taking my baby" (Malladi 280) with her sister-in-law Kaveri, who reminds Asha that it's not her baby but Priyasha's. After becoming pregnant, Asha forgets one of the emotions, laughing. She always seems serious and somber. At that time, she laughs at Pratap's joke, Manoj sweetly says, "I like to see you laugh. You should do it more." (Malladi 160) and she hides all her pain and assures her son that she will laugh all. "A good laugh is sunshine in the house" (Thackeray). Accordingly, Asha emerges as a beacon of light, illuminating people around her through hope amid adversity.

Poverty haunts only her body but not her good nature. She seems more emotionally attached to the baby before its birth. As she bears physical pain, but not the pain in her heart, so she says:

But after just four pushes, she felt the baby slide out of her and heard its first cry. It was the last time she felt the baby, the last time she heard it, the last time she was connected to it. Once they cut the umbilical cord, it was like a dam had broken, and Asha started to howl...Asha closed her eyes...God, please don't make me see the baby, she thought. Please, let them take it away, far away from me. I can't bear this. (Malladi 295)

Consequently, Asha demonstrates the inscrutable emotional world and the journey of the surrogates.

Carl Ransom Rogers is a prominent American psychologist and foremost pioneer of the humanistic perspective in psychology. Roger's humanistic psychology comprises a theoretical approach which accentuates awareness of one's potential and the process of one's personal growth. Through his humanistic perspective in psychology, Rogers initiates and has developed 'client-centered therapy', also known as 'person-centered therapy' that emphasizes unconditional positive regard, empathy, genuineness, and self-actualization. At the time of delivery Asha endures a lot of pain, but she refuses to take pain killers when the nurse offers it, just because those pills will affect the baby. Consequently, Asha reflects genuine human integrity, and unconditional positivity which was proposed by Carl Ransom Rogers. During the childbirth, Priyasha "was worried not only about the baby but also about Asha. She had gotten to know Asha and her family, had slept in the same bed with Manoj, held his hand and talked about his dreams with him. Asha was now family and Priyasha wanted her to be as safe as her own child" (Malladi 294). Accordingly, Priyasha stands as a beacon of empathy and genuineness, a core concept within Carl Rogers' humanistic perspective.

According to Carl Rogers' humanistic theory "all individuals have an innate drive, which he termed the 'actualizing tendency,' to realize their full potential and achieve personal growth" (Brainly). Priyasha is cognizant of her inability to sustain pregnancy and give birth to a child. Her 'actualizing tendency, the innate drive persuade her to realise her full potential innovatively, to achieve a child of her own. Madhu and Priyasha named their baby Ayesha to render their gratitude to Asha. Madhu says with tears, "She's... my God, she's all here. Hello, sweetheart," and he hugged both of them and dropped a kiss on Priya's head (Malladi 297). Roger's major concept of humanistic approach, the 'unconditional positive regard' of Priyasha, facilitates the eradication of psychological and emotional barriers, thereby enabling her towards motherhood.

Priyasha and Asha, both the protagonists, show how marginalized women negotiate their ability to act within exploitation and how their resilience, self autonomy and determination assist them to encounter sterility, and patriarchal discrimination, and courageously convert their inward journey as a platform for their transformation. Both the characters stand as the gem of courageousness, Maya Angelou aptly puts it in 'Still I Rise'.

"You may shoot me with your words,
You may cut me with your eyes,
You may kill me with your hatefulness,
But still, like air, I'll rise". (Angelou lines 21–24).



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CONCLUSION

The analysis of introspective peregrination in *A House for Happy Mothers* exposes that motherhood is not merely a biological condition but a transformative emotional journey navigated by struggle, reflection, and resilience. Through the interlaced experiences of Priyasha and Asha, the study illustrates how geographical displacement, ethical dilemmas, and societal demand become stimulants for inner enhancement and self-evolution. Both the protagonist's emotional voyages shift from uncertainty and fragmentation toward empathy, empowerment. At its core, the present study concludes that emotional peregrination is a process of healing and renewal, affirms personal transformation can even emerge amid the composite structures of global inequality.

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RESEARCH ARTICLE

Plague, Despair, and Self-Realization in Philip Roth's *Nemesis*

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ABSTRACT

Philip Roth's *Nemesis* stands out from the other novels of Roth in a way that it categorically lays bare the powerful and burning existential outrage of the writer through the character of Bucky Cantor. *Nemesis* perfectly portrays the anxiety, fear and the hopelessness created by the polio epidemic in the Newark Jewish community through the character of the twenty-three-year-old, Bucky Cantor. Set in the year 1944, Roth explores the terrible effects of the epidemic, the description of which uncannily resembles with that of the current coronavirus pandemic. With the epidemic killing people and leaving the survivors with permanent disability and the protagonist himself getting affected by it, Roth deals deeply with the protagonist's inner conflicts and the existential angst experienced by him, as he becomes more and more disillusioned with his own beliefs. It is not so arduous a task to notice even in the first reading of the novel, the recurring instances of the protagonist reeling under the burden of existential crisis and who is apparently seen to be in a perpetual conflict with himself, to the extent that he decides to relinquish everything he ever desired in his life. Though existentialism as a philosophy became popular during the twentieth century after the World War I and continued to have its sway through the Great Depression and the World War II, its relevance in the contemporary times cannot be ignored, especially when humanity as a whole is still stuck in the trauma of the irreparable devastation caused by the Covid19 pandemic, which again perfectly parallels the plot of *Nemesis* where the impetus which initiates the existential crisis in the protagonist is the tragic event of the polio epidemic. Kierkegaard's philosophical concepts and constructs on the human condition and his views on notions such as self-realization, anxiety, despair, tragedy and the search for meaning are particularly inviting to apply those concepts to Roth's *Nemesis* which would eventually render a new appreciation for the novel.

Keywords: Philip Roth, Epidemic, existentialism, Kierkegaard, disillusionment, existential angst, guilt





INTRODUCTION

The French Catholic philosopher, Gabriel Marcel coined the term 'existentialist' in the mid-1940s and applied it to Sartre (Flynn 89). The existentialist doctrine focuses on the existence of the individual, who, being free and responsible, is held to be what he makes himself by the self-development of his essence through acts of the will. Apart from struggling with the reality of their own impermanence, the existentialist characters often lack faith in religion, persistently raise existentialist questions, grapple with their own existence and with the reality around them. *Nemesis*, which is Philip Roth's last novel in his career as a prolific novelist, abounds in strong existentialist themes which include questions about death, God, existence and fate. One of the popular opinions about the existentialists, as Flynn mentions is that the existentialist enters this world of limited and relative observation and assessment with his/her drive to 'personalize' the most impersonal phenomena in our lives (5). This could be noted throughout *Nemesis*, as we find Bucky Cantor struggling with his own choices, which he made in the past and constantly caught in a gripping sense of guilt throughout his life. The only instance where this study found an ideological departure in the protagonist of *Nemesis* and with that of the philosophies of Kierkegaard is the protagonist Bucky Cantor's despicable attitude towards God. Otherwise, there are various and enumerable instances in the novel which are perfectly in accord with the philosophies espoused by Kierkegaard in his various works, which deal exhaustively with issues like anxiety, sin, guilt, freedom, choice and God.

Considering the novel, *Nemesis*, it could be observed that the development of angst and guilt in Bucky Cantor was a gradual process, which gets accentuated by the Polio epidemic and finally pushes him into an eternal abyss of guilt. Bucky, having lost his mother in his childbirth and having got a thief for a father, was brought up by his grandparents. His grandfather's firm upbringing had fostered in him a strong sense of responsibility and had taught him to "stand up for himself as a man and to stand up for himself as a Jew, and to understand that one's battles were never over" (Roth 25). The twenty-year-old Bucky, who had high aspirations to join the army and fight in the war, feels broken when he gets rejected in the recruitment due to his poor eyesight. Feeling that he had let down the expectations of his grandfather, he breaks down silently in his bedroom, when his friends Dave and Jake get recruited and are taken for the training. This thought of not being able to take part in a war in which young men like him have got an opportunity to serve the nation haunts him for a long time. Nevertheless, he manages to secure the position of summertime playground director of Chancellor Avenue School, located at the Weequahic section of Newark, even before he secured his graduation from Panzer College of Physical Education. In accordance with his grandfather's upbringing, he aspires to teach the kids, who were mostly Jewish, "toughness and determination, to be physically brave and physically fit and never allow themselves to be pushed around or ... to be defamed as Jewish weaklings and sissies" (28). When two playground kids, Herbie Steinmark and Alan Michaels get affected by Polio and when the remaining kids get anxious about it, Bucky tries to alleviate their fears by reassuring them that everything will be alright soon. It was only when the news of Alan and Herbie's death that Bucky's faith in God and life got shaken. When he visits Allen's home to offer his condolence, he finds himself unable to soothe the father who had just lost his vibrant and innocent son to the polio attack, particularly when Alan's father asks, "So why did he die? Where is fairness in that? ... You try to be a thoughtful person, a reasonable person, an accommodating person, and then this happens. Where is the sense in life?", for which Bucky answers, "It doesn't seem to have any." (47).

As a dutiful person, Cantor attends the funeral service of Alan Michaels at the synagogue and follows the prayers in the prayer book and joins the congregation in the recitations. Though he had been through the death of his beloved grandfather, the death of Alan was something he wasn't able to come to terms with. It was at Alan's funeral that the absurdity of life and the existence of God pounded his heart with strong questions:

They all joined the rabbi in reciting the mourner's prayer, praising God's almightiness, praising extravagantly, unstintingly, the very God who allowed everything, including children, to be destroyed by death. Between the death of Alan Michaels and the communal recitation of the God-glorifying Kaddish ... he himself hadn't dared to turn



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against God for taking his grandfather when the old man reached a timely age to die. But for killing Alan with Polio at twelve? For the very existence of polio? How could there be forgiveness – let alone hallelujahs-in the face of such lunatic cruelty? (74-75)

The above excerpt directly mirrors the opinions of Philip Roth, who is a self-proclaimed atheist and has on numerous occasions openly despised the ideas of God and religion. This is the only aspect in *Nemesis* that is dissident with the ideology of Kierkegaard, where faith is the distinctive feature of his philosophical and religious concepts.

Further, to make matters worse, more and more children from the playground begin to contract polio and the mother of the Kopferman children, accuses Cantor of criminal negligence for making her children contract the deadly virus. His speculation, scepticism and resentment towards God keeps growing with the mounting tragedies happening around him. On multiple occasions, we could find the ruminations of Cantor, not only during his conversations with Marcia and the narrator, Arnold Mesnikoff, but even during the moments of his lonely musings about his dead mother, where, “it suddenly occurred to Mr. Cantor that God wasn’t simply letting polio rampage through the Weequahic section but that twenty-three years back, God had also allowed his mother, only two years out of high school and younger than he was now, to die in childbirth” (125). We find that Bucky Cantor, in his inability to come to a meaningful conclusion concerning the deaths of the innocent kids, has his “anger provoked not against the Italians or the houseflies or the mail or the milk or the money or malodorous Secaucus or the merciless heat ...but against the source, the creator – against God, who made the virus” (127).

It was when Cantor finds himself confused with all those happenings around him, which of course were beyond his control that he receives a phone call from his lover, Marcia, who is away at the summer camp at Indian Hill. Marcia, the daughter of Dr. Steinberg had been Cantor’s colleague at the Chancellor’s. She tells him of a job opportunity at the camp where they are in need of a waterfront director. Bucky Cantor immediately rejects the offer saying that he cannot leave the playground and the kids, and escape to the summer camp at Indian Hill. Marcia pleads him to consider the offer which would enable him to join her and her little sisters at the camp happily without having to worry about polio. Though Bucky initially casts-off such an idea, his meeting with Dr Steinberg during which he asks for his approval to be engaged to Marcia, brings in a change of mind in him and he makes up his mind to leave for the summer camp. He wanted to meet Dr Steinberg to talk about the deadly disease that is attacking the innocent children that would in turn give him a sense of reassurance. When Dr Steinberg understands his worries, he says, “You have a conscience, and a conscience is a valuable attribute, but not if it begins to make you think you’re to blame for what is far beyond the scope of your responsibility” (104). These words of the doctor further kindle Bucky’s inconsolable heart and he feels provoked to ask, “Doesn’t God have a conscience? Where is His responsibility? Or does He know no limits?” (105).

Caught up in a terrible state of perplexed mind, all he could think was that, “he could stop hating God, which was confusing his emotions and making him feel very strange. On their island he could be far from everything that was growing harder and harder to bear” (87). This is yet another decision for which Bucky Cantor feels guilty throughout the rest of life. From the moment he leaves the job of the playground director, an unconscious guilt starts to settle in his mind which surfaces later and keeps tormenting him. The moment he hangs up the call after telling Marcia that he has made up his mind to come and join her at the Indian Hill camp, he battles with his own ideals:

... ideals of truthfulness and strength fostered in him by his grandfather, ideals of courage and sacrifice that he shared with Jake and Dave, ideals nurtured by him in boyhood to place himself beyond the reach of the crooked father’s penchant for deceit – his ideals as a man demanding that he immediately reverse course and return for the rest of the summer to the work he had contracted to perform.

How could he have done what he’d just done? (135)

Even when Bucky has a good time after reaching the camp, his conflicting thoughts come to haunt him, which again lead him to contemplate on God’s plans, “Why does He set one person down in Nazi-occupied Europe with a rifle in





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his hands and the other in the Indian Hill dining lodge in front of a plate of macaroni and cheese? Why does He place one Weequahic child in polio-ridden Newark for the summer and another in the splendid sanctuary of the Poconos?" (154). The ever-swirling vortex of anxiety and existential crisis come to drag him again when on their way back from the lonely island, Marcia tells him how she prayed to God to protect him, on hearing which Bucky, unable to restrain himself, erupts in anger with a concatenation of questions:

Why didn't God answer the prayers of Alan Michaels's parents? They must have prayed. Herbie Steinmark's parents must have prayed. They're good people. They're good Jews. Why didn't God intervene for them? Why didn't He save their boys? ... I don't know why God created polio in the first place. What was He trying to prove? That we need people on earth who are crippled? (170)

This could be paralleled with the famous series of questions posed by Kierkegaard in his work, *Repetition* through the character of the Young Man, where he questions about his existence and God:

One sticks a finger into the ground to smell what country one is in; I stick my finger into the world-it has no smell. Where am I? What does it mean to say: the world? What is the meaning of the world? Who tricked me into this whole thing and leaves me standing here? Who am I? How did I get into the world? Why was I not asked about it, why was I not informed of the rules and regulations and just thrust into the ranks as if I had been bought from a peddling shanghai of human beings? How did I get involved in the big enterprise called actuality? Why should I be involved? Isn't it a matter of choice? If I am compelled to be involved, where is the manager-I have something to say about this. Is there no manager? To whom shall I make my complaint? After all, life is a debate-may I ask that my observations be considered? If one has to take life as it is, would it not be best to find out how things go? What does it mean: a deceiver? (200)

When Bucky gets to hear about the closing of the playground from his grandmother, his conscience torments him so much that he feels that he had failed in his ethical responsibility of facing the war waged by the epidemic on the Newark children. Though Marcia tries to console him that he couldn't have done anything even if he had stayed there, he says, "I left. There's nothing more to say. A fact is a fact. I left" (Roth 196). This feeling of failing in his moral obligation gets escalated with the news of his friend Jake's death in the war in France and the subsequent attack of Polio on one of the boys, David Kaplow in the camp.

Bucky Cantor starts associating every misfortune happening around him with his presumed failing sense of duty which in turn intensifies his existential angst, which is apparent from the way he anxiously confides to Dr. Huntley that it was he who "sat next to him [David Kaplow] at Indian Night. Now he's come down with polio. Doctor, am I the one who gave it to him? Am I going to give it to others? Is that possible?" (236). Kierkegaard, in his 1847 work, *Upbuilding Discourses in Various Spirits*, talks about human beings' nature to stand against one's own self. According to him, "The person who is to be master (it is, of course, he himself) ruins it; such a person works with perhaps scarcely a third of his power in the right place and with more than two-thirds of his power in the wrong place or against himself" (*Upbuilding Discourses* 295). This holds true with Bucky Cantor, who undeservingly punishes himself for the workings of fate. The readers only feel pity for Bucky, just like the narrator, and in the words of Kierkegaard, "Ah, if one looks at people's lives, one often must say in sorrow: They do not themselves know what powers they have; they more or less keep themselves from finding that out, because they are using most of their powers to work against themselves" (296), aptly fits to describe Bucky's fate. Ultimately, it is when he himself becomes the victim of polio that he confronts the overpowering role of fate and chance in his life, which again make him a casualty of his own choices. He wants to spare Marcia from marrying a cripple like him and so decides to relinquish her and move on with his life, as he tells the narrator, "I didn't want the girl to feel stuck with me. I didn't want to ruin her life. She hadn't fallen in love with a cripple, and she shouldn't be stuck with one" (Roth 255). This particular attitude of Bucky, could be compared to the Young Man in Kierkegaard's *Repetition* and also to Kierkegaard himself, as the Young Man's problem directly reflected Kierkegaard's own with Regine Olsen (Garff 175-78). The Young Man proposes his love to the girl, she accepts but then he changes his mind. Here the same happens between Bucky and





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his fiancé, though for an entirely different reason. But from the way Bucky justifies his choice to leave Marcia, he could well be equated with what Kierkegaard calls the Young Man, the “sorrowful knight of recollection’s only happy love” (*Repetition* 146). The narrator’s continuous desperate attempts to convince Bucky to not hold himself guilty for whatever happened goes in vain:

That the polio epidemic among the children of the Weequahic section and the children of Camp Indian Hill was a tragedy, he could not accept. He has to convert tragedy into guilt. He has to find a necessity for what happens. There is an epidemic and he needs a reason for it. He has to ask why. Why? Why? That it is pointless, contingent, preposterous, and tragic will not satisfy him. That it is a proliferating virus will not satisfy him. Instead he looks desperately for a deeper cause, this martyr, this maniac of the why, and finds the why either in God or in himself, or mystically, mysteriously, in their dreadful joining together as the sole destroyer. (Roth 265)

This feeling of guilt is in tandem with what Kierkegaard espouses in *The Concept of Anxiety*, where he says

Whoever learns to know his guilt only from the finite is lost in the finite, and finitely the question of whether a man is guilty cannot be determined except in an external, juridical, and most imperfect sense. Whoever learns to know his guilt only by analogy to judgments of the police court and the supreme court never really understands that he is guilty, for if a man is guilty, he is infinitely guilty. (161)

The narrator, Arnold Mesnikoff’s concluding remarks about Bucky’s guilt establishes him as a typical existential hero: “The guilt in someone like Bucky may seem absurd but, in fact, is unavoidable. Such a person is condemned. Nothing he does matches the ideal in him. He never knows where his responsibility ends” (Roth 273). Thus, Bucky Cantor’s tragical life makes him a knight of infinite resignation, living in the ethical realm as an existential hero, holding himself guilty by believing in his subjective reflection of a natural tragedy.

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RESEARCH ARTICLE

Online Narratives and Cultural Identity in Northeast India

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ABSTRACT

This study explores how online narratives contribute to the construction and expression of cultural identity in Northeast India. With the rapid growth of digital platforms such as social media, blogs, and online storytelling forums, individuals from the region have found new ways to represent their traditions, languages, and lived experiences. These platforms allow marginalized voices to be heard beyond geographical boundaries and enable cultural preservation in a modern context. The research focuses on how digital storytelling reflects identity, community values, and hybrid cultural forms shaped by globalization. It also examines the role of language, especially the use of English mixed with local dialects, in shaping these narratives. By analyzing selected online texts, posts, and creative works, this study highlights how young writers negotiate tradition and modernity. While online spaces provide opportunities for visibility and cultural pride, they also create challenges such as cultural dilution and commercialization. The study concludes that online narratives play a significant role in redefining cultural identity in Northeast India, acting as both a space of preservation and transformation in the digital age.

Keywords: Online Narratives, Cultural Identity, Northeast India, Digital Storytelling, Language Hybridization

INTRODUCTION

Northeast India is a region rich in cultural diversity, consisting of multiple ethnic communities, languages, traditions, and histories. Each state in the region has its own unique cultural practices, folklore, and social structures. For many years, the representation of Northeast India in mainstream literature and media has been limited or stereotypical. However, the rise of digital platforms has created new opportunities for individuals to represent their own stories and identities.



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Online narratives refer to stories, experiences, and expressions shared through digital platforms such as Facebook, Instagram, blogs, and online magazines. These narratives include personal stories, poems, short fiction, videos, and even memes. For many people in Northeast India, especially the youth, these platforms have become an important space for self-expression and cultural representation. Through online narratives, individuals can share their experiences of identity, belonging, migration, and modern life. Cultural identity is a complex concept that includes language, traditions, beliefs, and social practices. In Northeast India, cultural identity is often influenced by both traditional values and modern global influences. The interaction between these two forces creates a dynamic and evolving sense of identity. Online narratives play a key role in this process by providing a platform where individuals can negotiate and express their identities. One important aspect of online narratives is language use. Many writers from Northeast India use English along with local languages, creating a hybrid form of expression. This reflects both the influence of globalization and the desire to maintain local identity. Such linguistic practices also make the narratives accessible to a wider audience while preserving cultural uniqueness.

This study aims to examine how online narratives contribute to the construction of cultural identity in Northeast India. It focuses on how individuals use digital platforms to express their identities, how language is used in these narratives, and what challenges and opportunities arise from this digital expression. By analyzing selected online texts, this research seeks to understand the relationship between technology, culture, and identity in the region. Another important dimension of online narratives in Northeast India is the role of digital communities in shaping collective identity. Social media platforms not only allow individuals to share personal stories but also create spaces where communities can interact, support, and affirm each other's cultural experiences. Through hashtags, online campaigns, and shared content, people from different parts of the region can connect and form a sense of unity despite geographical distances. These digital interactions often strengthen cultural awareness and encourage the preservation of traditions among younger generations. At the same time, they also open up spaces for dialogue about issues such as identity politics, cultural representation, and social change. Therefore, online narratives are not only individual expressions but also collective processes that contribute to the ongoing construction and redefinition of cultural identity in Northeast India.

REVIEW OF LITERATURE

The concept of cultural identity has been widely discussed in cultural studies and sociology. Scholars have argued that identity is not fixed but constantly shaped by social, political, and historical factors. Cultural identity is often understood as a sense of belonging to a particular group, expressed through language, traditions, and shared experiences. In the context of Northeast India, cultural identity is particularly complex due to the region's diversity. Previous studies have shown that literature plays an important role in shaping and preserving cultural identity. Traditional forms such as folklore, oral narratives, and community storytelling have been central to the cultural life of Northeast India. These forms of storytelling have been passed down through generations and have helped maintain cultural values and collective memory.

With the advent of digital technology, storytelling has taken new forms. Online narratives have emerged as a modern extension of traditional storytelling practices. Scholars have noted that digital platforms allow for greater participation and democratization of storytelling. Individuals who may not have access to traditional publishing platforms can now share their stories online. Research on digital storytelling highlights its role in identity formation. Online narratives provide a space where individuals can explore and express their identities in new ways. This is particularly important for marginalized communities, as digital platforms offer a space for visibility and representation. Studies have also shown that online narratives often reflect hybrid identities, combining elements of local culture and global influences. Language plays a significant role in online narratives. The use of English as a global language allows writers to reach a wider audience, while the inclusion of local languages helps maintain cultural specificity. This mixing of languages, often referred to as code-switching or hybrid language, is a common feature of online narratives from Northeast India. However, scholars have also raised concerns about the impact of



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digital platforms on cultural identity. Some argue that globalization and digital media may lead to cultural homogenization, where local cultures are overshadowed by dominant global cultures. Others point out that the commercialization of online content can lead to the simplification or misrepresentation of cultural practices.

In the context of Northeast India, there is limited research specifically focusing on online narratives and cultural identity. Most studies have focused on traditional literature or mainstream media representation. Therefore, this study aims to fill this gap by examining how online narratives contribute to the construction and transformation of cultural identity in the region. Another significant area of scholarly discussion is the relationship between digital media and memory. Researchers argue that online platforms function as digital archives where cultural memories are recorded, shared, and reshaped. In the context of Northeast India, where much of the cultural heritage has traditionally been preserved through oral practices, the shift to digital storytelling marks an important transformation. Online narratives help document stories, rituals, and personal histories that might otherwise be lost. At the same time, these digital forms are not exact reproductions of tradition; they often reinterpret and reshape cultural memory to suit contemporary audiences. This process highlights the dynamic nature of culture, where preservation and innovation exist together. Scholars emphasize that digital storytelling does not simply replace oral traditions but works alongside them, creating a new hybrid space for cultural expression. In addition, recent studies have focused on the role of youth in shaping online cultural narratives. Young people in Northeast India are among the most active users of digital platforms, and their engagement has significantly influenced how culture is represented online. Researchers note that youth often experiment with identity, blending traditional values with modern global influences in creative ways. Through blogs, videos, and social media posts, they challenge stereotypes and present alternative narratives about their communities. This active participation also reflects a sense of agency, as young creators take control of their own representation rather than relying on external perspectives. However, scholars also point out that this process may create generational differences in the understanding of culture, as older and younger generations may have different views on authenticity and change. These discussions highlight the importance of examining online narratives as evolving spaces where identity, culture, and power intersect.

METHODOLOGY AND DISCUSSION

METHODOLOGY

This study uses a qualitative research approach to analyze online narratives from Northeast India. Qualitative research is suitable for this study because it focuses on understanding meanings, experiences, and interpretations rather than numerical data. The data for this research is collected from various digital platforms, including social media posts, blogs, online magazines, and storytelling websites. A purposive sampling method is used to select texts that are relevant to the research topic. The selected narratives include personal stories, poems, short stories, and opinion pieces written by individuals from Northeast India. These texts are chosen based on their focus on cultural identity, language use, and representation of local experiences. The analysis is conducted using thematic analysis. This method involves identifying and analyzing recurring themes in the selected texts. The main themes explored in this study include identity expression, cultural representation, language use, and the influence of globalization. The study also examines how digital platforms shape the way these narratives are created and shared. In addition to thematic analysis, this study also applies elements of discourse analysis to understand how language constructs meaning within online narratives. Discourse analysis helps examine how writers present their identities, how they describe their cultural experiences, and how they position themselves within society. By focusing on word choice, tone, and narrative style, the study identifies how cultural identity is not only expressed but also shaped through language. This approach is particularly useful in analyzing digital texts, where informal language, emojis, and code-switching are common.

Ethical considerations are also important in this research. Since the data is collected from publicly available online platforms, the study ensures that personal information of writers is not disclosed. The aim is to respect the privacy



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and ownership of digital content while analyzing general patterns and themes. Moreover, the research avoids misinterpretation by considering the cultural context in which each narrative is produced. Another important methodological aspect is the limitation of the study. Since the research focuses on selected texts, it may not represent all communities in Northeast India. The region is highly diverse, and experiences may vary across different ethnic groups, languages, and locations. However, the selected data provides a useful insight into common patterns and emerging trends in online cultural expression.

DISCUSSION

One of the key findings of this study is that online narratives provide a platform for expressing cultural identity. Many writers use digital platforms to share stories about their traditions, festivals, and daily life. These narratives often reflect a strong sense of pride in cultural heritage. At the same time, they also address issues such as discrimination, stereotyping, and marginalization. Another important theme is the negotiation between tradition and modernity. Many online narratives reflect the challenges of maintaining cultural traditions in a rapidly changing world. For example, young writers often express the tension between following traditional practices and adopting modern lifestyles. This tension is a common feature of identity in Northeast India. Language use is another significant aspect of online narratives. Many writers use a mix of English and local languages, creating a unique form of expression. This hybrid language reflects both the influence of globalization and the desire to preserve cultural identity. It also allows writers to communicate with a wider audience while maintaining a connection to their roots. Online narratives also play a role in challenging stereotypes about Northeast India. Mainstream media often presents a limited or stereotypical image of the region. However, online narratives provide a space for individuals to present their own perspectives and experiences. This helps create a more nuanced and authentic representation of the region. However, the study also identifies some challenges associated with online narratives. One of the main concerns is the risk of cultural dilution. As narratives are shared online, they may be influenced by global trends and commercial interests. This can lead to the simplification or modification of cultural practices. Another challenge is the issue of accessibility. While digital platforms provide opportunities for expression, not everyone has equal access to these platforms. Factors such as internet connectivity, language barriers, and digital literacy can limit participation. Despite these challenges, online narratives remain an important tool for cultural expression and identity formation. They provide a space for creativity, dialogue, and cultural exchange. They also help preserve cultural traditions in a modern context.

Identity Expression and Self-Representation

Online narratives allow individuals to construct and present their identities in ways that may not be possible in offline spaces. Writers often share personal experiences related to culture, family, and social life, creating a sense of authenticity and emotional connection. These narratives help individuals assert their identity and challenge misrepresentations. For example, many writers highlight their cultural traditions and everyday practices to show the richness of their communities. This form of self-representation is especially important for regions like Northeast India, which are often misunderstood or underrepresented in mainstream media.

Preservation of Culture through Digital Media

Digital platforms act as modern archives where cultural knowledge can be preserved and shared. Many online narratives include descriptions of festivals, traditional clothing, food habits, and rituals. By documenting these aspects, writers contribute to the preservation of cultural heritage. This is particularly significant for younger generations who may be disconnected from traditional forms of storytelling. Online narratives make cultural knowledge more accessible and relevant in contemporary contexts.

Hybrid Identity and Global Influence

A major theme observed in online narratives is the development of hybrid identities. Writers often combine elements of their local culture with global influences, creating new forms of expression. This is evident in language use,



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fashion, lifestyle, and attitudes. While some narratives celebrate this hybridity as a sign of progress and openness, others express concern about losing traditional values. This dual perspective reflects the complex nature of identity in a globalized world.

Language Innovation and Code-Switching

Language plays a crucial role in shaping online narratives. Many writers use a mixture of English and local languages, a practice known as code-switching. This linguistic blending reflects both cultural pride and practical communication needs. It allows writers to express cultural concepts that may not have direct translations in English. At the same time, it helps reach a wider audience. This creative use of language also demonstrates how digital spaces encourage innovation and flexibility in communication.

Resistance to Stereotypes and Marginalization

Online narratives serve as a powerful tool for challenging stereotypes about Northeast India. Writers often address issues such as racial discrimination, cultural misunderstanding, and social exclusion. By sharing their own experiences, they counter negative representations and present more accurate and diverse perspectives. This form of digital activism helps create awareness and promotes cultural understanding. It also empowers individuals to take control of their own narratives.

Community Building and Collective Identity

Another important aspect of online narratives is the formation of digital communities. Through comments, shares, and interactions, individuals connect with others who share similar cultural backgrounds or experiences. These interactions create a sense of belonging and solidarity. Online communities also provide support and encouragement, especially for those who may feel isolated in offline environments. This collective engagement strengthens cultural identity and fosters a sense of unity.

Challenges of Digital Representation

Despite the many benefits, online narratives also present several challenges. One major issue is the risk of cultural simplification. In order to attract attention or fit into popular trends, some narratives may present a limited or simplified version of culture. This can lead to misunderstandings or loss of cultural depth. Additionally, the pressure to create engaging content may influence how culture is represented. Another challenge is digital inequality. Not everyone has access to the internet or the skills needed to participate in online storytelling. This creates a gap where certain voices are more visible than others. As a result, online narratives may not fully represent the diversity of Northeast India.

Impact of Algorithms and Platform Culture

Digital platforms are influenced by algorithms that determine what content is visible to users. These algorithms often prioritize popular or trending content, which can affect the type of narratives that gain attention. As a result, some cultural expressions may be highlighted while others remain unnoticed. This raises questions about visibility, power, and representation in digital spaces. Writers may also adapt their content to fit platform trends, which can influence the authenticity of their narratives.

CONCLUSION

This study has examined the role of online narratives in shaping cultural identity in Northeast India, highlighting how digital platforms have transformed traditional storytelling practices and created new opportunities for cultural expression. Online narratives allow individuals to share personal experiences, represent their communities, and connect with wider audiences beyond geographical boundaries. These platforms have become important spaces where voices that were once marginalized can now be heard and recognized. The study shows that cultural identity in Northeast India is not fixed but dynamic and constantly evolving, influenced by both traditional values and



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modern global forces. Online narratives play a key role in this process by providing a space where individuals can negotiate, reinterpret, and express their identities. The use of hybrid language, combining English with local languages, reflects the interaction between local culture and global communication, demonstrating how writers maintain their cultural roots while adapting to modern contexts.

At the same time, the study identifies several challenges related to digital storytelling, including cultural dilution, commercialization, and unequal access to technology, which can affect how culture is represented online. These challenges highlight the need for a balanced approach where innovation does not come at the cost of cultural authenticity, and where digital platforms remain inclusive of diverse voices. Furthermore, online narratives contribute not only to individual expression but also to the formation of collective identity by enabling communities to share knowledge, support one another, and strengthen cultural awareness. These narratives encourage dialogue about identity, belonging, and social change, making them important tools for both cultural preservation and transformation. Overall, online narratives have a lasting impact on cultural identity in Northeast India, acting as a bridge between tradition and modernity, and emphasizing the growing importance of digital storytelling in contemporary society.

Scope for Further Research

This study focuses on a limited number of online narratives and platforms. Future research can expand the scope by including a larger dataset and a wider range of digital platforms such as YouTube, podcasts, and digital art. Comparative studies between different states of Northeast India can also provide deeper insights into regional variations in cultural identity. Further research can explore the role of gender, class, and migration in shaping online narratives. Another important area of study is the impact of digital literacy and access to technology on participation in online storytelling. Researchers can also examine the role of algorithms and platform policies in shaping visibility and representation. In addition, future studies can use mixed research methods, combining qualitative and quantitative approaches, to provide a more comprehensive understanding of online narratives and cultural identity.

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RESEARCH ARTICLE

Mapping Margins in Fiction: Intersectionality and Power Structures in Zadie Smith's *On Beauty*

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ABSTRACT

The present study examines the multiple forms of oppression that intersect to create complex experiences through Kimberlé Crenshaw's foundational ideologies, such as interlocking oppressions, matrix of domination, double bind, and intersectional invisibility. Specifically, the focus will be on the simultaneous experiences of racism and marginalization and the superiority of whites towards the colored in the community, as well as the various forms of oppression the blacks are subjected to. The present study conducted a textual analysis of the novel. As a theoretical approach, the study explored racism and Intersectionality. Kimberle Crenshaw's critical and theoretical concepts are more specifically employed to analyse the novel by Zadie Smith, which is rooted in racist ideologies and discrimination. In this regard, the notions of interlocking oppression, matrix of domination, double bind, and intersectional invisibility were employed as critical lenses to investigate the novel. The study reveals that Zadie Smith's novel successfully portrays the oppression and marginalization of the people of colour. It delves into the intricate details of subjugation in the white dominated community. Through the theory of intersectionality, the study focuses on the systematic racism on multiple grounds towards marginalized communities. *On Beauty* presents racism as a persistent force from life to death, shaping both the emotional and social realities of its characters. This study demonstrates how *On Beauty* functions as a fusion of diverse racism contributing to the understanding of literature, race and identity as a dynamic and interconnected entity. The novel's detail narration on different aspects of racism coupled with second generation and mixed race marginalization makes the entire narration unique and different from other writers.

Keywords: Race, intersectionality, marginalization, oppression, identity





INTRODUCTION

Race is a most important, dominant, historically socially constructed ideology. The discussions and debates on race, identity, ethnicity, equal rights, oppression, and stereotypes are an ongoing occurrence and circumstance in the modern world. As a reaction to the Nazi Project, the term 'racism' was devised in the 1930s to make Germany *judenrein*, or clean of Jews (Rattansi, 2020, p.3). Race, as a term, imbibes various ideologies and cognate terms such as ethnicity and ethnocentrism, nation, nationalism, and xenophobia. Robert Knox mentions that race is the key concept to understand human variation in *The Races of Men* (1850). The French Count Arthur de Gobineau regarded the history of every social order as the result of conquest by a dominant and powerful race, which forms the nobility, a bourgeois class with mixed origins, and the lower class, with the common people.

The questions about race and racism have been refashioned in ways to emphasize cultural difference. Banton perceives the race correlation from a global and historical perspective, focusing on cultural contact, beliefs about the nature of race, and social relations formulated based on racial categories. The arguments segmented by writers as diverse as Banton, Rex and Wilson were shaped by the discussion of race relations that was developing during the 1960s and 1970s in both USA and Britain. This was the period when social reforms were enforced in the aftermath of the Civil Rights Movement, urban violence and unrest and the development of black power ideas and forms of cultural nationalism helped to reshape the politics of race in America and other parts of the world. David Goldberg points out that "the presumption of a single monolithic racism is being displaced by a mapping of the multifarious historical formulations of racisms" (Goldberg 1993). All the major discussions about race are based on interconnections between race and nationhood, patriotism and nationalism rather than analysing ideas about biological inferiority.

More than three-quarters of the black American population in the United States is expected to have European or Whites as their ancestors. The rich men had 'mulatto' mistresses in southern cities during the time of slavery, while on the plantations, the white owners took advantage of the black slaves, and they believed they had sexual rights over female slaves. The reputation and condition of mulattos became uncertain. Different racial classifications emerged to denote their black ancestry, such as "Sambo" and "meamelou". Various names associated with Black ancestry include "Sambo" and "Meamelou." They belong to hypodescent, where the children born out of a mixed union between different socio-economic or ethnic groups are automatically assigned to the group with lower status. It is also associated with the principle of invisible blackness, where any person with one ancestor of African ancestry is considered black.

The concept of institutional racism in the 1960s in the USA was popularised by Stokely Carmichael and Charles Hamilton. The basic highlights of institutional racism are the fact that blacks and whites strived hard for a decent and better standard of living, where most of the blacks were denied opportunities and outcomes, and whites were prioritized. The inadequate housing, discrimination among whites and blacks, and schools with the least resources led to lower educational achievement, which led to lower admissions in colleges, and the result was a deterioration in employment progress. The white employers were hostile and hard on the black workers. The result of this segregation and difference is high unemployment, drug consumption, an increase in the crime rate, and unsafe neighbourhoods. Police, courts, and legal resources became biased. Black children grow up in a negative environment that stereotypes them, that destabilises their aspirations, and leads to massive underachievement. As a result, the community of black continues to remain under the white generation after generation. The future of the black community is determined by the supremacy of the white. The ideologies of racism and nationalism are interdependent and complex. Both ideologies arose and expressed together, and have high influence on each other. Hobsbawm argues that the 'dual revolution' (French Revolution and Industrial Revolution) created nationalism. After the dual revolution, racism was created and remains a continuous and ongoing challenge and discussion in day-to-day life. Balibar is influenced by the ideologies of racism and nationalism and mentions that a nation will





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inevitably identify with its race. The country's historical, cultural, political, and other factors are ultimately incorporated into the idea of race. (Miles, R., & Brown, M., 2004, p. 10) This leads to the concept of nationalistic pluralism, an ideology in which 'we' and 'they' are not differentiated.

Smith and Intersectionality

This article examines the ideology of Kimberlé Crenshaw's intersectionality theory, which explores the intersection of different forms of oppression, including racism and sexism. The British writer Zadie Smith's *On Beauty*, shortlisted for the 2005 Man Booker Prize brings in details about racist stereotypes and discrimination and diversity. The novel highlights intellectual debates among faculty members and the conflicts and issues that arise from issues of race, politics, and cultural identity. Smith also depicts that discrimination is practised not only by the whites but also by the elite blacks. Crenshaw's intersectionality helps to understand and analyse the complexity of human experiences. Social division among people gives rise to multiple forms of inequality. Crenshaw defines intersectionality as a "metaphor for understanding the ways that multiple forms of inequality or disadvantage sometimes compound themselves and create obstacles that are not understood among conventional ways of thinking". (Crenshaw, K. 1989. p. 140).

In this article, we draw upon Kimberlé Crenshaw's intersectionality to argue that Zadie Smith addresses social stratification and issues of race, where simultaneous membership in multiple interconnected social categories shapes people. Power structure plays a vital role. Intersectionality is not a synonym for diversity; it is a functional tool for understanding invisible power relations and how they shape inequality, rather than identity. Intersectionality argues that the system of oppression has a profound impact on individual lives. It aims at inequality and the outcomes it creates. To further analyse the novel *On Beauty* (2005) by Zadie Smith in detail, we will focus on intersectionality theory to examine the marginalisation and discrimination of people, as well as inequalities based on race, power relations, and sexuality.

Zadie Smith and Identity Politics

Smith was born in London to a Jamaican mother and English father. Her literary works are grounded in the themes of race, culture, society, and family relations. Her writings often deal with the difficulties and challenges of racial experiences in contemporary society. The novel was published in 2005 and is modelled on E.M Forster's *Howards End*. The novel discusses the conservative policies of elite universities and the mental trauma experienced by underprivileged and suppressed black youth. Through her writings, she proposes a re-examination of citizenship, race, and plural nationalism. (Amine, 2025, p. 2).

As a woman and writer of colour, she explores culture in literary spheres that are exclusive and restrictive. Her honest and reflective examination of the issues of identity and race has become essential to conversations about contemporary society. Her playful wittiness in her writing and vibrant narratives help to apprehend complex and difficult themes like race, class and culture. Smith says that she believed she has to play a dual role as both an author and a 'voice' of her community. "My trouble is I can't think of community in the singular. Doesn't everyone exist in a Venn diagram of overlapping allegiances and interests? I am a black person, also a woman, also a wife and mother, a Brit, a European – for the moment – a Londoner, a New Yorker, a writer, a feminist, a second generation Jamaican, a member of African diaspora, a Game of Thrones-er, an academic, a comedy-nerd, a theory- dork, a hip –hop-head and so on. I am delighted to be all these things, and everyone, no matter where they are from- if they really think about it – will find themselves with a similar plurality of communities. At different moments, you will feel the pull of certain commitments more strongly, especially if an aspect of your identity is particularly embattled state university". (Cronan, 2022, p.4).

Through her essays and novels Smith examines the idea of race, identity, and inequality in the multicultural world. Her diversity of subjects is a remarkable example for future generations to comprehend the idea of generosity and perception, covering a range of subjects from Brexit to Jay-Z and Justin Bieber. Smith is a regular contributor to The New Yorker and The New York Review of Books, her prose mimics the nuances, cadences, and occasional slang of



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the North West London district, proving her mastery of tone, compartmentalisation of experience, desire, and subjectivity. (Magee, 2012). Cronan (2022) describes Smith as a “sparkling effervescence, a veritable volcano of wonderfully life-affirming ideas.” Her ideas, often idiosyncratic and authentic, breathe life into her characters, allowing her to create vivid portraits of contemporary life. Over time, Smith has become increasingly skilled at blending societal and existential concerns with questions of manners and morality. Through her writing, she expresses a deep emotional and intellectual engagement with the world. In a cultural landscape that frequently reduces identity politics to a form of personal branding, Smith interrogates such issues with far greater depth and a genuinely political lens.

Theoretical Framework

The colonial legacies shape power relations among and within the countries. The social framework of discrimination and white privilege exists because of colonial legacies that create power structures. The intersectionality theory analyses the social, political and cultural identities that create inequality and oppression based on race. Kimberlé Crenshaw used the term “intersectionality” to refer to the double discrimination of racism, analysing the single-axis framework that is dominant in anti-discrimination law and anti-racist politics. She further argues that intersectionality is a metaphor to understand how various forms of inequality or disadvantage sometimes compound themselves and create obstacles in the way of life of people that are not understood by conventional thinking method.

The diversity wheel was created by Crenshaw to offer different perspectives on individuals and the organisations they are involved in, providing various perceptions of the individuals and organisations. Each intersects with the other through systems and structures that shape one’s experience, personality, and identity. There are three segments in the diversity wheel. The primary dimensions are considered to be personal standards, such as age, ethnicity, and gender, which are acquired at the centre of the circle. Socially and culturally, the person is influenced by environmental, social, and cultural factors and experiences, as well as learnings from family, friends, community, nationality, and belief system. These ideologies then acquire the second circle. The final circle includes the organisations detailing the influence a person might have in the work area, and the structure or processes they operate within may include systematic barriers and biases. (Scottish Government, 2022)

Intersectionality is directly connected to inequality. Marginalisation, suppression, discrimination, and stereotyping are the tribulations people create among each other, and blacks have to endure in society. People from different categories and communities strive to live in harmony, but the differences in opinion and social identity often create inequality and a violation of basic human rights. Crenshaw believes that people are shaped by society and the categorisation as it was fixed right from the beginning, which has become hardened and toughened to change with any rules and policies favouring blacks. The interaction between different communities and categories of people occurs within their respective contexts and societal structures, where power becomes a dominant philosophy. Intersectionality recognises all the inequalities and their progression across multiple social categories. A key aspect of intersectionality is the recognition of inequality in power. Crenshaw believes that diversity cannot be understood through intersectionality, as there are no intersectional groups of people, and the individuals who experience inequalities in society are considered intersectionally marginalised communities. Invisible power relations exist in society, shaping inequality among individuals. Intersectionality is a primary tool for analysing the deep-seated consequences that lead to differences in opinions, stubborn rejection, and inequality, despite the fact that blacks are educated and mannered. It deals with the interlocking systems of oppression and the influence they have on independent lives. Intersectionality details how different dimensions and multiple schemes of inequality persist among people, leading to diverse and distinctive consequences and experiences. (Rosette et al., 2018). Crenshaw mentions that stubborn endurance of the structures of white dominance, in other words, the American legal and socio-economic order, largely built on racism, is the reason for the existence of racial discrimination. (Coaston, 2019). Intersectionality is an exploration of people’s lives in multiple, coexisting identities. Oppressed communities are marginalised in society, and intersectionalities are considered additional barriers with different rules and policies.





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White Domination and Supremacy towards Black

Racism is explored in the novel *On Beauty* through two different families with distinct approaches and contrasting standards towards life. Both families are involved in pedagogy and maintain high academic standards in their approach to life. The families of Belseys and Kipps have contrasting views on race, identity and class. Their ideologies highlight the fact that racism is evident in every aspect of life systematically. The novel deals with the complicated and entangled racial issues that is evident in American universities. Kiki, a black woman and wife of Howard Belsey, a white university intellectual faculty member. Through Kiki, Smith aims to reveal and denote how a black woman feels suppressed in her own space of life and is often compelled to relate and live in the expectations of the white community. The voice of Kiki is authentic and the pain she endures denotes the multiple forms of oppression, issues of marginalization that is evident in the community that emphasizes the domination of white. The racial oppression that happens socially, culturally and historically are presented through the lives of two families Belseys and Monty Kipps.

Racism is evident in different forms throughout the novel. The characters in the novel have a detailed connection to exclusion and marginalisation. Kiki, when offering a party at her home with all white educated elites, pictures herself through their eyes as “sometimes you get a flash of what you look like to other people. This one is unpleasant: a black woman in a head wrap, approaching with a bottle in one hand and a plate of food in the other, like a maid in an old movie” (Zadie Smith, 2005, p. 98). Kiki is often subjected to racial stereotyping, experiencing microaggressions from her husband’s academic colleagues. She is considered a subject of discussion among family and friends as if she represents the entire African American community. This leads to questioning her identity and inadaptability to the situation, where she uses humour, withdrawal, and assertion as mechanisms to deal with racist remarks. Crenshaw argues that racial identity is not a matter of individual prejudice and preconception but is deeply rooted in cultural norms. (Crenshaw, 1989). She further says that intersectionality highlights the interconnection of race and sex, emphasising that these identities are mutually constitutive.

Crenshaw in her essay “Unmasking Colourblindness in the Law” argues that patterns of segregation and racial power were built not simply on formal rules and “White only” signs but also on practices, networks, and other social interactions that predictably reproduced white dominance across the social terrain (Crenshaw et al., 2019, p. 52). Kiki’s life is surrounded by dominant whites and isolation and suppression has distanced herself from the white community. Kiki’s intersectional invisibility is an outcome of several marginalised blacks in white-dominated communities. This isolation from the society and white dominant academic culture encouraged her to meet Mrs. Kipps, who is a black woman. The bond grew solid, firm and wiser as they continued meeting in various places, though their husbands were rivals at the university. Mrs. Kipps mentions, “There is such a shelter in each other” (Zadie Smith, 2005, p. 94), signifying that Kiki’s invisibility in the white community found solace and comfort internally in Mrs. Kipps’s existence as a neighbour. After encountering double-bind remarks about being a black woman from the workplace, a shopping mall, and Claire, a white colleague of Howard, Kiki finally found Mrs. Kipps, who appreciated her identity. “You have a marvellous face,.....and the moment I saw you I knew I would like you”. (Zadie Smith, 2005, p. 96)

Crenshaw’s Theory of Intersectionality

Crenshaw advocates for systemic change and the need to dismantle racist institutions and policies for the people rather than focusing on individual attitudes and behaviours. (Crenshaw, 1989). Crenshaw believes that there are high complexities in being black, as racist remarks can occur from multiple directions, and it's not always easy to defend and prove that equality exists. Carl Thomas, a young, black, talented music artist, street poet and rapper, more concerned with African American tradition, was falsely accused of stealing a painting from Monty Kipps' office because of his race, class and identity. On representing the black community, he was made to feel embarrassed at Kiki's anniversary party by Howard and was denied university education. He says, “The future's another country, man.....And I still ain't got a passport”(Zadie Smith, 2005, p.140). Carl is a representation of the entire black community, which seeks validation, identity, and equal opportunity, just like whites. The Matrix of white domination is Carl's reason for disillusionment towards the society he is trying to adapt to. Inequality was evident



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between the Wellington students and Carl, despite his being given a job in the Black Music Library at Wellington University. Interlocking oppression was quite evident when Carl participated in Claire's poetry class, despite not being a student at Wellington, creating controversies and complexities of identity and belonging. Carl's experiences highlight the themes of marginalisation and exclusion from society.

Crenshaw employs intersectionality to communicate the challenges faced by Black people and people of colour. Crenshaw's racist ideologies discuss the fact that coloured are differently situated in the economic, social and political worlds. The matrix of domination recognises that oppression is planted on structures of the society and institutions such as education, employment and criminal justice. The matrix of domination also highlights how dominant groups maintain power and privilege over marginalised groups. Smith conveys the pain of suppression through the voice of the Haitian people in the novel. "Don't ever sell your soul, my brother. Don't sell it for a few dollars. Everybody tries to buy a black man. But he can't be bought. His day is coming". (Zadie Smith, 2005, p. 362) Crenshaw focuses on the intersections of race and gender, foregrounding the fact that the social world is constructed and assembled on multiple grounds of identity. (Crenshaw, 1991). Levi feels at home around the black people and mentions that "How strange it was to see streets where everybody was black!...nobody looked at him twice"(Zadie Smith, 2005, p. 356). Representation of Levi's fair pay for Wellington Haitian workers and the support he rendered for the Haitian group signifies his relatability to his black identity.

"That is the question I pose to all fair-minded Wellingtonians today. Are we truly steadfast in our commitment to equality of opportunity, or not? Do we presume to speak of progress when, within these very walls, our policy remains so shamefully hesitant? Are we satisfied that the African American youth of this fair city?" (Zadie Smith, 2005, p. 402)

Social Justice and Activism

Levi had the privilege of studying at Wellington University because of his mixed-race identity and his white father; he often wonders and questions whether racism and differences of opinion have something to do with blackness. His friend Felix from Haiti was blacker than any black man; his skin was like slate, but he withheld the true essence of blackness. His appearance was different and contrasted significantly with that of other Swedish men, who often had translucent eyelashes and a pure, white complexion. Haiti is known for the slavery of black people, which Smith details in the novel about the enslavement and oppression.

"A country close to America that you never hear about, where thousands of black people have been enslaved, have struggled and died in the streets for their freedom, have had their eyes gouged out and their testicles burned off, have been macheted and lynched, raped and tortured, oppressed and suppressed and every other kind of pressed..." (Zadie Smith, 2005, p.355)

Levi was depressed by the fact that men hate each other in terms of race and colour. Levi was raised by his parents as a concerned, sympathetic and gentle person, with an intense and great sensitivity to the pain of others. Each time he read the book about Haiti's struggle and mission, he felt a deep-seated passion and a profound sense of misery. Today's racism leads to tomorrow's agony and pain of a generation. Levi identifies himself as Black and enjoys the freedom he has within the Black community. It was like a homecoming for him, and many hurried past him as if he belonged to the black community. He was so satisfied that nobody looked at him twice. Levi had found it difficult to adapt in his family, as there was a matrix of domination from the white father, who never allowed his black friends to meet him.

Smith's ideology on race had social justice and activism. The most significant part of the novel was the surreal gathering of Mrs. Carlene Kipps' funeral. The narration of the funeral in the novel had all kinds of people from various races, persuading Jerome to mention that "You can tell she knew every type of person. Can you imagine a funeral - or any other event - like this, back home? (Zadie Smith, 2005, p. 282). The Belseys looked around themselves, and people from every age, colour, and faith were dressed and walking in. Smith tries to navigate that death is





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eternal, and racism cannot commute beyond this. On being disturbed by the funeral, Howard went to meet his parents, leading to interlocking oppression. Howard's father doesn't like Kiki and constantly finds fault with her. Interlocking oppression and the Matrix of Domination connect to identify the different forms of suppression and oppression faced by people in the community. Crenshaw argues that a black woman may experience both racism and sexism, resulting in a unique form of marginalisation and exclusion from society. (Crenshaw, 1991). Kiki, a loyal woman, on being black is stereotyped and a new form of marginalisation is developed. Howard had a relationship with his white colleague Claire and a young black girl Victoria, which was unnoticed, and society is reluctant to blame him. The matrix of domination by the white in the family leads to a deeper sense of segregation and isolation in Howard's family, as his children are mixed race. Howard's father mentions, "You couldn't expect black people to develop mentally like white people do" (Zadie Smith, 2005, p.296). He doesn't like the fact that his grandchildren are mixed-race in their identity. As Howard was depressed, his father questioned him about Kiki. "She found a black fella, I spose. It was always going to happen though. Its their nature" (Zadie Smith, 2005, p. 301).

The street poet from Haiti, Carl Thomas was denied a prospect to study poetry at Wellington College as he was black. Levi was not interested in college, he was compelled to attend because of his white father. The issue with the immigrants from Haiti was the same. They were denied the basic rights of the people, and without proper foundational education, are constrained to do undervalued jobs in the country. "This was a Haitian fellow driver called Pierree, one of the many from that difficult island who now found occupation" (Zadie Smith, 2005, p.24). On visiting the market, Kiki met a Haitian trader. His depression on the new land and suppression in the white-dominated community were highly evident when Kiki questioned his identity. On calling him an African American, he refused and declared that he was from Haiti and mentioned the difficulties the Haitians undergo every day.

Discrimination towards Colored

Black women live through discrimination and marginalisation, shaped by race and gender. Crenshaw states that Racism and Sexism are interconnected and considered to be the interlocking oppression, especially the black women face in every aspect of their life, both personally and professionally. (Crenshaw, 2006). Howard met his wife Kiki, who is black, as a young nursing student at a time when her beauty was natural, honest, powerful, unmediated, and full of genuine desire. Although she was not one of Howard's intellectual arenas, she was actively political and womanly. Later, Howard became intolerant towards her weight gain and old age. His dislike lead to an affair with Clarie Malcolm, a white colleague of Howard. "In the spring it was someone, a nameless someone, it was a one-night stand - now it's Claire Malcolm. It went on for weeks!" (Zadie Smith, 2005, p. 205). After Howard's affair extended to Mr. Kipps' daughter Victoria, Kiki left him in isolation to reflect on his mistakes. She tolerated all the Matrix of White domination, oppression by his educated white colleagues, and marginalisation in the white community she lived in. Still, Howard failed to perceive her needs and wants as a black woman. His white superiority was often evident in every walk of his life, especially when he travelled to England to stop the relationship between Jerome and Victoria because of her black heritage. Victoria praises Kiki's looks to Howard and acknowledges the fact that her mother was particular about people. They have to be real people like Kiki, who was modest and true to herself and her family. Victoria calls Kiki "She's like a Queen. Imperious-looking..Like an African Queen" (Zadie Smith, 2005, p.313). Victoria praises Kiki's blackness in terms of loyalty and faith.

Jerome and Victoria's relationship was highlighted at the beginning of the novel, as Jerome, who had a white father, Howard, was in high praise of Kipps's family, finding adaptability easy for him. The Kipps prioritised their family over their busy schedule. Jerome says, " I love living here. It's a different universe" (Zadie Smith, 2005, p. 3). Jerome did not experience Intersectional invisibility and domination here; rather, he found his identity as black, as evidenced by his comment, "The Kippses continue to grow on me" (p. 5). When Monty suggested that minority groups often claim equal rights they haven't received, Jerome allowed this strange idea to take hold within him, identifying himself as belonging to a minority group. When Michael argued that being black was not an identity but an accidental matter of pigment, Jerome decided about his challenging future in the country, though being a mixed-race individual and having a white father. The accidental pigment determines the opportunities the person will encounter in the rapidly progressing world. Kiki experiences social isolation with her family members. Kiki's children deny her





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the right to contact Mrs. Kipps, as the family is rivals to Howard. Kiki feels connected to Mrs. Kipps. They share the same identity and experience in the white-dominated society. Crenshaw mentions that individuals experience marginalisation within their marginalised groups, leading to isolation and exclusion. (Crenshaw, 1991).

“You have friends, Jerome. And Zora has friends, and Levi practically lives with his friends - and Kiki followed the thought to the edge of the cliff and beyond - well, we sure as hell know now how close your father is to his friends - and what? I can't make friends. You all have your life, and I have no life?” (Zadie Smith, 2005, p. 165)

Kiki's social isolation intensifies as she mentions that she is alone in the sea of white, “My whole life is White” (Zadie Smith, 2005, p. 206). She argues that she finds the black population only when they are cleaning the floor in the cafe at Wellington College or pushing a hospital bed. She is unable to connect with the dominant white population; rather, she sympathises with the black community on the inequality she perceives. Crenshaw argues, “If you are a woman, then you are more victimised than a man, and if you are black, then you are more victimised than if you were white” (Coaston, 2019). Kiki identifies herself as the only black woman attending the Wellington Choir. She views it as a devil's army as the choir is dominated by the whites in both critical evaluation and the end judgment. Surprisingly, Jerome understood the white Greek music and was fully involved in the Choir. Kiki was so proud and felt that she had raised a young man of intelligence and sensibility. “After all, how many other young black men would even come to an event like this - I bet there isn't one in this entire crowd”. (Zadie Smith, 2005, p.70). The matrix of White domination, interlocking oppression of blacks, double bind and intersectional invisibility of the other community are evident here when the blacks are not given a chance or invited to be in the white elite community. Kiki expresses her pride for her son as well as her regret for the other black people for not being included in the white community and continuously being oppressed and marginalised. Kiki conveys a massive message to the black community in the novel, “And there's no big secret, not at all, you need to have faith, I guess, and you need to counter the dismal self-image that black men receive as their birth right from America - that's essential - and, I don't know.....get involved in after school activities, have books around the house, and, sure, have a little money, and a house with outdoor...” (Zadie Smith, 2005, p.71)

Institutional Racism

Howard, a white professor from Wellington College, created a mixed-race family with his Black wife Kiki. His exaggerated praise towards the white community to his academic colleagues and unconcerned neglect of his family and their opinions on inadaptability to the white community leads to Kiki's oppression and marginalisation within the constraints of the family itself. Kiki was not invited into the white-educated elite community, and she always felt isolated and distinct. Racial equality is not appreciated; rather, a matrix of white domination and intersectional invisibility is evident here. Kiki is denied her voice in the family and excluded from her needs as a mother and wife. Crenshaw further argues for equal opportunities for Blacks, proclaiming “Today, the claim that equality does not exist for Black America may fall upon deaf ears - ears deafened by repeated declarations that equality exists” (Crenshaw, 1988).

Crenshaw emphasises that racism is not just about individual actions but also about institutional practices and policies that perpetuate racial inequality. Institutional Racism hinders the growth of the next generation. In the novel, the University has a diligent black student population, creating a mini-university within a university. Levi wondered why Wellington had this little black enclave. Black students experience intersectional invisibility and often hide within their community. The matrix of domination by white people suppresses and marginalises the students of colour suppressed and marginalised. The institutional racism extends to the faculty as Howard and Monty Kipps become rivals, and their ideologies regarding the painter Rembrandt are highly opinionated, with paintings that feature uncompromising realism. The discussions between them often lead to racist remarks at the university. Crenshaw advocated for systematic change and the need to dismantle racist policies. Mr. Kipps, who is black, values the painting and acknowledges that Rembrandt is a genius. Kipps, who is black, values the painting and acknowledges that Rembrandt is a genius, as well as the notion that beauty comes from God. Howard, who is white, is sceptical about the art and believes that it is overrated, with the paintings lacking aesthetic value. Institutional



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Racism is at its peak when Howard sees Monty's Rembrandt book as “retrogressive, perverse, infuriatingly essentialist, but it was neither vulgar nor stupid” (Zadie Smith, 2005, p. 21). However, the book was originally detailed and thorough, and it had the great advantage of being bound between hard covers and distributed throughout the English-speaking world. Howard's book was on the same topic and remained unfinished.

Howard and Kipps had been in the same organization for more than fifteen years. Howard always disliked Monty because he dedicated his entire life to the perverse politics of right-wing iconoclasm. He never really hated him until he heard the news about Kipps' book, Rembrandt. Howard recognised that even before it was published, it would be highly popular. It was this thought of that book and its successful fate that prompted Howard to write a letter against Mr. Kipps. Howard hatred on Kipps extends to the family discussion where he coverts his desperation into rage mentioning “Take your pick. State of Britain, State of the Carribean, states of blackness, state of art, state of women, state of the states - you hum it, he ill play it - he's a charmer, he is a”(Zadie Smith, 2005, p.121). Kiki supports mentioning his anti-affirmative bill. She mentions that he is a black conservative and he believes that it's belittling for African-American kids to be told they need special conduct to succeed. As a black woman, she stands firm on the policies established by Mr. Kipps.

Haitian art is not just paintings and sculptures; it also incorporates unique drum art and Voodoo flags, using vibrant colours and motifs that have intricate meanings. It not only pertains to a single culture but also inspires Europeans and Americans and has received international acclaim. (Hatta, 2018). Monty Kipps informs that he curated and organised the first American exhibition of the Caribbean “Primitives” in New York in 1965. “I have the largest collection of Haitian art in private hands outside of that unfortunate island”(Zadie Smith, 2005, p.113). The representation of the black culture in the white-dominated community becomes difficult when the interlocking oppression and marginalisation are on a high scale. Whites often fail to recognise the purpose and significance of the artwork from other cultures due to the matrix of domination.

CONCLUSION

This study investigates the intersecting forms of oppression portrayed in Zadie Smith's *On Beauty*, focusing on how racism and white domination shape the lived experiences of people of colour. Drawing on Kimberlé Crenshaw's theory of intersectionality which uses multiple frameworks to examine the systemic racism on marginalised communities. Through this, we argue that racism spreads in all areas of life, from education and employment to social spaces and personal relationships. The novel highlights how oppression is experienced at multiple levels, particularly in the experiences of Black individuals within a white-dominated society. The rivalry between Howard and Mr. Kipps, centred on Rembrandt, portrays the existence of racial tensions within elite academic spaces. Kiki's emotional conflict, her search for identity, and her eventual connection with Mrs. Kipps culminate in her symbolic death and the final gift explains her marginalisation and intersectional invisibility. The experiences of characters such as Levi, who seeks belonging in the Haitian community, and Jerome, who feels accepted by the Kipps family, further extend the novel's portrayal of double marginalisation and cultural displacement.

Crenshaw's ideology on power dynamics is essential to understand the functionality race and identity in the novel. *On Beauty* exposes the nature of oppression not only for immigrants but also for mixed-race and second-generation individuals. Through characters like Jerome, Levi, and Kiki, Smith demonstrates how race, power, and identity intersect within everyday experiences. Mrs. Kipps's comments on Kiki's appearance and her final gesture convey the broader idea that the preservation of Black identity and culture must be driven by Black communities themselves. Ultimately, *On Beauty* presents racism as a persistent force from life to death, shaping both the emotional and social realities of its characters and illuminating the transformative potential of confronting intersectional injustice.





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RESEARCH ARTICLE

Integrating Gamification and Project-based Learning: Designing Student - Created Tools for English Language Learning

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ABSTRACT

Gamification in teaching English in engineering education may face several difficulties such as student engagement and applicability in practice. This paper aims to reframe gamification not only as a tool but also as an approach to learning through design whereby students create their own gamified educational experiences. This paper discusses a 30-hour elective course where first-year engineering students designed digital games for enhancing certain aspects of English language skills. The data was collected from 48 participants based on performance scores and project outputs. The results of the research suggest that gamification designed by students increases engagement of thinking processes as 67% percent of participants demonstrated above-average performance scores. Moreover, qualitative analysis of the obtained results demonstrates that designing the games improved the students' linguistic awareness, ability to solve problems, and teamwork – abilities that are not typically achieved through passively consuming gamification-based tools. Overall, this paper offers a radical shift from learning using gamification to learning through gamification design which can be used to implement gamification at scale.

Keywords: gamification design, English language learning, student-centered learning, project-based learning, engineering education



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INTRODUCTION

Communication in English is an essential competency for graduates from engineering colleges in their work in international interdisciplinary teams. Nevertheless, teacher-centered method of language teaching leads to lack of interest among students and poor information retention in language classes. Gamification, which according to Kapp is "the use of game design elements in non-game contexts" [1], has been recognized as one of the teaching strategies used to combat the above problem. Indeed, gamification enhances motivation, persistence, and achievement of desirable results, provided that the application of game mechanisms is consistent with teaching goals [2], [3]. The following theories can be applied to explain why gamification increases learning achievements. First, Self-Determination Theory claims that people develop an intrinsic motivation while being in environments which provide support for autonomy, competence, and relatedness [4]. Second, according to flow theory, people achieve high concentration levels when there is balance between task difficulty and skills and continuous feedback about goal achievement [5].

Gamification provides engineering students, who rely on English as both a tool for gaining employability and a technical challenge, with an opportunity to reconceptualise language learning into a productive, goal-oriented activity. In this paper, we present an elective course, Gamification in Education (24INO121), where not only was gamification used but also actively created by the students. To that end, the elective course incorporated both experiential learning [13] and project-based pedagogy [14], thus balancing engagement, linguistic development, and multidisciplinary literacy.

Objectives of the Study

The present study is based on three interrelated objectives, which address the pedagogical approach itself as well as its outcomes: Firstly, we seek to establish the potential of a gamification elective to improve engagement and performance within the scope of engineering English. Secondly, we aim to explore the mechanisms of self-directed and self-managed learning embedded in the game design that reflects Self-Determination Theory (SDT), Flow theory, and Multimedia learning, all with the purpose of achieving certain language goals, such as developing vocabulary, idioms, and grammar. Finally, and most importantly, we hope to reveal the strengths and weaknesses of project-based gamification as a pedagogical method and assessment tool.

LITERATURE REVIEW

Gamification has gained considerable attention in the realm of education. For instance, according to Deterding et al., gamification refers to the introduction of elements such as points, levels, and badges from game environments to real-life contexts. Kapp and Hamari et al., on the other hand, stress the motivational and performance-enhancing effects of gamification when it is properly integrated into the design of the learning environment.

Theoretical Perspectives

From the perspective of SDT [4], gamification is said to be effective if learners experience competence (through scores), autonomy (through choice of tasks), and social connection (through collaboration). On the other hand, the concept of Flow theory [5] shows how clear objectives and appropriate challenges can result in engagement. Gee's approach [6] further reveals how games incorporate certain "learning principles," including taking risks, feedback, and progression.

Gamification in Language Learning

In second language acquisition (SLA), gamified platforms such as Duolingo and Memrise employ streaks, leaderboards, and adaptive tasks to sustain daily engagement [12]. Mayer's work on multimedia learning [11] demonstrates that multimodal, interactive inputs reduce cognitive load, making digital gamification particularly effective for language acquisition. For idioms and figurative competence specifically, Boers [8] and Liu [10]

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emphasise the role of metaphor awareness and contextualised practice — conditions that puzzle-based games can replicate effectively. Schmitt [9] underscores vocabulary repetition with variation; an approach well aligned with gamified drills and adaptive quizzes.

Gaps in Literature

While ready-made platforms for gamification have been shown to be effective, a glaring gap exists concerning student-designed gamification platforms. Current literature places the learner as an end-user of existing platforms but rarely as creators of a new one. Creating a learning game requires a different form of cognitive engagement compared to playing it. The former entails much more cognitive processing than the latter; the current study seeks to fill this literature gap by analyzing the cognitive processes of creating language learning games among engineering students in the context of an elective subject.

METHODOLOGY

Course Context and Design

Gamification in Education (24INO121) was a one-credit elective subject offered to first-year B.E./B.Tech students. The course was designed to run for 30 hours as follows:

- Module 1 – Introduction to Gamification: its theory, benefits, and practical applications, including case studies of existing gamified learning platforms.
- Module 2 – Designing Gamified Learning Games: vocabulary-based games, grammar-based games, interactive stories, and feedback loops.
- Module 3 – Researching and Evaluating Gamification: prototyping and testing games, feedback and challenges during the learning process.

Participants

There were altogether 48 participants from varied fields of engineering taking up this elective course. They were assigned to work within interdisciplinary groups comprising five to six people for developing game tools to enhance English language learning.

Assessment Framework

The assessment of these groups took place continuously throughout the semester and not through any terminal examination. The groups were evaluated based on three course objectives, namely,

- CO1 — Understanding Concepts: understanding concepts of gamification including their underlying theories and mechanics.
- CO2 — Development: Developing a gamified application that works well with its mechanics in line with a language learning objective.
- CO3 — Evaluating Application: Evaluation of the application designed by each group through testing and peer feedback.

Data Collection

Data from two sources, namely quantitative and qualitative data, were used in the study to allow for a triangulation analysis. The quantitative data comprised internal scores based on a grading system out of 100, which underwent statistical description of the scores to establish the students' average performance. The qualitative data, on the other hand, was collected from project reports and presentation reflections done by the participants. Four illustrative examples of projects were used to represent projects dealing with different types of language skills: Hangman (vocabulary & spelling), Idiomatrix (idioms & figurative language), ELITZ – Learn Modals (grammar through game and puzzle) and Tweet Tweet (letter collecting game/vocabulary).



**Sreejana and Jaidev****Analytical Approach**

Quantitative data analysis used descriptive statistics, which included computing the average score and score distribution. Qualitative data was thematically analyzed according to three parameters: (i) language skills developed, (ii) application of principles of gamification and (iii) acquisition of interdisciplinary skills.

RESULTS**Quantitative Results**

The analysis of student performance (N=48) showed that the course had an excellent achievement profile, where the results varied from 58% to 89%. The mean score was 74.2%, which can be seen in Table 1. According to the table below, 66.7% of students performed above average, showing that the gamification elective was helpful not only to high-achieving but also average students.

Qualitative Results: Case Study Projects

Four exemplary projects presented the variety of gamification concepts created by students for different areas of English language learning.

Hangman (Vocabulary and Spelling)

The students developed a website game using HTML, CSS, and JavaScript. This game helped to foster students' deductive reasoning and vocabulary learning process with instantaneous feedback for right and wrong answers. However, choosing appropriate vocabulary to form a word bank and adjusting game difficulty level involved deep cognitive reflection on how one acquires new vocabulary, which is rare when playing similar games.

Impact: Vocabulary recall, collaborative problem-solving, and debugging skills.

Limitation: Relying too much on uncontextualized vocabulary memory techniques.

Idiomatrix (Idioms and Figurative Language)

This puzzle game, developed with Python in the Pygame library, presented visual cues and multiple choice questions to test understanding of idioms. The process of researching idioms, anticipating learner difficulties and creating visuals enhanced students' own abilities with figurative language. Outcome: Allowed learners to better associate images with figures of speech, operationalizing Boers' [8] work on metaphors.

Problems: It was difficult to adjust level of difficulty; some idioms were unknown to learners with particular cultural backgrounds.

ELITZ — Learn Modals (Grammar Practice)

Dual mode, presenting grammar questions in a multiple choice quiz format or through a word-puzzle game. Auditory and visual components worked in harmony, following principles set out by Mayer [11], decreasing cognitive overload and maintaining learners' focus.

Outcome: Provided an environment where grammatical corrections were immediately provided alongside auditory and visual reinforcement.

Problems: Prototype offered only a selection of sentences and should include grammar module in the future.

Tweet Tweet (Letter Collection Vocabulary Game)

A bird character collected falling letters to create target vocabulary words, utilizing animation and vocabulary games together. The animated game kept students engaged, which was not possible with traditional vocabulary lists.

Impact: Enhanced spelling accuracy and focus; engaging animations helped learners pay attention for longer periods of time.

Problem: Difficulty in creating smooth animations for lower-end machines.



**Sreejana and Jaidev****Course Outcomes (CO) Achievement**

All three course outcomes have been clearly reached in projects and reflective journal entries, as outlined in Table 2 below.

- CO1 (Principles): Met through explicit references to gamification components, namely points, levels, feedback, and badges, in the context of language learning.
- CO2 (Design and Development): Proven through the creation of four unique applications that cover vocabulary, idiomatic expressions, and grammar.
- CO3 (Evaluation): Manifest in student reflections, repeated peer testing, challenges faced during design and development, and subsequent revisions.

DISCUSSION

The most critical discovery made by this research is not the effectiveness of gamification, which has been proven before [1]–[3]. The critical difference is that designing gamification provides a learner with qualitatively more meaningful experiences than consuming it. This is what this project was about, and the data collected proves its viability on several levels. First, there is a high percentage of learners with high achievements, 67%. They scored above 70 in the course and are consistent with the results obtained by Hamari et al. [3] and proving that gamification fosters learners' persistence and productivity. Still, the most compelling argument can be found in the qualitative evidence: the struggling English learners managed to develop better linguistic awareness due to their involvement in the design process. To create a vocabulary-learning game, one has to understand how vocabulary learning works.

Theoretical consistency is solid as well. The elective design is aligned with self-determination theory [4] and Flow theory [5] in terms of fostering intrinsic motivation through autonomy, competence, and relatedness. Autonomy comes from freedom in choosing mechanics and content. Competence is achieved via progressive scoring and improvement over time. Relatedness comes from teamwork. From the perspective of language skills, student projects confirmed existing theories of second language acquisition. The Idiomatrix system utilised the metaphor-awareness theory suggested by Boers [8] in terms of the association between idioms and imagery. ELITZ implemented Mayer's [11] multimedia learning theory by combining auditory and visual prompts for grammar lessons. The games of Hangman and Tweet Tweet were based on Schmitt's [9] vocabulary repetition strategy using different approaches. The two-stage aspect of the teaching approach, learning English and learning how to design, is in harmony with Kolb's experiential learning model [13] and results of project-based learning studies [14]. Students were not limited to practicing their language skills but used them in a variety of ways, developing a range of skills across disciplines – programming, teamwork, documentation, and critical reflection.

Among the limitations in conducting the study is the small sample size of only 48 students as well as the lack of pre- and post-language proficiency tests for quantifying actual language improvement as a result of the experiment. However, the varying degrees of technical proficiency of the student-developed games also indicate that further iterations of this model would require more assistance from the instructor in the design and development module. Nevertheless, the overall success in terms of quantitative performance and qualitative reflections warrants further implementation in other academic settings.

CONCLUSION AND FUTURE WORK

The current research aimed at exploring how Gamification in Education (24INO121) as a project-based elective would affect language learning among engineering undergraduate students. Based on the research findings, the integration of game design in English language instruction positively affected not only the level of engagement of the learners but also their performance and creative skills. In numbers, 67% of the students scored over 70 while Hangman, Idiomatrix, ELITZ, and Tweet Tweet showed creative use of game design principles in practice.



**Sreejana and Jaidev**

The primary innovation offered by the study is a conceptual one; it illustrates that the act of designing a gamified tool, in itself, represents an extremely valuable form of pedagogy. Students engaged in creating games for others must first absorb what they hope to impart and will gain a deeper knowledge of it through the act of building the game itself than would be possible otherwise.

Pedagogical Contributions

- Illustrates that the potential application of gamification extends far beyond vocabulary-building exercises, allowing for the introduction of project-based learning to the teaching of English that builds language competencies and interdisciplinary skills simultaneously.
- Provides a template for other engineering schools looking to incorporate elements of active learning, interdisciplinarity, and authentic assessments into their English language curriculum.
- Establishes gamification not only as a pedagogy but also as a mode of assessment based on the learning-by-design process.

Limitations

- Carried out on a limited sample of 48 engineering students, reducing generalizability to other schools and/or cultures.
- Student progress assessed based on grades and reflection rather than using standardized tests measuring language ability.

There was a great deal of variation in the technical quality of the games produced and retention was not examined over time,

8.3 Future Work

- To extend the scope and scalability of project-based gamification, future directions include the following:
- Cross-Institutional Collaborations — Conducting multi-campus studies in which student-created games are shared, tested, and refined across institutions, building a common evidence base.
- Adaptive and AI-Driven Gamification — Embedding adaptive difficulty, personalised learning pathways, and learning analytics into student-designed games to increase pedagogical precision.
- Immersive Technologies — Leveraging VR and AR environments for role-play scenarios such as debates, interviews, and cross-cultural communication tasks.
- Longitudinal Studies — Tracking how gamification design impacts long-term outcomes including employability, communication confidence, and global competence.
- Repository of Student Games — Building a curated, peer-reviewed platform of student-created English gamification tools available for reuse across classrooms.

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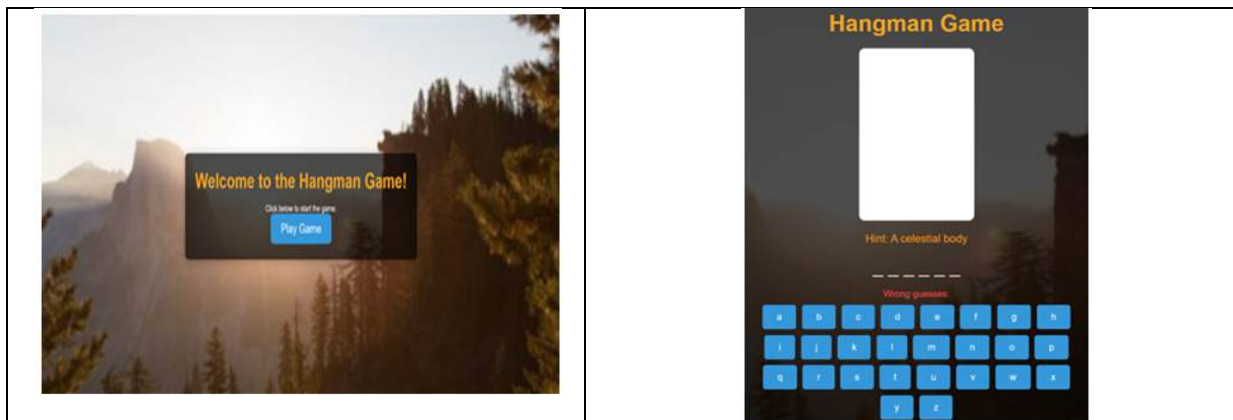
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Table 1: Score Distribution

Category	Number of Students	Percentage
High Achievers (80+)	11	23%
Above Average (70–79)	21	44%
Average (60–69)	15	31%
Low (<60)	1	2%

Table 2: Course Outcomes And Evidence

CO	Description	Evidence from Projects
CO1	Understand gamification principles	Reports articulating mechanics: points, levels, badges, feedback loops
CO2	Design gamified tools	Hangman, Idiomatrix, ELITZ — Learn Modals, Tweet Tweet
CO3	Evaluate effectiveness	Reflective reports, peer feedback sessions, iterative testing cycles





Sreejana and Jaidev

Correct! Hit the nail on the head!

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RESEARCH ARTICLE

Effects of AI-Mediated Task-Based Language Teaching on ESL Learners' Speaking Accuracy and Fluency

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ABSTRACT

The aim of the study is to explore the impact of task-based language teaching through artificial intelligence on the speaking accuracy and fluency of English Second Language (ESL) learners enrolled in an autonomous engineering college in India. Communicative language teaching and technology-based teaching methods were at the core of the research, which utilized a ten-week quasi-experimental study to explore the impact of task-based language instruction on 100 engineering students, who were randomly allocated to an experimental and a control group. The experimental group of the study engaged with a digital form of language instruction through an artificial intelligence tool to enhance their speaking skills, while the control group received regular classroom teaching. Further, speaking proficiency measures involving analytic rubrics formed part of pre- and post-test data, while analysing them via paired and independent samples t-tests with effect size calculations highlighted statistically significant gains on learners who experienced AI-integrated TBLT, while large effect sizes signified its strong impact as instruction. In addition, although results were not explicitly mentioned, qualitative self-reports accentuated learners' self-confidence, motivation, and self-regulation of learning. In conclusion, these results provide robust quantitative evidence of the integration of AI-based pedagogies in engineering colleges, revealing their potential for developing learners' comprehensive speaking proficiency while encouraging growth in learner-oriented language studies in technology-enhanced learning environments.

Keywords: Artificial Intelligence in Language Learning (AI-LL), Task-Based Language Teaching (TBLT), L2 Speaking Development, Speaking Accuracy and Fluency, Technology-Enhanced Language Learning (TELL), Quasi-Experimental ESL Research.



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INTRODUCTION

The accelerated use of artificial intelligence (AI) in recent times has brought about an impact on modern educational practices, especially in language learning settings across diverse educational systems. The latest publications show how AI can assist in offering corrective feedback, anticipating students' learning requirements, as well as creating actual communicative situations, making it easier for students to become involved in enhanced learning. Furthermore, it has accelerated language acquisition (Holmes et al., 2022). Therefore, as higher education institutions aim towards introducing innovative teaching practices, AI-assisted language learning seems to be an essential part of digitally enhanced language learning. Parallel to these technological advancements, Task-Based Language Teaching (TBLT) has continued to be one of the most evidentially confirmed language teaching methods for developing communicative language competencies. This is particularly because, by shifting the focus of instruction from linguistic forms to meaning-focused tasks, language learning can be optimized for enhanced authenticity, both accuracy, and fluency, all through interaction-based language learning processes (Ellis et al., 2020). Recent investigations into the application of technology to TBLT environments have confirmed this potential to improve language learning outcomes, particularly by providing learners with learning options that transcend traditional classroom borders, along with immediate feedback mechanisms that are hard to achieve traditionally (González-Lloret, 2021).

This integration of AI and TBLT represents a significant change in learning pedagogies, shifting from teacher-centric learning environments to intelligent and learner-centric learning environments. Speech recognition technologies, which fall under AI, have demonstrated significant promise in improving pronunciation, grammatical, and communicative skills through repetition. Moreover, a meta-analytic review of intelligent tutoring systems using AI-based technologies reported positive learning outcomes, which indicates a promising potential of AI-based learning environments for second language learning, especially speaking skills. Despite all these developments, speaking fluency has been repeatedly cited as a problematic skill, which ESL students struggle to achieve. Since speaking involves the simultaneous and control-demanding processing of grammar, vocabulary, and pronunciation, it causes cognitive overload as a traditional classroom setting fails to afford an opportunity for repetition (Sweller et al., 2019). The virtual environment can afford such flexibility to the students to repeat the tasks as many times as needed and encourage self-regulated behaviours using the feedback provided (Kukulka-Hulme, 2020).

The relevance of AI for speaking skills development is further supported by empirical studies. For example, a study on the impact of feedback systems motivated by artificial intelligence found that the tools contribute to the development of accurate pronunciation and enhanced speech intelligibility, as well as the learners' self-confidence, particularly due to the low-anxiety levels (Sun, 2023). Another study on interaction with technology, where AI is a central medium, identified a positive correlation with learners' engagement and communication willingness, areas which predict speaking development as core factors (Tai & Chen, 2023). The role of AI is reportedly conditioned by its incorporation into a sound instructional theory, not merely as a technology support (Luckin et al., 2022). Despite the proliferation of literature on the subfield of AI-Assisted Language Learning, several gaps emerge from the existing work. Firstly, much of the existing work appears to operate from a short-term perspective, such as exploratory works. Secondly, relatively little work uses the design necessary to account for both increased performance and learner perceptions simultaneously. Lastly, engineering programs, a field where communicative competency is becoming increasingly important from a HEA perspective focused on global collaboration, appear underrepresented in the existing ESL literature in spite of the distinctive discourse requirements of academic/technical work (Rienties et al., 2022).

Autonomous engineering colleges represent a particularly motivating site for investigation. Unlike highly centralized universities, these institutions often enjoy curricular flexibility that allows the implementation of innovative pedagogies and emerging technologies. In the same vein, students of engineering often emphasize technical



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coursework, leaving them with fewer structured opportunities to develop their oral communication skills. This imbalance underlines the need for pedagogical models that efficiently integrate language development into discipline-focused programs while maintaining academic rigor. The present study addresses these gaps by investigating the impact of AI-mediated TBLT on ESL learners' speaking accuracy and fluency within an autonomous engineering college. Using a quasi-experimental mixed-methods design, the research attempts to develop sound empirical data regarding the instructional worth of AI-integrated task-based pedagogy while providing insight into learner experiences within technologically enriched learning environments.

The present study situates AI not only as a technologically enhanced tool but even more so as a pedagogic driver that can reshape communicative language teaching. Developing empirical clarity on these issues will be critical, informing curriculum design, institutional investments of resources in educational technologies, and effective, evidence-based teaching practices amidst rapidly shifting academic ecologies.

Research Objectives

- To investigate the impact of AI-based task-based language instruction on the speaking accuracy of ESL learners.
- To assess the effect of AI-based task language teaching on the fluency of speaking among ESL learners.

Research Questions

1. To what extent does AI-mediated task-based language teaching improve the speaking accuracy of ESL learners in comparison to more conventional approaches of teaching?
2. How is AI-mediated task-based language teaching effective in improving the speaking fluency of ESL learners in technology-enhanced contexts?

Hypothesis

- H1: ESL students instructed in AI-mediated TBLT will show significant improvement in speaking accuracy compared to traditionally instructed ESL students.
- H2: ESL learners undertaking AI-mediated TBLT will show greater improvement in speaking fluency compared with a control group.

LITERATURE REVIEW**Task-Based Language Teaching and Speaking Development**

Task-Based Language Teaching (TBLT) has emerged as one of the most fully developed and supported methods to facilitate communicative language competence in second language acquisition. Based on the tenets of interactionism and cognitivism, TBLT focuses on the necessity for using tasks to help learners access meaning and utilize linguistic knowledge to accomplish communicative functions. More recent research prioritizes that task involvement is essential to enhance deeper processing, promoting both procedural knowledge and automatization—two necessary prerequisites for oral fluency (Ellis et al., 2020).

Results of contemporary extensions of TBLT research increasingly explore the effects of task complexity on learner performance. Robinson's Cognition Hypothesis assumes that cognitively challenging tasks can drive learners to use more sophisticated grammatical complexity and accuracy through attention to form while communicating (Robinson, 2022). Other assumptions, such as Skehan's Limited Attentional Capacity Model, state that learners allocate their finite cognitive abilities across task requirements such as fluency, accuracy, and complexity, often at the expense of each other (Skehan, 2023). Internal sources of validation for this approach lie in the recent findings from classroom-based studies. For example, a large-scale meta-analysis carried out by Chong and Reinders (2021), to a significant extent, validates the effectiveness of TBLT approaches, showing superior outcomes for speaking performance compared to form-focused approaches, especially when interactive elements such as problem-solving and information gap tasks were built into tasks. Furthermore, Lambert and Kormos (2024) show the importance of task repetition for fluency, highlighting the fact that processing demands are reduced and faster access to vocabulary is promoted, indicating a potential advantage when working with novice learners. A new trend of research focuses



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on the importance of feedback within task-based environments. Corrective feedback provided while or just after completing a task appears to assist with grammatical knowledge while minimal communicative interruptions result (Li, 2022). What is more, researchers have started to argue that the effectiveness of TBLTs can be increased when learners have opportunities to rehearse and reflect on the learning cycles, and these behaviours have been connected to self-regulated learning and long-term retention. However, such developments have faced various impediments, especially considering large class sizes, instructional time, and participation. Consequently, the emphasis on conducting research for technology-assisted task environments, which transcend temporal and spatial boundaries, is growing, as highlighted by Ahmadian & Long (2021). This implies a shift towards digital models of TBLT, which may meet the communicative concerns of contemporary higher education.

Artificial Intelligence in Language Learning

Artificial intelligence is significantly changing the language education landscape with AI-based adaptive systems that can respond to the changing performance of learners. For AI systems, they can listen to human speech, recognize mistakes, and provide corresponding feedback, which would be difficult for traditional human educators. This power of AI bears a similarity with the current emphasis placed on precision education, which relies on various forms of analytics to provide students with customized teaching intervention (Holmes et al., 2022). The most influential application of AI technology in language learning appears to be intelligent tutoring systems, or ITS, through one-to-one continuous assessment and support. Recent studies on autonomous language learning through experimentation show the positive impact of ITS systems on learner autonomy and the improvement of language learning skills (Ma et al., 2024). The dynamic difficulty management through intelligent systems also maintains the optimal degree of challenge for learners, thus enhancing learner motivation.

Automated feedback technologies also have shown significant pedagogical potential. Advances in automatic speech recognition accordingly make it possible to identify segmental and suprasegmental features with high accuracy, allowing learners to practice and improve their pronunciation iteratively. Empirical results indicate that training based on ASR not only leads to improved intelligibility but also lowers speaking anxiety because learners can first practice privately before communicating publicly (Sun, 2023). Conversational AI is another game-changing evolution. The dialogue agent can simulate real interaction because it could respond in unpredictable ways, which would allow negotiation of meaning—a very important mechanism for language acquisition. Tai & Chen (2023) report that learners interacting with AI-powered chatbots show greater willingness to communicate and higher-level engagement than peers taught within conventional classrooms. Adaptive learning systems continue to enhance artificial intelligence's pedagogical relevance by continuously recalibrating the instructional pathways on the basis of learner analytics. Such responsiveness has been associated with increased persistence and more efficient skill acquisition in environments where the learners have heterogeneous proficiency levels (Luckin et al., 2022). However, scholars do warn that technological sophistication in and of itself does not guarantee educational effectiveness; AI must instead be conceptualized within theoretically framed pedagogical systems if it is to create sustainable learning gains.

Incorporating Artificial Intelligence into Task-Based Language Teaching

The convergence of these AI technologies with TBLT therefore represents an important evolution in communicative pedagogy. TBLT provides the theoretical architecture for meaning-making interaction, while AI provides the infrastructural capacity to operationalize tasks within intelligent feedback-rich ecologies. This is a synergy that has spurred growing scholarly interest in technology-mediated task-ecologies that extend opportunities for authentic language use beyond the physical classroom (González-Lloret & Ortega, 2023). One of the major benefits of AI-assisted tasks is the potential for immediate and individualized feedback delivery without hindering communicative exchange. This also serves to promote a noticing effect, which is recognized as an important thinking process for interlanguage development, within task performance in an authentic way. Smith & González-Lloret (2020) claim that digitally mediated task performance may actually facilitate learner noticing of form through feedback being an integral part of communicative exchange rather than an isolated function.



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The emerging body of empirical research indicates that task environments enabled by AI can have a positive effect on various facets of speaking development. In this sense, a study carried out by Fryer and Carpenter (2021) showed that learners who were engaged in a dialogue with AI were more fluent and lexical diverse than learners who completed a task using a textbook. Similarly, a study conducted by Rienties et al. (2022) showed “deep engagement” and “sustained interaction,” which are two factors that predict development “oral proficiency.”

From a theoretical point of view, the combination of AI and TBLT corresponds to the socio-cognitive perspective on language acquisition as an adaptive process in which learning is mediated by interaction and feedback. Finally, intelligent systems work as mediational devices for language learners; as such, language acquisition happens within the zone of proximal development, but with the increasing internalization of language structures. This supports the ineradicable argument that AI not meant to replace teachers but to enrich the Teaching Design. Nevertheless, the empirical base supporting AI-mediated TBLT appears relatively underdeveloped. Indeed, the majority of existing studies investigate the use of technology-mediated learning more generally rather than task-based approaches in more specific ways. Accordingly, Chapelle (2020) and others have highlighted the need for substantive studies of the type that can effectively examine the impact of task design with AI mediated instruction and measure the impact of instruction in language development.

Research Gap

Though research in the application of AI in language learning has experienced growing momentum, the interface between task-based learning and artificial intelligence has not been adequately investigated within controlled experimental setups. This has seen most studies focus on making perceptions, raising questions about their sustainability and degree of effect. Further, little research has targeted engineering students whose learning process increasingly requires them to achieve high levels of communicative skills to succeed in globalized environments. Not many studies have assessed the impact of AI-mediated TBLT and its quantifiable effects on the accuracy and fluency of engineering students’ speaking skills in ESL. Such a vacillation impacts us particularly because of the cognitive and communicative burdens associated with the production of oral language. Unless supported by robust empirical data, institutions may be unwilling to adopt a technology-rich teaching model, even when there is theoretical evidence to support it. The present study aims to address this gap by means of a quasi-experimental design to assess whether improvements in speaking could be achieved statistically with the application of task-based instruction supplemented with AI. This study contributes another dimension of significance, with the setting of this investigation situated in an autonomous college of engineering.

Conceptual framework

Artificial Intelligence (AI) tools, such as ASR, chatbots, and adaptive learning systems, are conceptualized in the framework of this study as the main enablers of technology-enhanced language instruction. These responsive learning environments support personalized practice, continuous interaction, and immediate feedback, hence contributing to more efficient skill development. At the pedagogical heart of this framework lies AI-mediated Task-Based Language Teaching that uses intelligent technologies to design and deliver interactive, meaning-focused, and feedback-rich tasks, thus promoting more authentic use of language and more active learner participation. This shift focuses away from form-driven instruction toward the development of communicative competence. The model reveals the possibility of the outcomes of tasks involving AI to influence enhanced speaking outcomes, especially with respect to the correct production of speech, or accuracy, and fluency. These outcomes, however, manifest under the strong influence of key moderating factors, especially learner engagement, task complexity, and the immediacy of feedback. High levels of engagement lead to higher levels of motivation, optimally taxing tasks result in greater cognitive engagement, and timely feedback facilitates rapid feedback regulations. All these factors, therefore, influence to what degree AI-assisted TBLT contributes to enhanced speaking outcomes.



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METHODOLOGY

This research employed an robust methodological framework in order to ensure transparency, replicability, and analytical preciseness. The section outlines the research design, participant characteristics, instructional treatment, research instruments, data collection procedures, and analytical techniques used for an investigation of effectiveness related to AI-mediated TBLT on ESL learners' speaking accuracy and fluency within an autonomous engineering college context.

Research Design

It used a quasi-experimental mixed-method design that combined both quantitative and qualitative approaches to provide an overall understanding of the instructional effect. Quasi-experiments are especially appropriate for research in educational settings, where random assignment is most often impractical because of institutional constraints yet where controlled comparisons must be used for establishing causal inferences. To use an evaluation framework, a pre-test/post-test control group design was employed to better assess the improvements made in terms of speaking ability over time. Two intact classes were selected as the experimental group and control group to ensure ecological validity in terms of learning environments. Unlike the experimental group, which was presented with AI-mediated task-based approaches, the control group was presented with traditional teacher-based communicative practices. This mixed-methods model has enhanced the robustness of the investigation, as it has allowed for the statistical evaluation of any learning proficiency gains, as well as increased understandings of student experience. Quantitative data has helped demonstrate the extent and importance of learning outcomes, while also revealing qualitative data that sheds light on affecting factors such as student engagement, confidence, and self-directed learning. These features meet expectations of high-impact applied linguistics studies.

Participants and Context

The study site for the research is a private autonomous engineering college in India, a type of setting associated with specific attributes like outcome-based education, industry-oriented curricula, and the growing use of digital learning infrastructures. The specific setting of autonomous engineering colleges constitutes a unique pedagogical setting, as it combines curricular flexibility with academic rigor comparable to a university, which is affiliated to this college. This setting formed a relevant context for exploring technology-based language learning for global professional communication. The participants were 100 undergraduate engineering students enrolled in a compulsory course on communication skills at the second year of their academic program. At this phase of education, students often progress from language fundamentals to subject-based communicative needs, which is a very significant learning period for communicative speaking skills.

Students showed possession of an intermediate level of English language proficiency, meaning they generally demonstrated B1/B2 CEFR criteria. Students' records, past test results, and speaking test results supported homogeneity among the population.

A purposive sampling strategy was used in the selection of the participants in order to obtain data from the individuals who met three criteria.

1. Registration in the assigned communications class
2. Regular class attendance
3. Willingness to participate with informed consent

After selection, the participants were divided into two equal groups:

- Experimental group (n = 50): Received AI-mediated TBLT instruction
- Control group (n = 50) participants: Traditional speaking instruction was provided to this group.

Although full randomization wasn't possible, baseline equivalence across groups was established through pre-test comparisons so that it would be possible to attribute with greater confidence subsequent differences not to pre-existing proficiency differences but to the instructional treatment.



**Prem Kumar****Pedagogical Intervention**

The pedagogical intervention was delivered over a period of ten weeks, consisting of two 90-minute sessions per week, totalling about thirty hours of guided speaking practice. The intervention was carefully structured in line with the traditional Task-Based Language Teaching (TBLT) cycle, consisting of three overlapping stages: pre-task preparation, task performance, and post-task reflection. This carefully structured approach was adopted to promote communicative competence while ensuring that the learners participated in meaningful and reflective communication.

AI Tools Employed

In order to promote communicative authenticity and immediacy of feedback, the experimental group was exposed to a thoughtfully selected set of AI-enabled tools. These tools included AI-powered speech recognition systems that had the ability to provide real-time pronunciation feedback, thus promoting increased phonological awareness. The learners were also exposed to chatbots that provided simulated professional and academic conversations, allowing for multiple encounters with relevant language use. Moreover, adaptive speaking tools provided personalized practice activities tailored to the learners' proficiency levels, while automated feedback tools systematically tracked learners' performance trajectories. The choice of these tools was informed by considerations of usability, congruence with TBLT, and institutional availability.

Task Types

The participants were required to undertake a series of increasingly complex communicative tasks that were carefully crafted to mirror actual engineering communication contexts as closely as possible. These tasks involved scenario-based role plays, for example client consultations and project presentations, which required the participants to work with meaning in professionally contextualized communication. Technical presentations were also included to develop organizational clarity and rhetorical sophistication, while problem-solving discussions were used to develop analytical articulation and collaborative argumentation. Debates were used to develop critical engagement with subject matter issues, while decision-making tasks were used to develop negotiation skills and interactive fluency. Taken together, these tasks emphasized meaning-centred communication while also drawing the participants' attention to linguistic form through feedback.

Feedback Mechanism

The dual-feedback approach was supported by the instructional design. First, immediate feedback was provided by the AI system to address crucial aspects of speaking ability, such as pronunciation, word choice, grammatical correctness, and speech rate. The instant diagnostic feedback allowed the learners to notice their weaknesses in real time. Second, instructor-mediated scaffolding was incorporated to complement the automated feedback with strategic, metalinguistic, and corrective feedback during post-task analysis. The multi-layered feedback system helped to facilitate deeper cognitive noticing of errors and improve the refinement of speaking skills.

By contrast, the control group was exposed to similar speaking topics but only received feedback in the form of teacher commentary and peer reaction, without recourse to automated diagnostic software. The deliberate integration of artificial intelligence in the TBLT cycle, therefore, represented the primary innovative aspect of this research, placing the educational treatment at the dynamic nexus of traditional educational theory and cutting-edge educational technology.

Instruments**Speaking Assessment Rubric**

Speaking ability was measured using an analytic rubric that was carefully crafted to identify two key constructs: accuracy and fluency. Accuracy included grammatical mastery, lexical choice, and phonological accuracy, thus capturing learners' mastery of formal linguistic aspects necessary for effective communication. Fluency, on the other hand, included criteria such as speech cohesion, speech rate, pause frequency, and overall speech coherence, thus highlighting the temporal and discourse aspects of speech production. Both constructs were measured using a five-point scale that enabled subtle distinctions to be made regarding learner performance.



**Prem Kumar****Validity**

Content validity was ensured by a careful expert review process carried out by three experts in applied linguistics and language testing. The group checked the correspondence between the rubric descriptors, course outcomes, and theoretically defined concepts of speaking ability, thus ensuring that the tool was representative of the skill area being tested. Construct validity was also ensured by linking the rubric to well-known frameworks of communicative competence and existing frameworks of oral proficiency testing, thus ensuring the interpretive validity of the results obtained from the tool.

Reliability

The internal consistency of the instrument was determined using Cronbach's alpha, which gave a reliability coefficient of 0.89, thus being very reliable, as expected in educational instruments. To make the results more reliable, the speaking samples were rated by two raters independently to reduce the bias. The inter-rater reliability was then calculated using Cohen's kappa, which was above 0.85, thus showing a high degree of agreement between the two raters. The reliability measures above demonstrate the stability of the instrument.

Data Collection Procedure

The data collection process consisted of four consecutive stages:

Stage 1: Pre-testing

The participants undertook an individual speaking task that was recorded in a standardized manner. The recordings provided a basis for determining the initial level of accuracy and fluency.

Stage 2: Intervention

The experimental group undertook AI-mediated activities for a period of ten weeks, while the control group adhered to the traditional learning process.

Stage 3: Post-testing

The participants undertook similar speaking tasks of equal complexity to the pre-test, thereby ensuring consistency in the measurement process.

Stage 4: Qualitative Data Collection

The participants maintained a reflective journal and responded to a short questionnaire to provide data on their views about confidence, engagement, and the perceived effectiveness of the instructional processes. All the recordings were anonymized and stored in a secure manner and used only for research purposes.

Data Analysis

The quantitative data was analysed with the aid of statistical software to ensure accuracy and replicability. Paired samples t-tests were employed to determine the improvement that occurred within groups from pre-test to post-test, while independent samples t-tests were used to compare the performance differences between the experimental and control groups. To supplement the significance testing, the effect sizes (Cohen's d) were calculated to determine the degree of the instructional effect, which has become an increasingly common requirement in high-quality empirical research. Before conducting the inferential testing, the assumptions of normality and homogeneity of variance were checked to ensure statistical validity. The qualitative data was analysed using thematic analysis, which involves coding, categorization, and pattern identification. This allowed the researcher to determine the attitudes and behavioural changes of the learners that could not be determined with the aid of numerical data.

The blending of statistical rigor with systematic qualitative interpretation added strength to the explanatory power of the study and made it more suitable for international scholarly dissemination. In conclusion, the methodological framework was designed to incorporate elements of experimental control, ecological validity, measurement reliability, and analytical robustness. This methodological clarity not only facilitates replicability but also places the study within the evidentiary requirements of high-impact research on technology-enhanced language learning.





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RESULTS

This section reports the results of the quasi-experimental study on the effects of AI-mediated Task-Based Language Teaching (TBLT) on the speaking accuracy and fluency of ESL learners. The results of the quantitative study are presented in this section.

Speaking Accuracy

The descriptive statistics of the pre-test and post-test results of the speaking accuracy of the experimental and control groups are shown in Table.1. The experimental group showed a great improvement in speaking accuracy, while the control group showed a slight improvement.

A paired-samples t-test was employed to investigate the within-group changes. For the experimental group, there was a significant improvement in accuracy from the pre-test ($M = 65.2$, $SD = 6.1$) to the post-test ($M = 81.3$, $SD = 5.9$), $t(49) = 15.92$, $p < .001$, $d = 2.25$, which is a very large effect. The control group also demonstrated a significant improvement from 64.8 to 68.2, $t(49) = 3.45$, $p < .01$, $d = 0.49$, which is a small-to-moderate effect. These findings indicate that AI-supported TBLT had a large positive effect on speaking accuracy compared to the traditional method.

Speaking Fluency

The descriptive statistics for speaking fluency are shown in Table 2. The experimental group showed higher mean gains than the control group after the intervention. Paired samples t-tests revealed significant fluency improvements in the experimental group, $t(49) = 14.83$, $p < .001$, $d = 2.10$, and smaller but significant improvements in the control group, $t(49) = 3.10$, $p < .01$, $d = 0.44$.

Between-Group Comparisons

Independent samples t-tests were used to examine differences between groups on the post-test. The results are displayed in Table 3. These findings suggest that the experimental group had a significant advantage over the control group in speaking accuracy and fluency, with large effect sizes.

Learner Progression

The mean scores for the pre-test and post-test results of both groups are shown in Table 4 below. Individual-level analysis showed steady improvement in the experimental group, which indicated the success of AI-mediated TBLT.

Qualitative Insights

The qualitative data collected from learner journals and post-test surveys provided some recurring themes that supplemented the quantitative results. The learners showed increased confidence in speaking, which was marked by reduced pauses and anxiety, along with increased engagement levels due to their motivation and participation in AI-mediated activities. The qualitative data also showed the development of autonomy among learners, who were able to assess their own performance and correct errors using AI-mediated feedback. A representative reflection is: *"The AI tool helped me identify and correct mistakes instantly. I now feel confident presenting in front of my classmates."* Taken together, these findings support the quantitative results, indicating not only improvements in linguistic skills but also in affective aspects such as motivation, self-efficacy, and autonomous learning.

SUMMARY OF RESULTS

The results show that the AI-mediated TBLT had statistically significant and educationally meaningful effects on the ESL speakers' speaking accuracy and fluency. The large effect sizes indicate the strong impact of the intervention, and the qualitative data support the increased learner confidence, engagement, and self-regulation. The quantitative



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and qualitative results together offer strong evidence of the efficacy of the AI-integrated TBLT in engineering colleges.

DISCUSSION

The results of this research offer conclusive proof that AI-facilitated Task-Based Language Teaching (TBLT) has a profoundly positive effect on the speaking accuracy and fluency of ESL students in an autonomous engineering college setting. The positive outcomes of this study can be attributed to the multimodal nature of AI-supported language instruction, which integrates immediate corrective feedback, adaptive scaffolding, and interactive communicative tasks. These aspects are in line with the fundamental principles of Second Language Acquisition (SLA) theories, specifically the interactionist approach, which highlights the significance of input, output, and corrective feedback in the linguistic development of learners (Long, 2020; Ellis, 2021). The use of AI tools to support language instruction enables learners to overcome cognitive overload, allowing them to attend to both form and meaning simultaneously during task completion, as postulated by Skehan (2019) in his task-based cognitive engagement framework.

The incorporation of AI technology into TBLT also promotes the sociocultural aspect of language learning. Vygotsky's (1978) concept of the Zone of Proximal Development (ZPD) emphasizes the need for scaffolded interaction in supporting learner development. The AI-supported environment in this study served as a persistent scaffold that enabled peer-like, responsive interaction, which in turn enabled learners to master correct linguistic forms while gaining confidence in speaking. This process may account for the significant rise in learner engagement and self-regulatory practices, as indicated by qualitative findings, echoing previous research on intelligent tutoring systems and adaptive learning technologies in higher education settings (Li & Wang, 2021; Chen et al., 2022).

By comparison, the findings support and build upon existing research on technology-enhanced TBLT. Although traditional TBLT has been found to enhance speaking ability (Robinson, 2019; Shintani, 2020), the addition of AI brings a degree of accuracy and immediacy to the feedback process that is not possible in teacher-mediated or peer-mediated activities. The quasi-experimental nature of this study offers strong empirical support, demonstrating that AI-enhanced activities yield greater gains in accuracy and fluency than traditional instruction. The results of this study highlight the strong pedagogical value of AI as a supplementary mediator of SLA, especially within the context of engineering students, who are often presented with limited opportunities for authentic speaking practice due to the nature of the curriculum and the technical demands of the program.

Moreover, the study points to particular instructional mechanisms that could explain the improved results. First, adaptive AI algorithms adjusted task difficulty in real time according to the performance of individual learners, thus providing optimal levels of challenge without provoking frustration. Second, conversational AI simulations provided immersive and contextualized speaking opportunities that approximated real-world communicative contexts, thus raising task relevance and learner engagement. Third, immediate and specific feedback on pronunciation, grammar, and vocabulary use facilitated iterative learning cycles that reinforced accuracy while preserving fluency. Taken together, these mechanisms illustrate the synergistic possibilities of TBLT pedagogy in combination with AI scaffolding.

The significance of this development for engineering education is quite evident. Engineering students tend to have strong analytical and procedural skills but lack opportunities to practice oral English. The integration of AI-mediated TBLT in such a scenario enables institutions to offer scalable, consistent, and learner-centric language practice opportunities. In addition, AI-based platforms encourage autonomy, which enables students to self-regulate, track their progress, and practice reflective learning outside the classroom setting (Zhang et al., 2023). The integration of AI-mediated TBLT in engineering education not only helps overcome linguistic deficiencies but also enables the development of critical soft skills such as communication, collaboration, and critical thinking, which are essential for engineering practice in a globalized world.





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Finally, this research contributes to the emerging debate on AI-enhanced SLA by providing a replicable model that seeks to strike a balance between empirical research and pedagogical innovation. In doing so, it sets a benchmark for future research by providing empirical evidence of the positive effects of AI on accuracy and fluency rates. This research also opens the door for further research into the effects of retention and transferability on the outcomes of AI-mediated language learning, as well as the effects of task complexity on learning outcomes.

Pedagogical Implications

AI-mediated Task-Based Language Teaching (TBLT) has significant pedagogical implications for ESL education in autonomous engineering colleges, as it enables the design of digitally enhanced speaking contexts that provide immediate feedback, scaffolded practice, and authentic communication opportunities. The integration of AI in language learning not only improves the learners' accuracy and fluency but also redefines the role of the teacher as a facilitator who plans goal-based tasks, helps learners use AI tools effectively, and fosters autonomy and self-regulation in language learning (Li & Wang, 2021; Zhang et al., 2023). Curriculum-wise, AI-mediated modules can be integrated into engineering courses without replacing technical education, as they enable flexible and scalable learning that caters to different levels of proficiency.

CONCLUSION

In conclusion, this study offers strong empirical evidence for the integration of AI-mediated TBLT in ESL higher education settings, as it has been shown to positively impact speaking accuracy and fluency while encouraging learner engagement, autonomy, and confidence. This study contributes to SLA theory by exemplifying the complementary role of task-based learning and AI-mediated scaffolding in the development of speaking skills. Looking ahead, AI-powered language learning has the potential to revolutionize ESL education by providing scalable, personalized, and contextually relevant interventions that empower learners with critical communication skills for the global academic and professional context.

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Table 1 Descriptive Statistics for Speaking Accuracy

Group	Test	N	Mean (%)	SD
Experimental	Pre-test	50	65.2	6.1
	Post-test	50	81.3	5.9
Control	Pre-test	50	64.8	6.3
	Post-test	50	68.2	6.5

Table 2 Descriptive Statistics for Speaking Fluency

Group	Test	N	Mean (%)	SD
Experimental	Pre-test	50	61.0	7.4
	Post-test	50	78.9	6.1
Control	Pre-test	50	61.2	7.1
	Post-test	50	66.8	6.9

Table 3 Independent Samples t-Test for Post-Test Scores

Variable	Group	N	Mean (%)	SD	t	df	p
Accuracy	Experimental	50	81.3	5.9	10.62	98	<.001
	Control	50	68.2	6.5	—	—	—
Fluency	Experimental	50	78.9	6.1	10.11	98	<.001
	Control	50	66.8	6.9	—	—	—

Table 4 Mean Pre-Test and Post-Test Scores

Group	Accuracy Pre	Accuracy Post	Fluency Pre	Fluency Post
Experimental	65.2	81.3	61.0	78.9
Control	64.8	68.2	61.2	66.8





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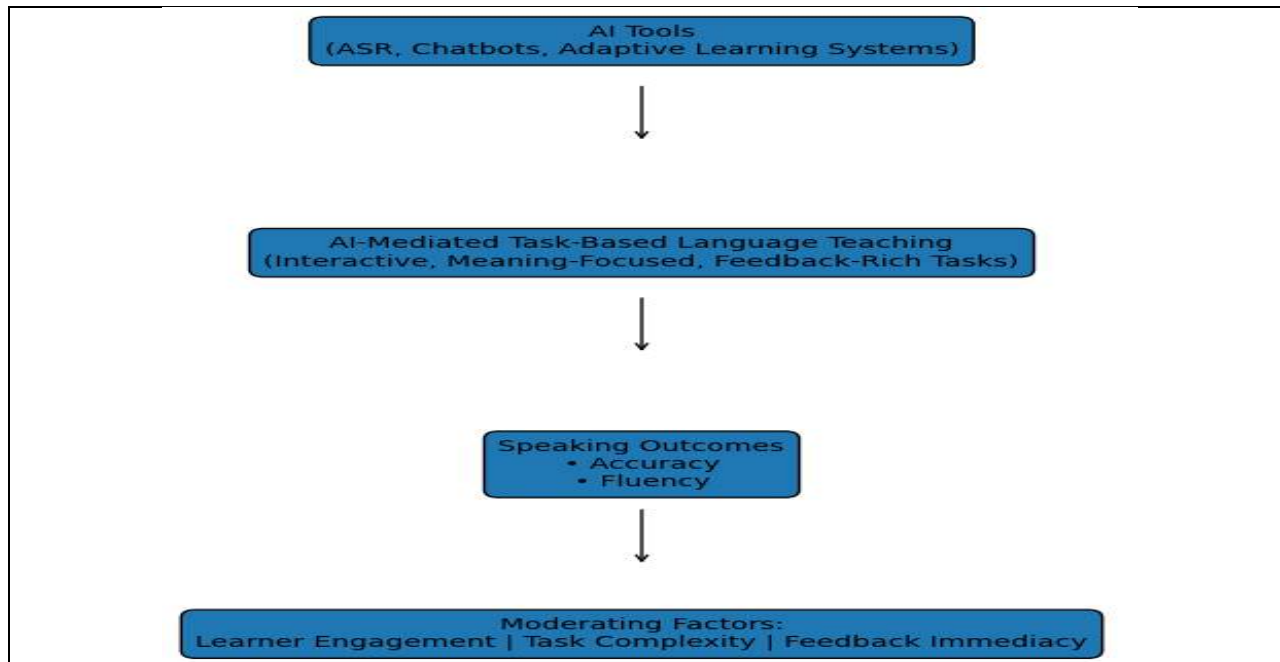


Chart 1. Conceptual framework

Figure 4.1. Speaking Accuracy: Pre-Test and Post-Test Scores

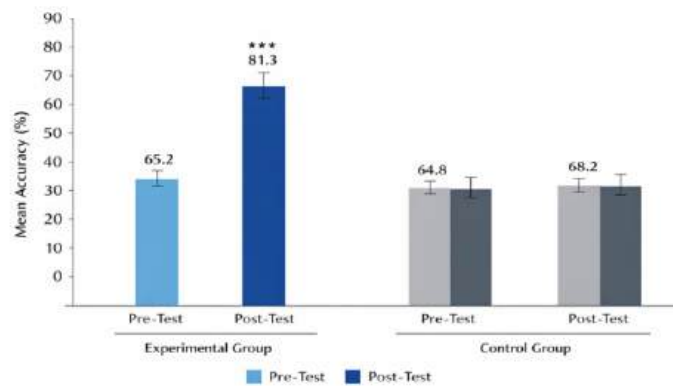


Fig.1. Descriptive Statistics for Speaking Accuracy

Figure 4.2. Speaking Fluency: Pre-Test and Post-Test Scores

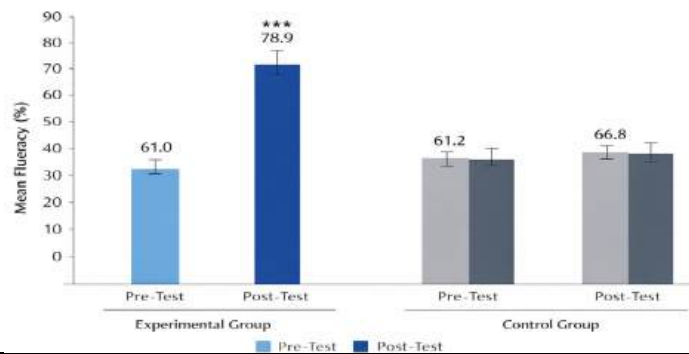
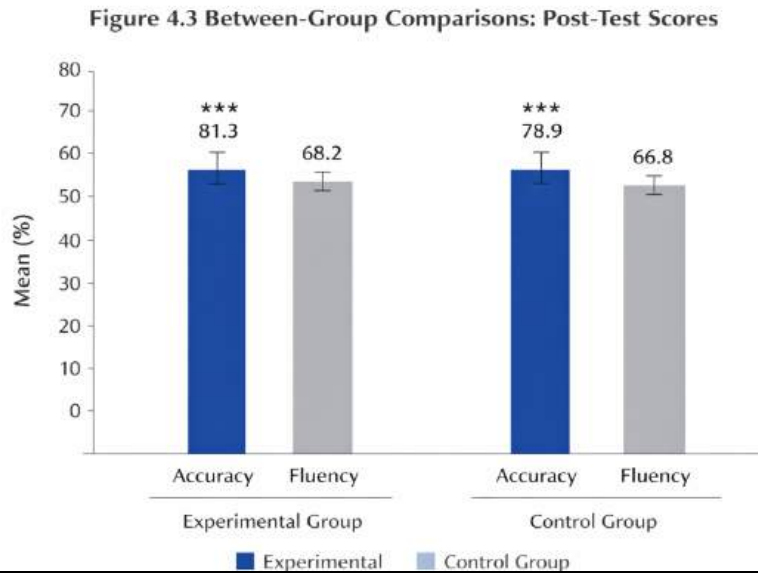
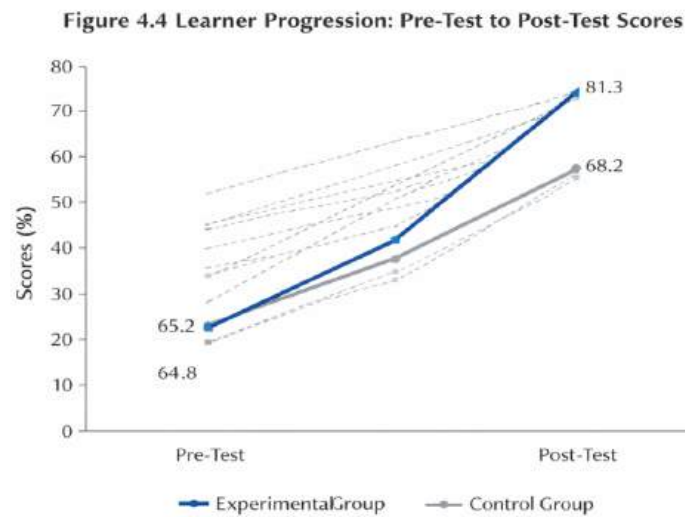


Fig. 2. Speaking Fluency





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**Fig. 3. Between-Group Comparisons****Fig. 4. Learner Progression**

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RESEARCH ARTICLE

Spiritual Psyche in Cultural Exile – Healing Embodied Trauma Through Literary Metaphor in Chitra Banerjee Divakaruni's *The Mistress of Spices*

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ABSTRACT

This paper analyzes the book *The Mistress of Spices* by Divakaruni in terms of the theory of trauma and psychoanalysis and explores how literary metaphors can help heal the diasporic spiritual psyche. Chitra Banerjee Divakaruni is a world-acclaimed author, born in Calcutta. She is a prolific writer of poetry, short tales, and novels. Tilo employs spices as treatment solutions to tackle the embodied trauma among the Indian immigrants in Oakland, which is expressed through domestic violence, racial hate and fragmentation of identity. Spices can be symbolically used as psychoanalytic instruments, which mediate the repressed past and the dangerous present. The editorial plot development of Tilo herself, as eternal Mistress into flesh and blood woman, is the reflection of the psychological experience of the unity of divided selves after cultural exile. Among the most important characters, there are such representatives of the somatic effects of the systemic oppression and patriarchal violence as Lalita and Haroun. In addition, the clash of cultural superego and individual desire is explained by the tension between duty and personal desire is heightened when each customer's visit reveals a new set of problems that Tilo tries to remedy with her magical spices, frequently with unanticipated results. The cataclysmic end of the novel, in which the store is shattered by an earthquake, is an indication of the need to give up magic isolation in favor of true human interaction. Finally, the analysis hypothesizes that Divakaruni creates the story of psychological restoration in which the healing process is not achieved with supernatural help, but with the help of the hybrid identities and communal strength in the wake of displacement. The spices hence are a medium of change of pain to power, which justifies the multi-layered immigrant journey in American society.

Keywords: Trauma Theory, Diasporic Psyche, Psychoanalysis, Embodied Trauma, Cultural Exile, Literary Metaphor, Healing.



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INTRODUCTION

The issue of cultural exile has become one of the most characteristic phenomena of the 21st century, radically transforming the psychological lives of displaced communities. According to Avtar Brah, the spaces of diasporas are built by a complex interplay of memory, history and the experience of displacement itself and may evoke a strong feeling of unbelonging (Brah 192). The effect of this displacement is often psychological fragmentation, in which individuals find it difficult to come to terms with the identities of the past and the realities of the present in a potentially hostile world. Caren Kaplan goes on to point out that issues of travel and displacement are not simple physical movements, but profoundly metaphysical transitions which affect both the orientation of the soul in the world (Kaplan 3). Such migration has a psychological effect similar in magnitude to that of extreme trauma, as it breaks the ongoing story of the self, leaving emotional scars on the psyche of the immigrant that are unlikely to fade away easily.

Trauma theory offers a critical approach to this type of disruption in literary studies. According to Cathy Caruth, one does not experience trauma fully at the time it occurs but returns to the survivor in the future as intrusive memories and flashbacks (Caruth 4). This hesitation to react is similar to the immigrant experience, in which the shock of breaking cultural contact takes effect many years after settling in the host country, in the form of anxiety and depression. Judith Lewis Hermann stresses that the process of recovery after the trauma presupposes the rebuilding of the meaning of the experience broken by the traumatic event in a safe community environment (Herman 175). In the case of migration, literature tends to be such a reconstructive tool, providing a figurative space for validation and processing. According to Dominick LaCapra, writing about history and trauma enables the working-through of past events and, thus, psychic healing and not acting-out (LaCapra 21).

Thus, literature serves as a therapeutic and critical tool for the diasporic subject searching for solutions. The psychoanalytic models of Sigmund Freud can indicate how the desires of the unconscious and repressed memory influence behaviour and this concept can be highly relevant to the case of the suppressed pain of the diasporic psyche (Freud 14). Gayatri Chakravorty Spivak goes further to the post-colonial subject who she says is striving to express her voice by way of narrative to recover her agency and identity (Spivak 28). In this context, Chitra Banerjee Divakaruni's *The Mistress of Spices* is a critical text for interpreting these healing dynamics. Divakaruni uses the metaphor of spices to encode healing procedures that can be accorded to displaced people in Oakland (Divakaruni 1). The novel examines the nature of the interaction between traditional knowledge and contemporary alienation to heal spiritual wounds. Vijay Mishra notes that the Indian diaspora literature tends to mediate the conflict between the homeland mythology and the hostland realities and produces a distinct form of hybrid consciousness (Mishra 115).

In this research paper, *The Mistress of Spices* is analyzed using the synthesized approach of trauma theory and psychoanalysis. It claims that the healing of embodied trauma due to cultural exile can be achieved through spice symbolism, as applied by Divakaruni. The hybridity concept introduced by Homi K. Bhabha implies that new identities co-created in the zones of intercultural borders can enable new identities to exist (Bhabha 2). This paper will initially examine the psychological disjunction of the protagonist, Tilo, as she struggles with her dual life. Secondly, it will discuss spices as psycho-somatic solutions to characters who have experienced domestic and racial violence. Lastly, it will discuss the reconstruction of the self through narrative integration and community support. This paper provides a collective role in preserving the lost psyche against globalization erasures by bridging the medical humanities and post-colonial studies.

Research Focus

The main objective of this study is to examine how the subject of psychological trauma is presented in *The Mistress of Spices* by Chitra Banerjee Divakaruni with the help of using spices as symbols, healing patterns and the meaning





these symbols portray to both diasporic identities and human societies. Combining the theory of trauma with psychoanalytic models, this research project addresses the point of convergence between the degradation of the spirit and the healing of emotions in the context of the immigrant experience in Oakland.

The main investigative questions were as follows:

1. How does Divakaruni use spice to symbolize diasporic trauma?
2. How does identity fragmentation and reformation depicted in the novel in terms of psychoanalytic theories?
3. In what ways does the story structure of *The Mistress of Spices* function as a tool for both the characters and readers?

The investigation underlines the immediate necessity to react to embodied trauma collectively, with a focus on holistic approaches to emotional action and the protection of the displaced psyche in post-colonial literature.

The Spiritual Psyche: Freudian and Post-Colonial Intersections

Freudian repression and post-colonial displacement combine to produce the psychological landscape of Chitra Banerjee Divakaruni's *The Mistress of Spices*. The psychoanalytic notion of the uncanny can be viewed in the case of Tilo as an immortal Mistress in an old mortal body, where the known and the unfamiliar intermingle in a disturbing manner due to the repressed (Freud 123). Her loss of self is the state of diaspora discussed by Avtar Brah, where memory and the past build a homing desire that can never be satisfied (Brah 192). At the beginning of the story, Tilo knows about this disintegration, declaring, "They do not know, of course, that I am not old, that this seeming-body I took on in Shampati's fire when I vowed to become a Mistress is not mine" (Divakaruni 4). This duality is used as a metaphor for the psyche of immigrants, who tend to hide inner trauma with a functional surface.

Trauma theory also explains Tilo's relationship with her customers. Cathy Caruth contends that one does not experience the trauma fully during the occurrence, but it comes back to haunt the survivor in the future (Caruth 4). The customers that Tilo works with—Lalita, Haroun, and Jagjit—are all traumatized victims of domestic violence, racial animosity, and acculturation stress. Tilo is a psychoanalytic listener who takes their pain in without touching it, "the delicate axis of giving and receiving on which our lives are held precarious" (Divakaruni 7). This restriction is in accordance with Judith Lewis Herman, who says that recovery after trauma involves rebuilding meaning in a secure environment, but the isolation of Tilo makes this difficult (Herman 175). The store is an area of liminality, parallel to the third space of Homi Bhabha, in which cultural hybridity is being contested and never settled (Bhabha 37).

The abject, which is described by Julia Kristeva as the boundaries between self and other being lost, also controls the spiritual psyche (Kristeva 2). The ban on looking in the mirror imposed by Tilo represents the renunciation of the mortal self in favor of the spiritual ability; however, this repression is a source of mental disorder. As she notes, "Once a Mistress has taken on her magic Mistress-body, she is never to look on her reflection again" (Divakaruni 156). This self-destruction is similar to that of Frantz Fanon of the colonized subject who internalizes the gaze of the other, resulting in a discontinuous identity (Fanon 82). The spices serve as objects of internal states, turmeric cures bruises, and chilies are the incarnations of anger. According to Vijay Mishra, diaspora literature tends to work out the conflict between the myth of the homeland and the reality of the hostland, forming a peculiar hybrid consciousness (Mishra 115). The struggle that Tilo endures leads to the breaking of love rules by her, whereby she realizes that "rules broken must be paid for. Balance upset must be restored" (Divakaruni 298).

Finally, the plot development shifts to repression–integration. Dominick LaCapra also assumes that writing trauma can be the working-through of the past events instead of merely assuming them (LaCapra 21). The fact that Tilo ultimately accepts her mortality after the earthquake is a sign of psychological acceptance of her disjointed selves. Avoiding the exoticism of the East, Edward Said's idea of Orientalism reminds us to treat the East as an authentic object of the psychological scale instead of a cliché (Said 12). The author criticizes the sacred/secular dichotomy and indicates that the solution to the problem of healing is to accept the imperfect world day in, day out (Divakaruni 312). In this respect, the novel employs psychoanalytic models to express the intricate trauma of cultural exile, whereby the spiritual psyche is not an avoidance of reality, but a survival mechanism (Ashcroft 104). This



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fusion of Tilo's identity is an indication of Keya Ganguly's argument that the identity of postcolonialism can be constituted by everyday exceptions and negotiations (Ganguly 45). In this way, *The Mistress of Spices* uses the spiritual psyche as the vehicle for filtering the collective trauma of displacement, which justifies holistic emotional healing in the disintegrated world (Spivak 28).

Spice as Metaphor: Embodied Healing and Symbolic Medicine

In *The Mistress of Spices*, Divakaruni builds a story in which food ingredients are used as psycho-somatic healing agents to bridge the gap between bodily experience and emotional traumatic encounters. The spices are not merely tastes but curative forces that respond to the somatic suffering of the diasporic subject. At the beginning of the story, Tilo claims, "Their heat runs in my blood. From amchur to zafran, they bow to my command" (Divakaruni 1). This bodily relationship implies that the process of healing is not thinking but rather corporeal, incorporating a reunion of the body and soul torn apart during migration. Memory is processed through the sensory images of smell and taste, which confirms Sutton's point that food is a channel through which one recalls repasts and homelands that have been forgotten (Sutton 89).

Turmeric is central to the representation of preservation and physical recovery in the text. Tilo describes it as "Turmeric the preserver, keeping foods safe in a land of heat and hunger. Turmeric the auspicious spice, placed on the heads of newborns for luck" (Divakaruni 12). For a victim of domestic abuse, such as Lalita, turmeric is seen as a protective barrier against the physical and emotional battering that a person endures. The same yellow powder reflects the strength needed to live in a competitive environment, and this can be linked to Herman's statement that recovery involves creating safety and rewriting the story about the trauma (Herman 175). The anti-inflammatory effect of the spice symbolically opposes the inflammation of racial and gendered violence. It provides a concrete way to deal with the pain when it is not possible to express it through words.

By contrast, chili symbolizes the perilous possibility of raw anger and passion. Tilo warns, "The dry chili, lanka, is the most potent of spices. In its blister-red skin, the most beautiful. Its other name is danger" (Divakaruni 156). The spiciness of the chili reflects the unstable temper of an immigrant such as Jagjit, whose anger was too suppressed to be revealed in other ways. There is a fine art in using the chili; otherwise, it will be burnt up, or it will do nothing. This ambivalence is an expression of the abject in Kristeva, in which the borders between the self and other are put at risk by extreme bodily experiences (Kristeva 2). The chili requires respect for the strength of emotion, which implies that the trauma should not be covered up to avoid outburst consequences.

Fennel is an intestinal stimulus for emotional upheaval; it is meant to be taken at the time of change. Tilo notes, "Fennel, which is the spice for Wednesdays, the day of averages... smelling of changes to come" (Divakaruni 298). In the case of Lalita, who suffers in an abusive marriage, fennel provides the psychological power to process her reality and be ready to change. Chewing fennel seeds turns into a ritual of returning to the present moment in the sea of chaos that the character is in. This is in line with Appadurai's argument that cooking and eating are activities that enable people to argue out their social identities and deal with displacement (Appadurai 20). The cooling effect of spices overrides the painful effect of trauma, allowing cognitive processing to occur.

Finally, the ban on touch shows the conflict between physical healing and spiritual obligation. Tilo explains, "It is not allowed for Mistresses to touch those who come to us. To upset the delicate axis of giving and receiving on which our lives are held precarious" (Divakaruni 7). This limitation highlights the somaticity of the trauma; touch is too strong, and there is a threat of overload of joint pain. Instead, the spices serve as middlemen, and they permit healing without being in direct contact. In this gastronomic magic, Divakaruni portrays that to the diasporic subject, the healing process is sensual, that the process of healing oneself starts with healing the sense of taste and smell (Counihan 15). The spices justify the immigrant experience, making simple cooking a survival and resistance gesture to cultural obliteration (Mintz 198).



**Jarina Begam and Md. Sahidul Islam****Cultural Exile and the Reconstruction of Selfbetween Worlds: Identity Fragmentation and Narrative Integration**

The plot development of *The Mistress of Spices* reflects the process of self-reconstruction after the disintegration of cultural exile. According to Avtar Brah, spaces of diaspora can be characterized by memory and displacement, and in most cases, they lead to fractured identities that need to be repaired through storytelling (Brah 192). This reconstruction can be traced in the secondary characters that are in the store Tilo lives in, and each of them represents a variant of immigrant trauma. Lalita, who is a victim of domestic violence, represents the silencing of the subaltern woman. Her inability to refer to her sufferings at first depicts the concept of the subaltern, who is not heard in the dominant constructs (Spivak 28). Tilo notices Lalita's bruised, concealed face and remarks, "They do not know, of course, that I am not old, that this seeming-body I took on... is not mine" (Divakaruni 4). This twofoldity reflects Lalita's hidden identity behind the veil of the submissive wife. The ultimate choice that she makes to move out of her husband's, which is conveyed in the form of a letter, symbolizes a reassertion of agency and breaking of silence (Divakaruni 310).

Haroun symbolizes the racial violence, trauma, and instability of the immigrant dream. His physical assault by the Dotbusters is an example of how xenophobia manifests physically, as conceived by Frantz Fanon about the colonized body under observation (Fanon 82). His hope becomes violence, Tilo discovers, and this is the case: "rules broken must be paid for. Balance upset must be restored" (Divakaruni 298). This healing, followed by the recovery of Haroun with the help of Hameeda, implies that community healing is important and that magical intervention may not be necessary; as such, the model of Judith Lewis Herman that suggests recovery needs connectedness within a safe environment is correct (Herman 175). Likewise, the conflict between generations in diasporic families is shown through Jagjit's efforts to overcome bullying and affiliation with a gang. Vijay Mishra states that the tension between homeland myths and an actual situation of a hostland is frequently negotiated in the diaspora literature (Mishra 115). The fact that Jagjit turns into a victim, but this is changed to a martial arts candidate due to the financial gift of Tilo, signifies a change from passive victimhood to proactive self-protection.

The store itself serves as a liminal therapeutic zone, a third space in which cultural hybridity is discussed, as determined by Homi K. Bhabha (Bhabha 37). However, it is also a place of imprisonment. Tilo admits that the store is two-sided: "This is what the customers see as they enter... a bent woman with skin the color of old sand" (Divakaruni 5). The store guardian offers protection and, at the same time, isolates and renders Americans unable to fully integrate into their society. Cathy Caruth is of the opinion that one cannot experience trauma completely until it is narrated and becomes a part of history (Caruth 4). The last change in Tilo from an immortal Mistress to a mortal woman represents such an integration. To embrace death and love, she transitions out of the magical realism of the island into the reality of American history. In his theory, Dominick LaCapra argues that it is possible to write trauma and thus work through the past events (LaCapra 21). This new identity, which accepts the imperfect world day after day, is symbolized in Tilo renaming her Maya (Divakaruni 312).

Finally, the novel indicates that self-reconstruction must be achieved by giving up magic seclusion and engaging in real human association. Edward Said cautions against exoticizing the East, but Divakaruni recovers the culture of spice as a true psychological instrument (Said 12). The collapse of the store through the earthquake means that there is a need to destroy the liminal space in order to enable belonging. Keya Ganguly claims that everyday exceptions and negotiations are used to create post-colonial identity (Ganguly 45). The fact that Tilo has decided to remain in Oakland and assist the victims of the quake instead of escaping to a heavenly earthly paradise with Raven proves her attachment to the real world. According to the recommendation of Chandra Talpade Mohanty, feminism across borders must be jointly engaged in the struggle (Mohanty 1). Tilo does not arrive at an island of fantasy but in the ruins of Oakland, where she discovers a new name and a new life, based on the fact of collective suffering and survival (Bill Ashcroft et al. 104). It is the process of being involved in the dynamics of the diasporic condition that results in the reconstruction of self, but not through escaping (Caren Kaplan 3).





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CONCLUSION

This study explains how *The Mistress of Spices* by Divakaruni employs the symbolism of spices to achieve the healing of embodied trauma stemming from cultural exile. As proven in the analysis, spices are psycho-somatic solutions to domestic violence, racial hostility, and identity fragmentation. The fact that Tilo is a woman after being immortalized as a Mistress and preceded it by being a fragmented personality demonstrates the required reunion of parts separated and the change between magic and genuine human relationships. Secondary characters such as Lalita and Haroun are instances of how narrative validation helps repair the broken identity of the diasporic experience of the world.

These results have important implications for medical humanities and post-colonial studies of trauma. The study emphasizes the role of narrative medicine in dealing with the somatic effects of displacement through the framing of literary metaphor as a form of therapy. It also implies that the process of healing in the diaspora must involve recognition of hybrid identities and not obsessive attachment to a strong cultural superego. The spice store is a liminal therapeutic zone where cultural negotiation takes place, and it provides a useful example of how to study resilience at the community level. However, this study has limitations. The research is based on interpretive models instead of empirical clinical evidence. Further studies might examine comparative studies with other diasporic literature or examine how bibliotherapy may be applied in the real world of counseling immigrants. Knowledge would be enhanced by examining the gendered symbolism of spices in other cultural settings.

This research confirms the importance of literature in the healing of psychology. The intricate immigrant experience depicted by Divakaruni can be confirmed by the story, which transforms suffering into strength by developing symbolic resonance. The novel creates a connection between the spiritual and secular, indicating that it is not necessarily the supernatural that can help people recover, but rather the adoption of hybrid identities and community strength. Therefore, literature is a deep-rooted witness to the ability of narratives to reconnect the fractured psyche.

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RESEARCH ARTICLE

The Psychology of Honor: Social Stigma, Shame, and Intergenerational Trauma in Imayam's *A Woman Burnt* and Perumal Murugan's *One Part Woman*

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ABSTRACT

This research paper offers an in-depth comparative psychoanalytic study of *A Woman Burnt* (2023) by Imayam and *One Part Woman* (2013) by Perumal Murugan, focusing on the interplay between trauma theory and social stigma in contemporary Tamil fiction. The novels' female protagonists are Revathy and Ponna, respectively. Both the physical representation of the female body (in Revathy's immolation) and its symbolic representation (in Ponna's infertility, which stands for society's primary site of violence and psychological upheaval) are examined in this study. The paper examines how caste honour functions as a destabilising agent by analysing changes in the protagonists' psychological states, showing how the individual's mental health is broken, to uphold the social stability of a group. The key to this exploration lies in the vexed nature of silence and bearing witness; Revathy's deception of the police to save her rapist is juxtaposed with Ponna's silent submission to ritualistic conception, both manifestations of profoundly traumatic complicity. Because physical symptoms are an expression of social oppression, the research emphasises that both writers emphasise the need of taking collective action to combat gender-based violence and the vulnerability of patriarchal institutions via the lens of the female body. Additionally, this paper explores how repression, shame, and intergenerational trauma can determine psychological well-being and choices in inflexible caste hierarchies. It introduces the Psychological Equation of honour to explain the interdependent relationship between the personal psyche and cultural resources. Finally, the paper suggests that these novels require a comprehensive view of social action, which reunites psychoanalytic theories with local cultural outlooks to protect the psychological and physical future of women against the oppressive, sometimes deadly, pressure of honour-based demands and societal



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continuity, asserting that it is the duty of society to prevent these long-standing psychological crises and build social strength.

Keywords: Psychoanalysis, Trauma, Social Stigma, Female Body, Caste Honor, Intergenerational Trauma

INTRODUCTION

Honor-based violence has become one of the pressing issues of the 21st century in modern Tamil society, the consequences of which extend across social stability, personal psychology, and the culture of the economy of human relationships. The growing effects of caste implementation, such as escalating communal tensions, acts of extreme immolation, mental breakdown, and loss of biodiversity of human dignity, are symptomatic of an ever-shifting social balance (Pandey 89). The main idea of this dilemma is the psychological equation of honor, a term applied in this design that explains the multifaceted Ness of the interrelation between the psyche of the individual, societal activities, and cultural resources, that is, lineage and caste status (Chakravarti). This research paper aims to explore the dynamics of trauma based on the psychological equation of honor, in which the human factor of caste expectations, family honor, and patriarchal industrialization has interrupted the fine balance of an individual's mental health. Trauma is among the topical problems of our world, and literature has turned out to be a significant means of inquiry and awareness concerning its far-reaching outcomes (Caruth 78).

A Woman Burnt by Imayam and *One Part Woman* by Perumal Murugan are two literary works closely intertwined in depicting the aspects of psychological trauma and social stigma experienced by Indian women. In *A Woman Burnt*, a poor woman suffers extreme hardship and oppression within a rigid caste-based society. Her life reflects the brutal realities of poverty, gender discrimination, and social injustice. In *One Part Woman*, a childless couple faces social stigma and emotional strain in a traditional village setting. Their marriage is tested when a controversial cultural ritual challenges love, faith, and identity. In *A Woman Burnt*, Imayam depicts "Revathi, a rural woman whose self-immolation becomes a central symbol to explore the psychological impact of social oppression regarding inter-caste love" (AWB 15). Likewise, *One Part Woman* traces the life of Ponna, whose infertility serves as a violation of the classic pattern of migration in the family line, making her sterile womb the place of violence in society (Murugan, 2). The barren womb, the female, and the burnt body are the main symbols to address the psychological effects of societal oppression. The body used in the novels is a point of entry to realise how the social world is interrelated and how any change in environmental conditions disturbs the fragile equilibrium of individual lives.

Since we live in a world of uncertainty about the future, building a holistic conceptualization of the psychological equation of honor is essential to make the world socially resilient, sustainable, and gender-just (Herman 123). This study aims to contribute to ongoing debates on the pressing need to respond to the crisis of honor-based violence through a collective global response. The interconnections between caste stigma, female body autonomy, and human experience are profound, as the literature around these texts points out. Altered psychological conditions, as specified by Imayam, "are an effective metaphor for general social disturbances brought about by honor codes" (Rege 56). The novel makes one think about how human beings receive and react to changes in social life and calls for more efforts to preserve the safety of women. The research and studies cited in the review mention the intricacy of psychological trauma in the context of a shifting social environment, and further social studies and interventions must be undertaken to safeguard vulnerable lives. In addition, the paper explores the use of silence and testimony in dealing with psychological crises, the collocation of caste inequality and psychological degradation, and the need to combine psychoanalytic and local cultural viewpoints. Finally, this paper argues that the novel not only raises awareness of the effects of social stigma on individual psyches but also demands a comprehensive method of social action in which all of society will have a shared duty to protect the mental and physical future of women. By placing the analysis of the correlation between the inner psychological disturbance of the characters and the external social





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pressures of the novel, the paper discusses the themes of displacement, adjustment, and the relationship between the trauma of the individual and the shame of the collective.

Research Focus

The main purpose of this study is to examine the ways in which *A Woman Burnt* and *One Part Woman* recreate the stories of trauma by using the female body and social relationships symbolically. This study examines the psychoanalytic aspects of shame and repression in caste hierarchies by considering the example of Revathi, whose act of immolation, and Ponna, whose infertility. The following are the main research questions that will be used to address this question:

1. What role do Imayam and Murugan play in the representation of the larger psychological impact of social stigma on the female body (the dismembered body and the unborn womb)?
2. In what ways do the two novels illustrate the disruption of natural social cycles and psychological stability?
3. To what extent do these novels reflect the presence of greater social crises represented by the changing psychological conditions of women?

Finally, the answers to these questions allow us to see how personal trauma and wider social honor are interconnected and what strong social resilience and gender justice urgently require.

Psychoanalytic and Trauma Themes in *A Woman Burnt* and *One Part Woman*

In *A Woman Burnt* by Imayam and *One Part Woman* by Perumal Murugan, the female body emerges as the central focus of violence in society, arbitrated by domestic caste honor and patriarchal decline. Both novels employ psychoanalytic patterns to understand how trauma has distorted the individual psyche, making women willing to sacrifice themselves to support societal order. The intersection of the narrative is the physical expression of this trauma: Revathi is burned in *A Woman Burnt*, and Ponna is conceived ritually in *One Part Woman*, both of which are a result of the rape of family ecosystems by caste honor. According to Cathy Caruth, "trauma is not a wound but a distraction of memory and time reverberating through the survivors" (Caruth 4). The somatic reaction to the psychological stress of inter-caste love in Imayam is the literal consumption of the body by fire, which is later confirmed when her mother is informed that "They say she has immolated herself" (AWB 34). Similarly, in Murugan's Ponna, the protagonist confronts the social death of barrenness and is thus subjected to a ritual that undermines her bodily sovereignty, with her womb being said to be a place where "not even a worm had crawled" (OPW 12).

The characterization shows that the lives of disruption represent psychological fractures. The silence of Revathi and her subsequent self-immolation symbolize a mental imbalance brought about by the "warmer temperatures of shame" inflicted on her by her family and society. "Her failure to express her love for Ravi is similar to the repression concept of Freudian theory, where the repressed emerges as destruction" (Freud 12). This silence is felt when Revathi is standing in front of her father, where "Revathi did not open her mouth... She stood looking at the floor" (AWB 5). According to Judith Herman, the process of healing from a traumatic experience involves power restoration and contact. "Both main characters lose their agency" (Herman 15). According to Judith Herman, "the process of healing from a traumatic experience involves power restoration and contact, and both of the main characters lose their agency" (Herman 15). The trip of Ponna to the temple of Ardhanareeswara is not a path of empowerment but a path of desperation, which is used to point out the fact that women are vulnerable because of social structures, which are vulnerable to the influence of men. The infertility stigma is a psychological cage just as the caste stigma that enslaves Revathi, as manifested when villagers assert, "That barren woman ran up and down carrying seeds. How do you expect them to grow once she has touched them?" (OPW 100).

The thematic lens depicts social structures as soft and prone to human influence, namely, honor killings and infertility stigma. The crisis of social action is exemplified by the misery of the characters, which the entire community must address. Academics believe that trauma is a disabling memory (Caruth 4); "testifying is the only





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way out of trauma" (Herman 12); caste imposes silence (Tharu and Lalitha 89); gender complicates the issue (Geetha 102); and the subaltern cannot speak (Spivak 24). There is a heavy overlap of theoretical nets that emphasize the intricacy of the presented trauma. The police testimony scene in *A Woman Burnt* demonstrates the ineffectiveness of institutional structures in protecting women, since a false statement by Revathi safeguards her abuser, a form of complicit action under the influence of trauma. She states clearly, "Neither did I set myself on fire, nor did my husband set me on fire. The fire was accidental" (AWB 113). The gaze of *One Part Woman* is a way in which the community polices the womb of Ponna and instances biological determinism that defines womanhood as motherhood. This mountain of pressure climaxes when her mother-in-law proposes this ritual, saying, "All men who set their foot in Tiruchengode on the fourteenth day are gods" (OPW 84). According to Swarnalatha Rangarajan, these caste realities are mediated most of the time by translation and representation, which makes the local universal (Rangarajan 45). The novels can therefore be regarded as a call to social action and how honor codes ruin the psyche of individuals. According to Lakshmi Holmström, writing by Tamil women tends to take these domestic silences head-on (Holmstrom 78). Finally, both writings hold that the mental and physical future of women is to be preserved by destroying the psychological equation of honor, which is more concerned with lineage than life. The vulnerability of the social world is reflected in the vulnerability of the female body, which requires a holistic approach toward the trauma that incorporates psychoanalytic knowledge with cultural criticism.

The Female Body as a Symbol of Psychological Disruption

"Caruth is correct when he claims that trauma distorts memory" (Caruth 4); "only testimony helps" (Herman 12); "caste instils silence" (Spivak 24); gender makes it more difficult (Butler 93); and shame disturbs systems (Ahmed 102). The female body is the site where this psychological fracturing is physically expressed in *Imayam*, *A Woman Burnt* and Perumal Murugan's *One Part Woman*. Ponna is not just an infertile woman, and Revathi is not just a burning corpse; they are metaphors of the psychological systems that have been shaken by social stigma. The body in the novels is used as a point of entry into the interrelationship of the social world and how changes in environmental conditions destabilize the fine-tuned lives of individuals.

Revathi's body, described as being "burnt fully" until she looked like "cooked meat" (AWB 139, 258), represents the psychological disturbance caused by shame. Her silence in front of the fire "is akin to the repression in Freudian theory, where the repressed reappears in the form of destruction" (Freud 12). "The incinerated body is an object of disgust that is discarded by societal structures, reminiscent of Kristeva's assertion that the object poses a threat to the line between the self and society" (Kristeva 4). When Revathi states, "Neither did I set myself on fire... The fire was accidental" (AWB 113), inscribed on the skin, representing the pain of caste honor, which makes the inner psychological disorder visible and indisputable. The burns are a somatic text, inscribed on the skin, the pain of caste honor, which makes the inner psychological disorder visible and indisputable. The burns are a somatic text, inscribed on the skin, the pain of caste honor, which makes the inner psychological disorder visible and indisputable.

Similarly, Ponna's sterility symbolizes a weak nature and social structures. She regrets that even a worm has not moved in her womb (Murugan2), indicating that fatherless women are as dead in society as worms. The infertility stigma is equivalent to a psychological cage, as the caste one is to Revathi. Ponna's changed direction of migration, adopted between the place where her father lived and the place where her husband now lives, is interrupted by infertility, which is used as a metaphor to signify lineage vulnerability. Her trip to the Ardhanareswara temple is not empowering but a desperate act, revealing the ineffectiveness of social structures in making women susceptible to the effects of humans. Communal gaze policing of Ponna's womb defines a biological determinism in which womanhood is synonymous with motherhood. This pressure reaches a climax when her mother-in-law recommends the ritual, pointing out, "All men who set their foot in Tiruchengode on the fourteenth day are gods" (OPW 84). In this case, the body does not belong to the woman but is a vessel of social continuity, which is vulnerable to the disruptions of honour and lineage demands.

These personal unifications indicate large-scale systemic disturbances in the daintily balanced arrangements of families and caste systems. Women have traditionally been shown moving out of their father's home to the warmer



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areas of their husband's home; however, in these novels, this journey is interfered with. Revathi remains at home/immolated, and Ponna tries to conceive ritually without a husband. This unexplained change in behaviour is a metaphor for the greater environmental changes that are occurring in the world, such as the increase in temperatures of social honour that interferes with the usual cycles of nature. At first, the entrance of women is seen as a miracle or a beauty show. However, as the novel unfolds, it becomes evident that their existence is not a natural process but a consequence of a social crisis. The change in the migration of women is a wake-up call for the protagonist and the community in which they live, realizing that greater, less apparent disturbances are taking place in the natural landscape. The change in the behaviour of women is similar to the inner changes experienced by the characters as they begin to understand how harsh social stigma and the problems of psychological breakdowns can be.

Finally, the female figure in these writings can be viewed as a predictor of change. The false testimony of Revathi and the ritualistic conception of Ponna are efforts by both to make the community acknowledge social changes. The novels suggest that the future mental and physical security of women will be secured through the destruction of the psychological equation of honour. The vulnerability of the social world is reflected in the vulnerability of the female body, which requires a holistic approach to trauma, combining psychoanalytic knowledge with cultural analysis. Through the story and how the characters react to the appearance of the women in the story, this paper will examine how the authors exploit the symbolism of the body to bring out the beauty and tragedy of psychological imbalance and challenge readers to see the bigger picture of societal degradation.

The Body as a Reflection of Human Lives

The burned body of Revathi and the infertile womb of Ponna are metaphorical portrayals of the human being caught up in the subjugating social machinery, and the metaphorical representations of psychological systems that are disrupted through stigma. The individual's awakening that trauma causes compel the characters to consider the urgency to deal with social stigma and demonstrates the interconnectedness of personal life and global social crisis. Revathi's self-destruction breaks the silence in her family, and Natesan is forced to understand how he is a collaborator in promoting caste over life. According to Judith Butler, the body realizes social norms, as vulnerability reveals the frailty of such constructions (Butler 93). Ponna's struggle underscores the importance of lineage requirements on female life, in which Kali has to challenge conventional masculinity and the so-called psychological equation of honour. The human body becomes a vessel for cognizing how changes in social conditions can upset the balance in individual lives.

Nevertheless, it is usually followed by human ignorance and denial before recognition. The social exclusion of women in the community is an indicator of the general rejection of social trauma. The example of false testimony by Revathi in *A Woman Burnt*, that the fire was accidental, is a form of complicity caused by trauma, to protect the abuser and preserve social order. According to Cathy Caruth, trauma interferes with memory and, in most cases, causes delayed cognition about the incident (Caruth 4). In *One Part Woman*, Ponna is accused by her neighbours of the failure of crops. They claim, "That barren woman ran up and down carrying seeds. How do you expect them to grow" (OPW 84). This mistrust reflects the rejection of oppression by caste, where infertility is not regarded as a disease but is considered a vice. V. Geetha highlights that caste imposes silence and makes gendered experiences of violence difficult to grasp, and yet the victims are isolated (Geetha 102). The change in skepticism to realization is essential in social resilience. According to Lakshmi Holmström, Tamil women writing challenges such domestic silences head-on, compelling a change from ignorance to accountability (Holmström 78). The novels show that environmental and social disturbances are not isolated cases but are a larger problem that touches the lives of people and non-people. The novels show that environmental and social disturbances are not isolated cases but are a bigger problem that touches on the lives of people and non-people. There is no other way out but to protect the future of women physically and mentally, shattering the psychological equation of honour, where lineage is put over life, then to approach the issue of trauma in a holistic manner in which the psychoanalytic knowledge is combined with the cultural criticality.



**Newton and Mangaiyarkarasi****The Role of Psychoanalysis and Knowledge in Understanding Trauma**

In *A Woman Burnt* and *One Part Woman*, Imayam and Murugan, respectively, heavily emphasize the role of institutional knowledge in the interpretation and understanding of psychological phenomena. The police magistrate in *A Woman Burnt* and the community elders in *One Part Woman* attempt to explain the impact of social trauma on the psyche. The perception and reaction to trauma depend immensely on the creation and propagation of psychological knowledge, and in such stories, these imperatives are altered by caste and masculine influence. In *A Woman Burnt*, "the police station is turned into a place in which the data of trauma are synthesized, even though the fear of social ostracization spoils the resultant testimony. Revathi's false statement to the magistrate, claiming the fire was accidental, illustrates how institutional structures fail to protect women when social honour outweighs justice" (AWB 89).

The way of interpreting and treating trauma relies heavily on the development and dissemination of psychological knowledge; yet, it is corrupted in the aforementioned plots by patriarchal and caste requirements. "To scholars, trauma disturbs memory" (Caruth, 4); "this can be cured by testimony" (Herman, 12); "caste makes it impossible to speak" (Spivak, 24); "gender complicates it" (Das, 89); "and honour is the determinant of response" (Chakravarti, 102). The fact that the theoretical frameworks appear to overlap each other so much helps to emphasize the complexity of the presented trauma. The police testimony scene in *A Woman Burnt* illustrates the ineffectiveness of the institutional structure in its favour because the lie told by Revathi retains the abuser, which is complicity by trauma. She explicitly states, "Neither did I set myself on fire, nor did my husband set me on fire. The fire was accidental" (AWB 113). In *One Part Woman*, the gaze of the community that polices the womb of the female creates an imposition of biological determinism that links womanhood and motherhood. This is so much that her mother-in-law suggests the ritual. The introduction of psychological institutions has been essential in absorbing information on trauma and dispensing it in sensible forms to inform international social discussions and decisions on policies. However, the circumstances in the country of these novels are the village council or the police station itself, and in this case, the power system is likely to suppress the truth.

The role of institutional knowledge in understanding and interpreting psychological phenomena is emphatic in Imayam's *A Woman Burnt* and Perumal Murugan's *One Part Woman*. The symbol of the police magistrate in *A Woman Burnt* and the representatives of the community in *One Part Woman* attempt to comprehend the influence of social trauma on psyches. The perception and reaction to trauma depend greatly on the formation and spread of psychological knowledge; however, in these stories, this knowledge is usually adulterated by caste and patriarchal norms. In *A Woman Burnt*, the police station serves as the place where data about trauma is synthesized; however, the testimony received is affected by the fear of social ostracization. Revathi's lie to the magistrate that the fire was accidental is an example of how a woman cannot be defended by the institution when social honour is more important than justice. Likewise, in *One Part Woman*, the community's awareness that Ponna is infertile is not addressed through medical or psychological assistance but through ritualistic intervention without tolerance towards biological determinism, where womanhood is equated to motherhood.

The legal community offers evidence-based projections concerning the effects of social trauma on families, caste systems, and individual psyches through police reports and testimonies of magistrates. Moreover, psychoanalytic information aids in determining and examining the causes of trauma, especially caste honour, family pressure, and patriarchal practices. To develop policies that would ensure that the body of women is safeguarded, it would be prudent to understand human actions that cause trauma. Even social investigation of law protection, psychological assistance, and caste elimination can be used to fight against trauma. Nevertheless, psychoanalysis does not just involve theoretical knowledge; it is crucial in addressing the social and political aspects of trauma. The knowledge of psychological science to the masses is a key to the collective action, and false information and trauma denial pose significant threats to the work of activists and law supporters. The communication of science, whether via old media or new platforms, can assist in bridging the gap between scientific knowledge and the knowledge of people. The communication concerning trauma should be transparent, open, and correct to enable individuals, communities, and leaders to make appropriate decisions regarding how to respond to social crises. According to Sara Ahmed,





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"emotions are social and influence the way bodies are influenced by suffering and shame" (Ahmed 102). Sharmila Rege argues that the voices of Dalit women have been continuously drowned out by upper-caste discourse; therefore, radically new thinking of knowledge production is more self-evident (Rege 56). In conclusion, both texts state that to protect the mental and physical future of women, one must break the psychological equation of honor, which puts lineage above life, and demand an integrative strategy toward trauma that incorporates knowledge about psychoanalysis as well as cultural critique.

Trauma, Rural Tamil Nadu, and Social Equity

The novels *A Woman Burnt* by Imayam and *One Part Woman* by Perumal Murugan find trauma in the concrete regional terms of Virudhachalam and Tiruchengode, where the communities of rural labourers and the working classes are disproportionately burdened with caste honour. Social sustainability in these contexts is usually confused with the maintenance of lineage, in which women are compelled to take on the role of guardians of family honour. Uma Chakravarti suggests that caste regimes are always based on the regulation of women's sexuality to maintain boundaries, and the female body becomes a regulatory zone (Chakravarti 102). The immolation of a woman in *A Woman Burnt* is not only personal, but also systemic where caste justice is lost to honour as seen when her family is called upon and told that "They say she has immolated herself" (AWB 34). This helplessness is even enhanced by the countryside setting, where Revathi has a father who is a headmaster and is more afraid of being socially shunned than of being beaten up, defining himself first and foremost to the police by his occupation: "I am the HM of the Mangalampettai Higher Secondary School" (AWB 103). Likewise, Ponna in *One Part Woman* is empty, and this emptiness makes her a subject to societal criticism, as her infertile womb is perceived as a threat to the ecological stability of the village lineage, as witnessed when villagers allege, "That barren woman ran up and down carrying seeds. How do you expect them to grow" (Murugan ch. 16). The family of Kali is dependent on the land to survive; thus, the absence of an heir is an economic crisis rather than a social one.

This social degradation can be explained through the theoretical framework of environmental justice. Similar to the case of vulnerable populations that are disproportionately exposed to environmental hazards, rural women with honour codes are exposed to even greater psychological violence. Veena Das observes that violence usually becomes normal and is ingrained in the everyday life of family and community (Das 89). This is seen when the neighbours of Ponna propose ritual conception, in which the continuance of the lineage takes precedence over her bodily right, whereby her mother-in-law reminds her that on the fourteenth day of the month of Tiruchengode, all men who have set foot therein are gods. Maintaining social resources by future generations is already a coercive demand in which intergenerational equity is distorted in opposition to the living woman. According to Sharmila Rege, the voice of Dalit women is largely suppressed by the upper-caste discourse, which requires a radical change in the production of knowledge (Rege 56). A good example of this silencing is Revathi's false testimony to defend her abuser, in which a sense of complicity created by trauma upholds the status quo when she says, "Neither did I set myself on fire, nor did my husband set me on fire. The fire was accidental" (AWB 113). This injustice is further enhanced by the police machine in Virudhachalam, where the government case is only used to provide easy release of corpses rather than justice. In the end, the two novels also criticize unfair allocation of social burdens as they state that real justice is the destruction of the psychological equations that make honour more important than human life. According to Cathy Caruth, trauma interferes with memory so that it may take a long time to understand the event (Caruth 4). This turmoil is evident in the rural soul, whereby social action urgency is postponed by traditional sluggishness, such that women such as Revathi and Ponna have to shoulder the disastrous price of social sustainability. These rural landscapes indicate that the caste-gender nexus indicates that social justice is impossible without focusing on the psychological violence in the maintenance of honour.

The Women's Migration and the Future of Society

In new Tamil fiction, when women leave their own homes to live with their husbands, this is an indication of social stability and the natural order, similar to the cycles of ecology. Nevertheless, *A Woman Burnt* and *One Part Woman* portray this migration as disrupted by social stigma, which is an expression of vulnerability in society. Revathi is cut short in her journey as her family receives devastating news: "They say she has immolated herself" (AWB 113). This





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sudden stop is an allusion to breaking the natural cycles because of the increasing temperatures of caste honour, where social pressure is akin to climatic pressure on the human psyche. Assimilatively, Ponna is forced to stop migrating because of infertility, and she cries, "Not even a worm had crawled in her womb" (OPW 12). Her sterility becomes a symbol of the weakness of lineage, which compels her to find herself in strange areas of cult-like conception beyond the scope of matrimonial relations.

Revathi (in the ICU) and Ponna (in the temple) mark the arrival of strange spaces of disruption as the disruption signal in both novels because of social honour. The ritual is demanded by the mother-in-law of Ponna, who remarks, "All men who set their foot in Tiruchengode on the fourteenth day are gods" (OPW 84). This force imposes biological determinism, in which womanhood is synonymous with motherhood and the female body is a means of social reproduction. The hospital has Revathi as a guest, and this situation is another indication that women are susceptible to human interference. It is an act of complicity caused by trauma that reinforces the status quo because institutional structures do not safeguard women when social honour becomes more significant than justice.

Finally, these stories appear as a microcosm of a greater social issue and the necessity to take action. Meanwhile, the changed migration of women is a wake-up call to the community to address less obvious disruptions, such as disgrace and sterility. The instability of the social world is reflected in the instability of the female body, which requires comprehensive treatment of trauma. According to both texts, the solution to the future is to break the psychological equation of honour. The interplay of caste and gender indicates that social equity cannot be established without addressing the psychological violence that is inherent in the maintenance of honour. The novels provoke the reader to think about the future implications of doing nothing and the necessity of shared responsibility in ensuring the sustainable future of all living species, namely, women. Through these disruptions, the study encourages the reader to consider the harmful effects of inaction in the long term and the importance of national action in ensuring the survival of all living beings in a sustainable environment. The destiny of all species on the planet is closely connected to the destiny of the female body. This is a call to action that prompts the seriousness of treating trauma in an integrated, internationally coordinated approach. Women are unable to migrate independently, just as human beings need to unite to overcome the social challenges that plague us.

The Disruption of Natural Cycles and Its Implications for Society

The disruption of natural cycles in *A Woman Burnt* by Iyayam and *One Part Woman* by Perumal Murugan is the manifestation of the disruption to the fine social fabric, such as marriage and childbirth, that supports life. When her family gets the call that Revathi has immolated herself. "They say she has immolated herself" (AWB 34), and Ponna is not only personally tragic, but it is also a sign of warming up social honour caused by human actions like the imposition of caste. This is the pressure that is observed when Natesan is concerned, "will they have any respect for me?" (AWB 9), linking human-induced factors to the natural mechanisms that balance personal mental health and social stability, just as climate change disrupts the natural systems. The literature on these texts describes the profound interrelations of social stigma, female body independence, and humanity. "It has been claimed that the issue of gender makes violence complex" (Butler 93); "caste imposes silence" (Chakravarti 102); "trauma drifts into the mundane" (Das 89); "and shame disables systems" (Ahmed 102). This thick overlap of theoretical models highlights the intricacy of the described trauma.

In *A Woman Burnt*, Revathi's testimony is false, which saves her abuser, and it shows how social institutions cannot work when social honour is more important than the law. On the same note, the community gaze in *One Part Woman* policing of the womb of Ponna is a way of asserting a biological determinism that equates motherhood with womanhood. Ponna laments that "not even a worm had crawled in her womb" (OPW12), and when villagers claim, "That barren woman ran up and down carrying seeds. How do you expect them to grow, they link infertility to agricultural failure" (OPW 100). The village residents face a threat of social stigma and how it has the potential of disrupting livelihoods. This is a sharp lesson on how society is prone to the effects of human activity. This is a sharp lesson on how society is prone to the effects of human activity. The novels show how ecological and social upheavals are not single events, but they are small components of a bigger problem of human and non-human life. The frailty of



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the social world is reflected in the frailty of the female body, which requires a holistic approach to the trauma that combines psychoanalytical knowledge with cultural criticism. Finally, to protect the mental and physical future of women, it is necessary to break the psychological formula of honour according to which the lineage is on par with life. The frailty of the social world is reflected in the frailty of the female body, which requires a holistic approach to the trauma that combines psychoanalytical knowledge with cultural criticism. Through this realization of these disruptions, the study challenges the reader to take into account the long-term effects of non-action and how collective responsibility is required to ensure a sustainable future for all living species.

The Role of the Female Body as a Harbinger of Change

In both stories, the feminine body acts as an agent of social transformation by compelling communities to address the psychological disequilibrium of caste and patriarchal honour. The burning of Revathi in *A Woman Burnt* makes her physical body a place of unquestionable reality as it is grotesquely described when her mother beholds her body that resembles "cooked meat" (AWB 258). This physical violation breaks the silence of caste honour and challenges the community to recognize the deadly effects of social stigma. According to Judith Butler, the body manifests the materialization of social norms; in such cases, vulnerability reveals instability (Butler 93). The body is a wake-up call when norms are broken by using burns to signify the break. Revathi's silence resembles Freudian repression, in which the repressed returns in the form of destruction. Society shifts from doubt to acceptance when it is proven beyond any doubt through physical evidence. This is the wake-up call and compels them to address the less apparent disturbances that occur in the natural state of social relations.

Eventually, these stories represent a crossroads of societal existence that must be approached with trauma as a whole. Infertility in *One Part Woman* by Ponna is a metaphor and symbol of the lack of strength in lineage, where she cries that not even a worm had crawled in her womb. Her sterility is an obstacle to natural social reproduction, which challenges patriarchal reproductive control. Interrupted female migration between the homes of the father and husband is a crossroads, similar to the social stigma against humanity. According to Judith Herman, "trauma can only be healed with the help of power and links, but both main characters are deprived of agency" (Herman, 15). This powerlessness underscores the dire need for concerted efforts to protect the future of women. The disgrace involved is shared and must be met with a shared response and not individual silence. The human race should collaborate to break the psychological formula of honour, in which lineage is more significant than life itself. The destiny of the female body is interwoven with the future of all species, and it calls on everyone to be responsible. The novels depict that social disruptions are an extension of a bigger problem that concerns human and non-human life. To protect the future, honour codes that place more emphasis on lineage than life must be broken down. The frailty of the social realm is reflected in the frailty of the female body, which requires a holistic method of incorporating psychoanalytic knowledge and cultural criticism. Similar to women, humanity too has a role to play in solving the social problems that plague us. Social equity cannot be realized without the psychological violence that is inherent in honour preservation.

CONCLUSION

In *A Woman Burnt* by Imayam and *One Part Woman* by Perumal Murugan, the interruption of female bodies is used as a potent metaphor for the destruction of social stigma. The act of immolation by Revathi and barrenness by Ponna indicate the warming of social honour caused by human actions, such as the implementation of caste and male pressure. The novels, through the prism of the female body, address the issues of psychological instability, human displacement, and the necessity of psychoanalytic and social intervention. The changed condition of the body is a metaphor for the larger psychological equation of honour that humanity should consider: the equilibrium between human actions and the social world is very fragile. The future of society, as the novels imply, will be decided by how we respond to social trauma.

This article examines the ways in which the storyline connects psychoanalytic, social, and cultural approaches to trauma, highlighting the complexity of the problem as well as individual and collective accountability.





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In this way, not only the social vulnerability of women but also the recognition of the essence of the changes that occur in our world appears. These novels offer a heartrending take on social stigma by using the symbol of the female body and its interrupted migration on the future of society. The novels demonstrate that psychological imbalances are not a one-time event but are components of the bigger picture of global problems of human dignity. The trip that was initially a representation of natural harmony has become a metaphor for social breakdown and the deterioration of dignity, which endangers the well-being of the community. The themes of disruption of women discussed by the authors in this research paper are instrumental in identifying social crises of the future, which society must address and react to. Understanding these disruptions, the work is a call to readers to think about the long-term effects of passive attitudes and collective responsibility in ensuring a sustainable future for all living beings. Finally, to protect the future of women, both mentally and physically, it would be crucial that the psychological equations that put lineage above life be shattered and that a holistic approach to trauma is taken to bring together the psychoanalytic knowledge base with cultural critique to create resilience to social life and gender justice in issues of honour-based violence.

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RESEARCH ARTICLE

In the State of Flow: Reading Bishwanath Ghosh's *Aimless in Banaras* through Flow Theory

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ABSTRACT

This paper examines the role of flow consciousness in shaping travel experience and creative narration in Bishwanath Ghosh's *Aimless in Banaras: Wanderings in India's Holiest City* through Mihaly Csikszentmihalyi's Flow Theory. Flow is an optimal experience characterized by intense concentration, loss of self-consciousness and deep immersion. This study argues that Ghosh's aimless wandering through Banaras creates optimal experiences that transform perception and self-integration. This immersive engagement enables Ghosh to merge with the environment, which leads to creative reflection. Ghosh's travel narrative emerges from this psychological state rather than from structured intention. By applying Flow Theory to *Aimless in Banaras: Wanderings in India's Holiest City*, this paper demonstrates that it is not just a travel record but a result of flow consciousness, in which wandering becomes a creative process that shapes both self and literary expression.

Keywords- Flow Theory; Bishwanath Ghosh; Travel Writing; Mihaly Csikszentmihalyi; Narrative Experience





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INTRODUCTION

Travel has been the essential activity because it is driven by curiosity, exploration and desire. The traveller goes in exploration of new places, culture, people and way of living which brings new insights and self – growth. This, Zian Fathima, in her study, says that travellers are motivated to deeply engage and experience the place through literature (3). Travel writing is the literary expression of these explorations, in which the travel writer explores different landscapes and their inner self. According to Bridges, travel writing is one of the significant genres that records journeys which changes the perceptions of place and identity. It is a unique way to transmit culture by capturing real-life events and expressing them verbally through travelogues (69). Recent studies recognize travel narratives as a way of self-discovery, subjective experience and personal transformation. Cassia and Melo say that travel narratives “have the potential to reveal more about the author and their point of view than the place visited” (65). Similarly, Srivaishnavi emphasizes “Indulging fictions about a place or describing about the place not visited, but hearing from other people and gathering information from the Internet makes travelogues and travel memoirs boring for the readers. Adding the author’s own personal and real experience, whether it’s pleasant or rough, increases readers’ curiosity to learn” (8277). This subjective engagement transforms travel writing into self-reflection. Sridharan further extends this argument by saying that travel is not for “something to do” but it is a novel experience that provides opportunity for self-growth (6). These perspectives states travel writing as a deeply immersive experience.

Bishwanath Ghosh holds a significant place in contemporary Indian travel writing, through his distinctive exploration of cities. His travelogue *Aimless in Banaras: Wanderings in India’s Holiest City* is an exploration of Banaras, one of India’s oldest and most spiritual cities. Ghosh’s narratives are not structured around planned itineraries but by aimless wandering and spontaneous encounters. Ghosh walks through ghats and galis of Banaras without any predetermined goals, through which he allows the city to unfold organically. Ghosh’s wandering shifts the focus from destination-oriented travel to experiential travel. Here, Banaras is presented not just as a physical landscape but as an experiential space that shapes the narrator’s self. Through this experiential travel, Ghosh transforms travel into a process of attentive engagement, emotional connection and creative reflection.

In existing study scholars have analysed *Aimless in Banaras* through cultural, historical, and oral narrative frameworks. Dattagupta analyses how Ghosh uses oral narratives and personal interactions to reconstruct the fragmented city’s history. She says that memories and personal stories of people contribute to a collective memory of Banaras, showing that the city is shaped through narrative accumulation (Dattagupta 180). Similarly, Maurya’s study focuses on cultural sensitivity and cross-cultural awareness in the *Aimless in Banaras*. He highlights how Ghosh engages with diverse cultural practices openly and adapts various social environments (Maurya 72). Both these studies focus on cultural and narrative aspects, but the psychological aspect that shapes the travel experience is unexplored.

The concept of immersion and psychological engagement has been extensively examined through Mihaly Csikszentmihalyi’s flow theory. Csikszentmihalyi defines flow as a state of deep involvement in which individuals become fully absorbed in an activity, experiencing intense concentration, enjoyment and loss of self-consciousness. Flow represents optimal experience, where action and awareness merge seamlessly. This theory has been widely applied to creative activities, artistic production and reading experiences. In Farsi and Vida’s study, they argue that literary engagement mirrors the flow experience, as readers become psychologically immersed in the narrative world. They emphasize that immersion involves emotional and cognitive absorption, which enables readers to experience narrative reality (Farsi and Dehnad 2). This connection between flow and narrative immersion allow to understand that literary creation may emerge from the state of flow.

Further studies have applied Flow Theory to travel and spatial experience. Pianzola analyses narrative engagement through flow theory, where flow is induced through emotional and cognitive immersion, demonstrating that storytelling can induce intense experiential involvement (18). Te Brömmelstroet extends flow theory by examining



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physical movement, arguing that activities such as walking and cycling can produce flow by synchronizing bodily activity with environmental engagement. His study highlights that movement through space stimulates focus and experiential experience (353). Similarly, Alam says emotional engagement elevates perception, creativity and psychological transformation (15). Together, these studies say that flow is not limited to artistic production but can emerge in travel, movement and spatial exploration.

Existing scholarship on *Aimless in Banaras* has focused on memory, cultural diversity and narrative, but the psychological aspect that shapes the travel experience is unexplored. While studies based on flow theory have examined reading, creativity and emotional immersion in flow but the travel, movement and spatial exploration remains underexplored. There is a significant research gap remains in the analysis of travel writing as a flow experience. By, applying flow theory to travel writing this study offers a new framework for understanding experiential travel as a psychological immersion and transformative experience.

The objective of this paper is to examine *Aimless in Banaras* through the lens of flow theory to analyse how aimless wandering produces psychological immersion, personal transformation, an altered sense of time and creative engagement. Ultimately, this study redefines travel in *Aimless in Banaras* as a state of flow in which wandering becomes a mode of psychological immersion and literary creativity.

MATERIALS AND METHODS

This study adopts a qualitative and interpretive research design to examine the flow consciousness in Bishwanath Ghosh's travel writing. This study employs textual analysis to explore how psychological immersion and experiential engagement shape the narrative. This design enables an in-depth examination of Ghosh's psychological consciousness and its role in creative expression. The primary source for this study is Bishwanath Ghosh's *Aimless in Banaras: Wanderings in India's Holiest City*, where the author wanders through the city of Banaras. This text offers rich sensory details, emotional engagement and reflective insight, which foregrounds to examine traveler's psychological aspect.

The theoretical framework for this study is based on Mihaly Csikszentmihalyi's *Flow: The Psychology of Happiness*. Flow Theory describes optimal experience as a state of intense concentration, loss of self-consciousness, deep immersion and involvement of self in the activity. Through this framework traveler's experiences in the travel narrative is analysed through psychological lens. Insights from scholarly interdisciplinary works on flow theory and travel writing were also used to strengthen the analysis. The analysis is made through close textual reading and theory-based interpretation. The analysis was made in four parts, which include flow as deep immersion, transformation of self, altered sense of time and flow as a source for creativity expression. The analysis focuses on the psychological state, demonstrating how immersive experience becomes the foundation of creative travel writing.

ANALYSIS AND DISCUSSION

Flow as Deep Immersion

Ghosh's deep immersion in Banaras's environment and aimless wandering becomes an act of psychological involvement. This immersion is evident when Ghosh says, "Sitting on a bench at Assi, I gaze at the river for a while" (23). This simplest act of gazing reflects sustained attention and intent presence, shows that the Ghosh is not just observing but immersing into the moment completely. This experience aligns with Mihaly Csikszentmihalyi's flow, in which "people are so involved in an activity that nothing else seems to matter; the experience itself is so enjoyable that people will do it even at great cost, or for the sheer sake of doing it" (16). In this flow state, external distractions will lose significance and there will be sustained attention. Ghosh's immersion in the moment reflects this involvement, where his attention is anchored in the present moment rather than distracted toward external goals. This immersion brings self and environment together, which Csikszentmihalyi describes as "the loss of the sense of





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self separate from the world around it, sometimes accompanied by a feeling of union with the environment” (91). Ghosh’s prolonged observation of the river aligns precisely with such a union, where the boundaries between observer and observed dissolve.

This deep immersion is also seen when Ghosh describes, “Once dusk settled over the Ganga, this place looked magical. I would sit for hours together and watch the reflection of lights creating abstract patterns on the Ganga” (183). The act of sitting for hours together illustrates deep concentration, a central characteristic of flow, in which Ghosh’s consciousness is fully engaged in the activity. Csikszentmihalyi says that in flow, “concentration is so intense that there is no attention left to think about anything irrelevant” (101). Ghosh’s deep immersion with the river’s reflections illustrates this intense focus of flow in which perception is elevated, and observation becomes innately rewarding. Te Brömmelstroet et al.’s argument supports this interpretation: “flow theory can provide an analytical framework to understand the complex relations between the mental and embodied aspects of different subjective travel experiences” (353). Ghosh’s experience represents this embodied immersion, in which his physical presence in Banaras and psychological engagement with its environment combine to produce a flow state. Thus, Ghosh’s wandering in Banaras becomes an immersive engagement that generates meaning and narrative.

Flow and Transformation of Self

Flow experience in *Aimless in Banaras* leads to a profound psychological transformation, in which immersion in the environment reshapes Ghosh’s identity and consciousness. This transformation is evident when Ghosh says, “I may have lived in Banaras only for four years, but my stay here remains deeply etched in my mind. Banaras taught me lessons which no book could have ever taught” (184). Here, Banaras becomes a site of experiential learning, where immersion elevates insight. This aligns with Thompson’s view of travel writing: “the travel account does not just offer a larger history of growing self; it is also plotted as a developmental narrative of growing self-knowledge and self-realization” (114). Csikszentmihalyi says that “flow helps to integrate the self because in that state of deep concentration, consciousness is unusually well ordered” (65). Through sustained immersion in the act individual’s psychic energy becomes organized around meaningful experiences. Ghosh’s transformation reflects this well-orderedness, as his engagement with Banaras leads to philosophical reflection and emotional growth.

This transformation becomes even more explicit when Ghosh says that, “There is now a bit of Banaras in me” (245). Here, the boundary between self and place has dissolved and Banaras has become part of his identity. Csikszentmihalyi notes that loss of self-consciousness in flow can lead to “self-transcendence, to a feeling that the boundaries of our being have been pushed forward” (92). Ghosh’s statement reflects this expansion of identity, in which the self is transformed through immersion in the environment.

There is also philosophical transformation when Banaras reshapes Ghosh’s understanding of life and death. He writes that, “Banaras has taught me many other things as well. A living being is Shiva and so is a dead body. The beautiful is Shiva and so is the ugly. Virtues are Shiva and so are flaws. A stroke of good fortune is Shiva and so is a rough patch. And in the end, no matter who we are, we are just a heap of ash” (Ghosh 245). This reflection of Ghosh shows how flow experience brings existential insight in the individual and engage deeply with fundamental questions of existence. Datta Gupta supports this interpretation by saying that Ghosh’s travel writing attempts “to reconstruct the city in his memories” (180). This reconstruction reflects the transformative function of flow, in which immersion produces new self-understanding. Similarly, Cassia and Melo observe that travel narratives “reveal more about the author and their point of view than the place visited” (65) which emphasizes that travel is a process of self-discovery. Flow thus becomes not just psychological absorption but a transformative state that reshapes perception and identity.

Flow and Altered Sense of Time

Flow in *Aimless In Banaras* reflects another defining character in which time feels suspended and slow. His prolonged engagement with the environment reflects a temporal experience shaped by immersion. This, Csikszentmihalyi says that in flow, “one of the most common descriptions of optimal experience is that time no longer seems to pass the

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way it ordinarily does” (94). This happens because attention is fully concentrated on the present moment. This altered temporal perception is evident when Ghosh says, “I walk all the way to Assi—an act of madness, in this heat” (244). Despite of the physical difficulty, Ghosh continues walking which is not because of necessity but by intrinsic engagement. This action of Ghosh reflects what Csikszentmihalyi calls autotelic experience, in which the activity becomes intrinsically rewarding and the individual engages in it for its own sake rather than for external rewards (98).

Pianzola supports the interpretation that in flow, “time seems to flow more slowly because predictive processing is focused on a very short time interval” (18). Ghosh’s wandering reflects this temporal immersion, in which his full attention is given to the present moments and temporal concerns loses its significance. Banaras’s cultural and spiritual environment also reflects this altered sense of time which emphasizes in enjoying the present moments of life. Ghosh’s experience of distortion of time reflects both psychological flow and cultural immersion which reinforces that flow shapes both perception and narrative.

Flow as Source of Creativity and Narrative Formation

In *Aimless in Banaras* narrative and meaning is shaped by flow experience which ultimately serves as the source of creative expression. The Ghosh’s narrative emerges from his immersive engagement with the environment. This creative emergence is evident in Ghosh’s reflection on his writing process: “How should I make my Banaras book different so that it doesn’t gather dust on his shelves? The thought weighs on my mind as I step out of the shop” (23). This question in him reflects his search for creative authenticity, which he ultimately achieves through optimal experience.

Csikszentmihalyi states that “flow drives individuals to creativity and outstanding achievement” (281). Ghosh’s narrative reflects this process, as his writing emerges from optimal experience rather than from structured observation. This creative process of Ghosh is found in his statement, “To find Banaras, lose yourself in the galis of Banaras” (23). Losing oneself becomes the condition for discovering the city and producing narrative. This discovery, what Ghosh says, is evident when he says, “I step out of the temple into the cool February night, the night of the snow moon, feeling a bit like Shiva” (Ghosh 244). This reflects the core principle of flow, in which loss of self-consciousness enables creative insight. Aligning to this, Te Brömmelstroet et al. says that flow experiences, “have a transformative aspect that lasts beyond the single experience” (353). This transformative enjoyment enables creative reflection, allowing experience to be transformed into narrative form. Thus, *Aimless in Banaras* emerges through Bishwanath Ghosh’s flow consciousness, in which wandering becomes a creative and the narrative emerges organically from the flow state.

CONCLUSION

This paper examines how flow consciousness shapes travel experience and creative expression in Bishwanath Ghosh’s *Aimless in Banaras*, using Mihaly Csikszentmihalyi’s Flow Theory. The purpose of the study is to show that Ghosh’s aimless wandering is not a passive or incidental act but a psychologically meaningful act with deep immersion that enables perception, self-transformation and narrative creation. The theoretical framework of flow provides a powerful lens for understanding Ghosh’s engagement with Banaras which involves deep immersion, loss of self-consciousness, an altered sense of time, integration of self and environment. This study analyses Ghosh’s aimless wandering through the ghats and galis of Banaras as a state of optimal experience. This optimal experience enables him to perceive the city through experiential travel in which he allows himself to transcend ordinary perception, leading to philosophical reflection and emotional growth. Through the analyses, this study states that flow plays a crucial role in shaping Ghosh’s creative expression. This study contributes to travel writing scholarship by applying flow theory as an interdisciplinary framework for literary analysis. It deepens understanding of travel writing by emphasizing its psychological dimension. By connecting flow consciousness to creative production, this study highlights the importance of attention, presence and experiential depth in shaping literary representation.





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RESEARCH ARTICLE

From Neglect to Nurture in Preeti Shenoy's *A Hundred Little Flames*

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ABSTRACT

Preeti Shenoy entered Indian letters almost by accident: after years of sketching portraits and filling illustrated journals, she started a blog that quickly found a wide readership, and a weekly column in *The Financial Chronicle* sharpened her plain-spoken style. Publishers noticed; her first novel struck a chord, and she steadily became one of the five highest-selling Indian authors—and observers like *India Today* point out she's the only woman who has stayed in that commercial bracket year after year. Awards followed (*Brands Academy's* *Indian of the Year* for literature, 2017), along with invitations to speak at IITs, IIMs, Infosys and KPMG, and profiles on BBC World. All of this sits alongside her continuing work in visual art, which she calls a private counterpoint to writing.

Keywords: letters, profiles, World, writing, visual art

Shenoy's books return again and again to inner lives that often go unmentioned in popular fiction: mental illness, the quiet erosion of self in marriage, the social rules that hem women in, and the small acts of courage that pry those rules open. *Life Is What You Make It* drew directly on conversations around bipolar disorder, giving a mainstream audience a narrator whose mind could not be reduced to "madness." *The Secret Wish List* took a middle-class housewife who rediscovers a teenage bucket list and asks what happens when private longing is finally spoken aloud. In the years since *Wake Up*, *Life Is Calling*, *It Happens for a Reason*, *A Hundred Little Flames*, *It's All in the Planets*, *The One You Cannot Have*, *The Rule Breakers*, she has moved among love stories, family sagas and light social critique, always keeping a conversationally direct voice that reads like late-night advice from a friend. Critics sometimes dismiss the prose as "too easy," but academics have begun to treat her novels as useful case studies in how popular fiction frames women's empowerment outside metropolitan elites. Translations into Hindi, Marathi, Malayalam and other languages have pushed that reach further, and the steady presence of her titles on airport shelves makes her one of the most visible models for younger Indian women who want to write about ordinary interiority without apology.





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In *A Hundred Little Flames*, Ayan's corporate world collapses, and he's sent to live with his grandfather, Gopal Shanker, in a sleepy Kerala village with no Wi-Fi. Gopal seems crusty and stuck in the past; Ayan feels stranded and impatient. As they share space, Gopal's old journals reveal family wounds and a tender love from decades earlier, while Ayan confronts his father's betrayals and his own shallow choices. The book tracks their uneasy truce turning into mutual care, showing how memory, ageing and simple daily rituals can rekindle a sense of belonging—Shenoy's "little flames" that outlast ambition.

At the outset the novel looks like a plain romantic novel. However, it has very serious concerns when we delve deep into the story. The protagonist Gopal and his bond with the society unveil the intricate plot of the novel *A Hundred Little Flames*. Gopal's past and present gets connected through his grandson Ayan. The stark generational differences seem blurring with the way Gopal and Ayan get along with each other.

In line with psychoanalysis, the novel offers multitudes of psychic transitions and social systems to explore. The three major characters Gopal, Jairaj and Ayan stand as Id, Ego and Superego personified. Gopal's personal life gets hit and goes astray when he's forced into a wedding by his family and he never retaliated. Though he leads a happy life with his spouse, that does not run smoothly during her last days.

All the three characters undergo an id, ego and superego clash. They grow up as individuals with their dominant trait and as a personality of how they feed these three. Jairaj who feeds the ego grow up to be a man with pure selfish attitude. He aspires wealth and money as his priority, breaks his relationship with his son and his father. Gopal who considered his family and parents as his priority, gives up his love matures to be a man of goodheart. His repressed emotions turn him a good journal writer. Ayan commits to id first and then to ego, then to superego and gradually fulfils his ego. His immediate temptations like quitting his job and sleeping with Shivani can be examples to what he has in mind. "The id is the dark, inaccessible part of our personality, a cauldron of seething expectations" (Freud 73). However, every now and then he follows the instructions of his father irrespective of whether he likes it or not. He never retaliates his father till the middle of the plot. Later, as a matured individual, he fulfils his ego and turns to be a person who is capable of taking his decisions. "The poor ego has a still harder time of it; it must serve three masters—the external world, the id, and the superego" (Freud 102).

Anna Freud defined defense mechanisms as "unconscious resources used by the ego to reduce conflict between id impulses and superego demands" (Freud 42). Each individual in the story expresses a unique set of defense mechanism. Rohini's art workshop, Gopal's journal entries, Ayan's football games, and Jairaj's obsession with money and entertainment are some examples of how each character cope with the clash of id, ego and superego. These defense mechanisms provide a vent for their internal conflicts and suppressed emotions. Even Ayan's refuge at *Thekke Madom* is an act of betrayal pattern that follows in the family. His innocence and submission which are pre-oedipal expressions get changed in due course and he evolves into a round and matured character.

Considering the novel as an epistolary novel, journal writing by Gopal Shankar is a perfect motif of expression of regression and repression. Preeti Shenoy adopts letters as a technique for story telling. In the same way, the novel conveys a psychoanalytic technique called 'Nashtraglichkeit' through this story telling. The concept of Nashtraglichkeit is nothing but 'a deferred action'. Though journals by his grandfather were forgotten and obsolete, they act as important connection between past and present. Ayan tries to adopt this methodology to understand his grandfather's past pain and tries to find solutions for the same in the light of the present. This connection makes the story interesting and interconnected as well.

He felt transported to an era where his grandfather and grandmother were playing out these roles. Reading these pages felt like the numerous time-travel memories he had watched - Kate and Leopold, Hot Tub Time Machine and a couple others whose names he couldn't recall.... Ayan felt that he was doing the same without any complicated machinery. (Shenoy 173)





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In the book, Preeti Shenoy presents Ayan unknowing shifts of feelings about his father onto his grandfather. At first Ayan resists Gopal, then nurtures and protects him. Gopal mirrors that by placing his own unmet hopes onto Ayan, pushing him toward writing. Their exchange through the journal layers past and present traumas, creating a generational transference that heals both. "When you heal historical and intergenerational trauma, you heal the people came before you. You also heal the generations to come" (Hubl 24). The interconnect creates a bond between the three generations of people. It also emphasises mirroring and counter mirroring technique throughout the plot. "Mirroring is the infant's first language: when caregivers reflect affect accurately, the child builds a self; when they counter-mirror—reflecting their own state instead—self-development twists" (Siegel 83). Ayan being devoid of parental care and close affection, develops a mirroring stage with his grand father. Shenoy builds the character with a developing connect with her grandfather. Not just Ayan, but even his grandfather identifies a bond with his grandson. He just reestablishes his social life only after meeting Ayan.

Apart from the characters and their developments in the story, the location also plays a vital role in the narrative structure. Preeti Shenoy chisels perfect locations for each part of the plot. The initial vacuum of Gopal Shanker is presented at Thekke Madom house, and it also reflects the slow life of the old man. His recliner in the courtyard and swing symbolise his loneliness. However, the same setting offers a solace and rejuvenation to Ayan. Jairaj's stay at Hyderabad during his initial stages of marital life, represents his busy and occupied life. His schedules, errands, responsibilities just fit in that backdrop. "In fiction, place presses on the body until it becomes mood; walls that refuse sound, streets that force encounters, houses that hold generational effect" (Heller 72). His sudden shift to Pondicherry contributes to the decent romance of the protagonist and the aesthetics contributed by Rohini. Pondicherry becomes a perfect place for the encounters between Rohini and Gopal. Their strolls, long talks and stay in 'Hideaway turn the plot so lively. Likewise, Ayan's stay at Pune turns a disaster and his welcoming stay at Kerala acts a turning point in his life. Ayan never knew his life would turn so sweet and surprising at this new place. For all the characters, the setting contributes to the psyche and spirit.

According to Erik Erikson's theory of psychosocial development stages, each individual develops a trait from infancy through a crisis. He enlists eight stages of development: mistrust vs. trust, autonomy vs. Shame, initiative vs. guilt, industry vs. inferiority, identity vs. role confusion, intimacy vs. isolation, generativity vs. stagnation and integrity vs. despair. The mention of various stages can be negligible though the prime concern of the study could be how these contrasting traits are still active in many individuals despite the age factor. For Gopal, he develops a trust with overpowering of mistrust. However, he also gains autonomy over shame. For Jairaj, it is always generativity beside stagnation in terms of money and wealth. Ayan undergoes role confusion and develops an identity though the process is slow and irregular. Rohini and Kamakshi express integrity and despair and that becomes their sole reason of their behavior with Gopal. "The ego evolves through crises: each stage - trust, autonomy, initiative, industry - asks for a virtue that balances inner need with cultural demand" (Erikson 94).

At the outset, the novel *A Hundred Little Flames* formulates a psychic revelation of three generations of people. The paper explores how inner and suppressed emotions get into positive outcomes when channelized properly. Gopal and Ayan express a strong bond beyond generation and their dreams become shared and re-lived. Jairaj and his obsession cuts him off from his bonds with Gopal and Ayan. Shenoy has presented a vivid picture of romance beyond generation and their true essence in this novel and she has reiterated how far a true love can support, empathise and can be sustainable too.

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RESEARCH ARTICLE

Interconnected Cultures and the Corruption of Modernity in Indigenous Life: An Ecocritical Approach to the Works of Easterine Kire and Witi Ihimaera

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ABSTRACT

"Nature is not a place to visit, it is home." — Gary Snyder. Nature is considered the home of many indigenous people. Looking through the novel "Sky is My Father: A Naga Village Remembered" by Kire and the short story "The Seahorse and the Reef" by Witi Ihimaera, it is found that the story connotes the idea of their cultural communal gathering as an example of their interconnected life. Easterine Kire and Witi Ihimaera are two famous indigenous writers who have been the mediators in vividly portraying their glorified culture and its destruction through their writings. The novel is based on the culturally connected traditional life, whereas the short story "The Seahorse and the Reef" revolves around the traditional life of Māori people. Colonial modernization has disrupted the peace, leaving people to face the postcolonial struggle of embracing either traditional life or modernity. Applying the cultural ecology theory from the perspective of the relationship between people and the environment, this study emphasizes an empathetic concern for the collapse of biodiversity. This paper analyzes environmental degradation and concern through the lens of an ecocritical approach, as it reflects a connection to the indigenous people and the environment, which stands as an emotional identity of their living culture. Therefore, communal gathering is seen as an identity to their roots.

Keywords: Biodiversity, Tradition, Modernity, Environmental Degradation, communal gathering, colonization, culture, etc.



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INTRODUCTION

“Indigenous peoples, also called tribal, aboriginal or autochthonous peoples, national minorities, or first peoples, are best defined by several criteria” (Toledo, 2013, p. 269). In indigenous literature, nature appears not as mere background but as an integral part of cultures and community life. An ecocritical approach reveals how numerous indigenous stories emphasize the strong interrelationship between community, land, and spirituality. This interrelation is especially found in the social meeting places, which form the centers of preserving and transferring cultural practices, environmental knowledge and the ancestral customs to their offspring. The communal gathering places of Easterine Kire's *Sky Is My Father: A Naga Village Remembered*, and Witi Ihimaera's “The Seahorse and the Reef” signify the strong bond between people and nature. These groups tend to be geographically indigenous and have their own traditions, “to specific village communities, many of which, in turn, correspond to cultures that can be considered as indigenous” (Toledo, 2013, p. 271). It may be the village gathering spot in Kire's story or the reef in Ihimaera's story, but those places are not just physical settings. They are places of ecological belonging, ancestral memory, and communal identity. Thus, the two authors show how the indigenous people preserve their cultural values by being in such close contact with nature. They not only show a detailed view of nature's devastation and modernity's influence on people's lives but also reveal the emotional bond.

The article by Dutta (2022), analyzed through the prism of ecocritical postcolonial studies, discusses how relationships with nature and indigenous people's beliefs were destroyed and their values undermined. It prolongs the discussion of the postcolonial impacts and environmental destruction, especially to the tribe of Nagas, and has a comparison of the text to Bibhutibhushan Bandyopadhyay. As the influence of the indigenous life is intense, “the white man although this legacy doesn't fit the indigenous community and their beliefs” (p. 138). The issue of identity and geographical displacement are also a major concern during the process of landscape alteration in order to extract natural resources. The article also discusses tribal communities' problems with development, like cultural alienation and maintaining identity. The paper by Mohanraj, Karthick and Sridevi (2025) considers the novel as a counter-narrative in postcolonial Nagaland with the focus on Naga cultural memory. They note that “the novel functions at once as a means of cultural preservation and a form of resistance” (p. 161).

Mehta's (2023) research investigates the role of oral narratives in saving Naga history, culture, and traditions by documenting the truth and memorable past. It highlights colonial impacts on Nagaland's indigenous peoples, noting that “resistance was taken as a challenge by the British and they took all possible measures to crush the clan by imposing heavy taxations, resulting in violence if refused” (p. 11). Reg and Jimsy Asha (2022) discuss the resilience that sustains Naga identity amid disruptions caused by colonial power. Saikia (2019) addresses cultural suppression in the indigenous world, while Makla (2024) critiques the underrepresentation of indigenous communities. Peeran and Chandrasekaran's (2025) paper elaborates on protagonist Levi's perspective, comparing it to Maslow's journey of self-realization while upholding clan legacy. According to the United Nations (2007), indigenous peoples have the right to preserve, manage, safeguard, and cultivate their cultural heritage, traditional knowledge, and traditional cultural expressions. Reg and Jimsy Asha (2022) discuss resilience through identity as a vital anchor for indigenous communities facing disruption, while Das (2023) explores resistance as ethno-spirituality, blending ancestral beliefs with acts of cultural defiance.

Lapka, Vávra, and Sokolíčková's (2012) study proposes an ecological sustainability model for mountainside tourism villages in East Java, emphasizing cultural preservation. It emphasizes harmonizing tourism development along with the help of nature to avoid harm by boosting community participation in resource management and welfare. “To sustain their lives, people must make adaptations, and this includes the people living in communities around tourism locations” (Wibowo, Suwanto, & Sugihardjo, 2022, p. 4). Using cultural ecology, this paper investigates how human societies' ties to the natural environment are maintained through four core principles, promoting environmental awareness and historical insights. Chaudhuri and Ramakrishnan's (2025) paper applies cultural ecological





knowledge to a case study on documenting health, healing, and resources amid cultural change. Yang, Zang, and Chen (2022) note that “What makes these two cases different in terms of cultural ecology is that Bai tie-dyeing was grounded in the rural village” (p. 12), exploring the role of cultural ecology in transmitting traditional handicrafts like Bai tie-dyeing and Beijing carved lacquer. The paper by De Bernard, Comunian, and Gross (2021) reviews literature on cultural and creative ecology and ecosystems, addressing their conflicts in the society.

The primary objective of this study is to explore the structured communal life and its destruction in the indigenous gathering communal space. The research reviewed above demonstrates how oral traditions, ethno-spirituality, colonialism, postcolonial resistance, ecocritical harm, cultural ecology, and environmental consciousness converge in literature to preserve and transmit cultural identity. This analysis employs a cultural ecology framework with an ecocritical lens to explore human cultural connections and adaptations to the environment.

In the novel *Sky Is My Father: A Naga Village Remembered*, the structured communal life is analyzed through activities such as harvesting, agriculture, weaving, and village festivals. These practices reveal the interplay of labour, ritual, and social bonds that sustained Naga traditions and their environment. On the other hand, Witi Ihimaera’s short story “The Seahorse and the Reef” depicts the destruction of the organized indigenous life as industrialization intrudes on Māori marine traditions. In both narratives, the communal gathering spot embodies memories of identity and psychological connection for indigenous communities. However, with the colonization these sacred spaces are shattered and become the images of loss. It systematically dismantles cultural bonds and collective memory, leaving lasting psychological scars on the communities.

Theoretical Framework

This paper adopts an interdisciplinary theoretical approach that incorporates both cultural ecology and the ecocritical approach to study the interaction among environment, culture, and literary representation. Cultural ecology, which Julian Steward has developed, throws light on the way that culture influences and is influenced by a certain environment. Based on the novel *Sky Is My Father: A Naga Village Remembered*, the paper will investigate the way in which community life and the surrounding environment shape the culture of an indigenous community. Then it follows the break-up of this communal meeting place and the cultural symbiosis in the short story “The Seahorse and the Reef”. Finally, the research shows how deeply a culture’s influence is connected to its surroundings.

Cultural ecology’s core concept deals with human interactions within ecosystems. The theory emerged in the late 1930s, “primarily through the work of Julian Steward” (Sutton & Anderson, 2010, p. 21). He combined various approaches to study these interactions and understand human adaptations. “The term *cultural ecology* to describe his approach and is frequently referred to as the father of ecological studies in anthropology” (Sutton & Anderson, 2010, p. 22). Steward’s approach argues that cultures in similar environments evolve alongside changing conditions. It examines how cultural practices, belief systems, traditional ecological knowledge, and social structures are shaped by environmental conditions such as land, climate, and natural resources. Through this framework, this paper shows how the environment shapes culture through daily practices and traditions.

The concept of cultural ecology by Julian Steward focuses on the complete interdependence between culture and environment. Steward’s emphasis on ecology, cultural types, and multilinear evolution gives an outline for anthropology in the 1930s and 1940s, giving an alternative to traditional cultural approaches. The term “multilinear evolution” (Steward, 1955, p. 18) suggests that cultures develop in diverse ways based on their ecological contexts. His theory of cultural ecology emphasizes that human societies are deeply intertwined within ecological systems, with cultural patterns emerging as responses to specific habitats. This marked a shift from environmental determinism to cultural adaptations shaped by the environment, placing society as an active response through technological, economic, and social strategies.

This study analyzes the intrusion of new adaptations into the lives of two indigenous communities. The communal gathering spot plays a pivotal role in exemplifying their heritage-rooted identity. Although both communities have



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transitioned toward modernity without fully losing their identity, an unexpected shift now prevents them from sustaining their culture on the land. The analysis of these two literary texts underscores the communal gathering place as more than a psychological connection for the people.

The ecocritical approach is a method of literary analysis that examines the relationship between literature and the environment. It explores representations of human and non-human worlds. The term “ecocriticism” was coined by William Rueckert in his 1978 essay “Literature and Ecology: An Experiment in Ecocriticism” (Kumar, 2020, p. 408). This approach studies the relationship between humans and nature. The portrayal of nature in literature reveals the unseen links between nature and communities. It also investigates how ecological awareness critiques environmental exploitation. Cheryl Glotfelty brought prominence to the field by defining its interactions with the physical environment in literature. Overall, this critical approach outlines reflections of environmental concerns and ecosystem damage, promoting awareness.

This study applies an ecocritical lens to illuminate cultural ecology, revealing the profound interplay between indigenous traditions and their environments. It examines how literature depicts harmonious human-nature bonds disrupted by colonization and modernization. Through texts like Kire’s novel and Witi Ihimaera’s short story, the framework uncovers ruptured and intact relationships, along with lost ways of life. Ultimately, it highlights the psychological connectivity and cultural roots embodied in enduring communal gathering spaces.

DISCUSSION

The Village Meeting Point: Land And Community

Easterine Kire’s novel *Sky Is My Father: A Naga Village Remembered* centers on the warrior Levi, who returns from imprisonment and finds his community transformed in ways he could not have imagined. As the village warrior, Levi worries that his sons fail to uphold this legacy: the elder lacks Levi’s sharpness, while education shifts the younger son’s indigenous worldview. This intrusion of modernity disturbs Levi, undermining his faith that community identity will endure rather than be erased from history. Similarly, Witi Ihimaera’s short story “The Seahorse and the Reef” depicts cultural destruction at a communal gathering spot. “The reef was just outside the town where my family lived” (Ihimaera, 1977, p. 1). Families once gathered there every summer to collect seafood, feeling ecstatic amid their community. As this communal spot is no longer viable, indigenous people are forced to leave their land. The plots of both the novel and the short story explore the emotional burden of culture slipping away from heritage.

Focusing on indigenous interconnected life, the novel and short story display each community’s distinct culture, born from their environmental ties. Easterine Kire’s novel reveals a deep interplay between environment, community structure, and indigenous spirituality. Set in Nagaland’s ecological and cultural landscape, the land acts not as a silent backdrop but as an active force shaping individual and communal identity. Applying cultural ecology through an ecocritical lens highlights the crucial role of shared ecological knowledge in the community’s web. The land emerges as a living cultural system, embodying the people’s innate, unpolluted way of life. The novel’s plot illustrates how the natural environment shapes daily routines through agricultural activities, seasonal cycles, and hunting practices tied to their cultural ecology. The community’s survival depends on understanding rainfall patterns, soil conditions, and spiritual rituals, demonstrating how ecological knowledge is embedded in cultural practices.

In the novel *Sky Is My Father: A Naga Village Remembered*, the author conveys a clear picture of the close-knit environment tied to Naga indigenous culture. The indigenous people gather to celebrate their interconnectedness by worshipping nature. As the novel shows, agriculture and weaving are the core of their occupations, developed from the environment to which they are adapted. The hill community around Kohima finds balance through agricultural occupation. These people depend entirely on nature for survival, which stands as the base in producing the culture.



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Nagaland culture features numerous festivals honouring the bond between land and people. As their lives blend cosmology and spiritual balance, the novel stands “representative of the story of Nagas” (Bhumika, 2021, p. 8).

Looking from the perspective of Julian Steward’s theory, the cultural practices of the Naga community show how human culture adapts to ecological conditions. The traditions inherited from the ancestors of the Nagaland community signify an extension of sacred connection. Agriculture is performed collectively, with families and clans participating in harvesting crops and spiritual honouring. “Push the soil down like this with your finger,’ his mother instructed” (Kire, 2019, p.12), illustrating an indelible occupation passed down through generations. This system acknowledges the glory of their survival, where environmental success relies on shared responsibility. The land is not privately controlled by the people; instead, it is treated as a shared ecological space sustaining the community’s growth. Kire’s depiction emphasizes that cultural connectivity is not materialistic but a form of environmental coexistence with spirituality and communality. Rituals performed before harvesting reinforce respect for nature and reclaim the strong bond with the indigenous cosmological worldview.

“Adaptation is regarded as responsive human behaviour to environmental changes that are taking place” (Wibowo, Suwanto, & Sugihardjo, 2022, p. 4). The weaving is also seen as an irreplaceable tradition that shows how their culture emerges from environmental adaptation. Basket weaving serves as both a primary occupation and a cultural practice tied to the land, with materials such as forest fibres and bamboo sourced directly from the environment. “As they grew older, they became adept at weaving the carrying baskets the women used for carrying water and wood” (Kire, 2019, p.12) shows that the crafted work was passed down through generations. Baskets made from supple reeds and vines hold a rich history of interconnected stories, human efforts, and culture within the cultural ecology web. All the fibres echo the intertwined rhythm of human hands, rivers, and forests to tell the world. This transformation from simple kitchen weaves to intricate works of art “progressed from simple weaving for the kitchen’s needs to the later stages which became veritable works of art” (Kire, 2019, p.10). Elders convey traditional ecological knowledge through close observation, thereby securing its continuation while depicting cultural ecology as an environmental adaptation mechanism.

Harvest seasons are celebrated immediately next to the village festival. The harvesting season exhibits a pictorial view of communal celebrations that stress ecological gratitude. Agricultural labour is seen as productive time spent with nature in tilling the land to reap a good harvest for their survival. This comes as one community coming together to share a ritual activity. These harvest gatherings function as an acknowledgement of nature’s spiritual role in their living. From an ecocritical approach, harvest celebrations reflect an environmental worldview in which humans are dependent on ecological cycles. Kire shows that harvest is seen not merely as a fruitful outcome but as a spiritual and cultural connection, recognizing the relationship between land and community. Through the novel, social communal unity is deeply evident, representing the communal sharing of harvested crops, which also strengthens the bond. Equally distributed responsibilities are seen in the characters, forecasting the cultural values of collective survival. Looking at overall harvesting practices, they contrast the ideas with modern systems of individual accumulation, but in Kire’s work, it is observed as communal ethics.

The festival lasts five to six days, seeking blessings from spirits for peace with humans. By the last day, “young children were appointed to perform the rhoutho ritual of seed-sowing” (Kire, 2019, p.82). With small hands, they scattered seeds into the soil to pray for good crops. “All the villagers followed the children and the elder to the fields to watch the performance of the ritual” (Kire, 2019, p.82). The festivals, held both before and after harvest, prepare the community for the vital task of sowing the seeds of the next season. Finally, the elders pronounce blessings, saying, “My paddy may grow well, though the weeds are abundant, my paddy grow you around the tree stumps and boulders” (Kire, 2019, p.82). Their strong, ancient lyrics create resilience in the soil, encouraging crops to grow despite nature’s challenges. On the fourth day, they do not go to the fields as the festival ends, in order to honour their interrelated lives. The “Genna Day” (Kire, 2019, p. 83) shows a strong bond of respect, as they sing songs to the land. These songs describe the traditional life of the people. On the third day, they dress in cultured traditional garments. The garments and ornaments, made from natural products such as bark fibers, feathers, and seeds, fully





adorn every person in the village. The natural adornments, made from beads and threads, include “young girls wore white teirhü around their shoulders, while some of the young men displayed teirhü on their headdresses” (Kire, 2019, p. 81). These simple adornments honour their deep bond with the land.

Following the thorough ritual comes a “Genna day, and the villagers returned home without doing any work in their own fields” (Kire, 2019, p.82). This sacred rest period for two or three days honours the spirits, letting the seeds settle in silence before growth or harvest begins. The core belief of Genna Day centers on harvest blessings; “the ritual of rhoutho was pronounced as completed” (Kire, 2019, p.82). If any individual violates “Genna Day” (Kire, 2019, p.82), it is a taboo in society. This day holds serious and deep meaning, even “the genna included a taboo on talking to sojourners” (Kire, 2019, p. 82). By hosting the “Genna day”, it carries cultural and ritual significance with a strong connection to ecological discipline. It represents a break in ecology. “Genna Day” simply shows how culture, spirituality, and nature live together peacefully. It suggests that harmony with the environment comes from adapting to the land. In the eyes of cultural ecology and the ecocritical approach, such limitations indirectly guard against environmental exploitation. They demonstrate how the native cultural system incorporates internal conservation values without any systematic arrangement. Kire's work brings respect to these rituals and accentuates their common responsibility for ecological and spiritual balance.

As the analysis shows, all these elements bring to light the interconnected communal life in *Sky Is My Father: A Naga Village Remembered*. Kire's novel explains that ecological knowledge is embedded in everyday life rather than separated into specialized scientific systems. In all aspects of the indigenous community's interdependent life, “the communal house - Thehou” (Kire, 2019, p.148) plays a significant role. This communal gathering space holds the community's identity, where people unite for storytelling, cultural ceremonies, festivals, and ritual initiations. It symbolizes unity in passing cultural identity and glorification from one generation to the next. It also vividly proclaims a place for celebrating the relationship among land, culture, and community. The communal spot “Thehou” (Kire, 2019, p.148) personifies an interconnected system, reflecting a core principle of cultural ecology. Culture evolves through environmental interaction more than through physical isolation.

The Reef as Communal Hub: Ecological Belonging

Witi Ihimaera's short story “The Seahorse and the Reef” depicts the communal life of indigenous Māori in postcolonial New Zealand. It illustrates how their lives were once closely linked to nature but have now been torn away. Once, their communal interconnected life thrived, but now their identity has been destroyed before their eyes through unseen enforcement. The lines reveal, “At that time, our family lived in a small wooden house on the fringe of the industrial area” (Ihimaera, 1977, p. 1). Life away from their village shows an invisible abandonment of their culture. The reef served as the communal gathering spot where family members met every summer weekend. Before colonizers intruded, they lived closely with sea life and depended on marine bounty for food. “It teemed with life and food. It gave its bounty to us” (Ihimaera, 1977, p. 1). Each tide brought sustenance that sustained their ways for generations. This reveals how environmental destruction is not only a physical crisis but also a cultural and moral disruption. The story shows how marine life, nature's balance, and human actions are linked, with damage coming from lost harmony between culture and nature. The short story also demonstrates the disrupted interdependent life and the resulting ecological imbalance in the indigenous community due to human actions that disrupt harmony between culture and nature. Through cultural ecology theory, it reveals how modern human ways are slowly destroying traditions. Traditional societies build lasting practices through adaptation and environmental awareness. Using the ecocritical approach, the story focuses on destruction and limits to their symbiotic way of life. The reef functions not only as a biological habitat but also as a metaphor for communal interdependence, showing that indigenous societies rely on ecological balance for survival.

“As long as we respect it, it will continue to feed us” (Ihimaera, 1977, p. 1). This simple truth underscores the mutual connection between nature and people, where harmony ensures endless provision. But the indigenous interdependent life was polluted by intrusion, snatching their freedom to live. “It is dangerous to take seafood from the reef, son” (Ihimaera, 1977, p. 2), the elder warned, as factory waste dirtied the once-pure waters. The reef



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symbolizes cultural ecology in the Māori ecosystem. They came to the sea to collect kaimoana (seafood). “We would laugh and talk and share the kaimoana between different families” (Ihimaera, 1977, p. 1), strengthening bonds through every shared bite. The reef and seahorse represent a natural system in balance before human disturbances. This interdependence broke, shifting environmental sustainability toward exploitation. “We have poisoned the land and now we feed our poison into your water” (Ihimaera, 1977, p. 2). What was once a balanced cycle now chokes on greed and waste.

In the short story, the kaimoana collection site serves as a communal gathering spot. After losing their land, the Māori reach the seashore seeking a new place to gather. Comparing this with Oodgeroo Noonuccal’s poem, which laments this loss, “Gone now and scattered. The scrubs are gone, the hunting and the laughter” (Oodgeroo Noonuccal, 19, 20), shows the shared theme of cultural erosion. These lines mourn the erasure of sacred places and joyful traditions, leaving only echoes of what was once cherished. But when the sea becomes polluted, it gradually abandons the people’s natural way of living. “The beach, the sea was empty of the family” (Ihimaera, 1977, p. 2) exposes the idea of cultural disconnection and loss of community traditions. The community, once lived with laughter and shared kaimoana, is now wrapped in silence and has lost the freedom of its communal spirit. The people’s simple, interconnected lives are taken away. A critical analysis of the story shows that the indigenous community is connected physically and psychologically. The reefs are not only physical structures but also represent continuity, protection, and coexistence. When the reef is damaged, the ecosystem suffers serious loss.

CONCLUSION

The two stories glorify the communal social space as the representation of an integrated culture. This is an indication that the indigenous narratives shape such spaces as ecological, cultural, and spiritual centers. Although the texts are written in different geographical and cultural backgrounds, indigenous people are psychologically attached to the land. Both writers present communal gathering spots as sites where environmental consciousness and collective identity are nurtured. The communal space in the novel by Kire is the bridging point between community cultural practices and decision-making. These places are considered cultural-ecological centers, which cannot be separated from nature and are placed in a landscape with forests, hills, and trees. Most importantly, they are strong ties, continuity, and stability.

Looking at the reef in the short story of Ihimaera is a symbolic community area, which is the beach. The reef is not just an ecological habitat, but also a collective cultural site that symbolizes the connection of the Māori ancestors to the sea. “The Seahorse and the Reef” together show how things depend on each other, how fragile they are, and nature’s balance through harmony. In Kire’s novel, the village meeting place stays the same. But in Ihimaera’s book, the communal spot is at risk of being ruined by the environment. After feeding people, the reef has become a target of human exploitation, disturbing the natural balance, making people culturally disconnected and lost.

The ocean has a connection with “Whakapapa is the Māori word for genealogy” (Mahuika, 2019, p. 2), connecting the people and their ancestors, as well as the non-human life forms to which people are related. The risk of disruption and crisis is therefore brought out in the short story, as opposed to interconnections. In both analyzes, native people seem to be psychologically attached to their land that their interdependent lives and adaptation take them through absolute dependence and adaptation. The village space preserves the oral traditions, rituals and agriculture in the novel by Kire. In the story by Ihimaera, the reef supports the marine life and depicts ancestral continuity. The two communal places are ecological centers of inter-relational living, and they represent the identity based on ancestral land and ecological belonging.

In Kire’s novel, people live in harmony with nature and spirits, as indigenous life is built this way. The village gathering spot includes rituals, harvest celebrations, war decisions, storytelling, and Genna Day events. It acts as a living center for culture and ecology. So, belonging to the village means belonging to the land. Identity forms





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through adaptation in communal life, intertwined with nature. “Adaptation of human beings includes the organisms and the environment that make up an ecosystem: a system or unit that functions and consists of a physical environment and the various organisms that live inside it” (Wibowo, Suwanto, & Sugihardjo, 2022, p. 6). Ihimaera's reef is a delicate shared space that ties Māori identity to the sea and family history. It is not just a sea home; it is part of *whakapapa* (genealogy) (Mahuika, 2019, p. 2), linking people to their ancestral memory. The damage done to the indigenous community threatens cultural continuity. This shared space, where elders transmit ecological knowledge and ancestral memory, becomes psychologically restorative. Its endangerment hints at the erosion of indigenous roots and collective belonging.

This concern resonates with Janice Pariat's observation in her article, “Colonisation and modernisation have largely erased the traditional way of life of people of the northeast” (Bhattacharya, 2024). It shows how outside forces have slowly destroyed indigenous customs and ties to the land. She highlights how urbanization and external influences distance younger generations from land-based living and collective cultural spaces. “Vast portions of histories and cultural archives have been erased deliberately, and there is no easy or clear way to bring them back” (Bhattacharya, 2024). This parallels the vulnerability in Ihimaera's “The Seahorse and the Reef” and reinforces the preservationist tone in Kire's novel. Therefore, this study shows that communal ecological spaces are not merely social settings, but foundations of identity and psychological connection deeply imbued in indigenous peoples. Protecting them safeguards memory, tradition, and the deep connection between people, land, and spirit.

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RESEARCH ARTICLE

Spectrum of Feminist Agency from Survival to Subversion in Anita Nair's *Ladies Coupé* and Kavery Nambisan's *The Hills of Angheri*.

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ABSTRACT

This paper presents a comparative analysis of feminist agency in Anita Nair's *Ladies Coupé* and Kavery Nambisan's *The Hills of Angheri*. It examines how female characters navigate obstacles, from survival to subversion, in societies that treat women as inferior, restrict their freedom, and confine them to prescribed roles. Agency emerges as a result of a shift in mindset, enabling women to pursue their dreams and act with courage. *Ladies Coupé* follows six women in a train compartment sharing their stories and speaking out against injustices, while *The Hills of Angheri* centres on Nalli, a village girl who aspires to become a doctor and serve her community despite family opposition and societal barriers. Both novels depict women confronting their environments and responding to limitations, showing that agency can manifest as small acts, strategies, or survival tactics against patriarchal structures. By analysing these characters, the study highlights the complex forms of agency women exercise and emphasizes the need for societal change to support their empowerment.

Keywords: Agency, Oppression, Societal barriers, Resistance, Strategy.





INTRODUCTION

In contemporary Indian literature, novels exploring women's lives, their struggles, complexities, and experiences under patriarchal oppression have increasingly gained attention. This marks a significant shift in Indian feminist literature. Gilbert and Gubar's (1979) *The Madwoman in the Attic* highlights how women writers have begun to subvert traditional literary conventions to assert their own narratives. Many contemporary female authors address not only the crises women face but also their resistance to patriarchal norms. Among them, Anita Nair and KavaryNambisan stand out as prominent writers who engage with feminist concerns with clarity and intensity.

While men and women are inherently equal, society often treats women as subordinate. This hierarchy is evident in ancient texts. Manu, the codifier of Hindu law, states: "The duteous girl obeys her father, Husband sways the duteous wife, Son controls the widowed mother, never free is a woman's life" (137). The *Manu Smriti* pointed out the restriction faced by women to access education and autonomy, reflecting deep-seated gender inequalities. Indian epics also mirror these societal biases. In the *Ramayana*, Sita is bound by rigid expectations and must prove her purity, while in the *Mahabharata*, Draupadi is gambled away in a dice game and publicly humiliated by the Kauravas. These examples underscore how women's agency has historically been curtailed and their dignity compromised, themes that contemporary feminist writers continue to explore and challenge.

Anita Nair is a prominent contemporary writer whose work presents a powerful feminist narrative. Her novels challenge societal expectations, rigid customs and traditional gender roles imposed by patriarchy, portraying women's journeys toward empowerment and self-discovery. Nair's writing resonates with Simone de Beauvoir's assertion that "the fact that we are human is much more important than our being women," emphasizing the universal struggle for recognition beyond gender. It highlights the historical suppression and oppression of women within male-dominated societies. Consequently, the quest for identity and self-realization has emerged as a central theme in postmodern literature, with many writers exploring women's desire for autonomy, individuality, and personal agency. Through her female characters and their lived experiences, Anita Nair delves into themes of liberation, identity, agency and sexuality, offering a nuanced exploration of women's lives in contemporary India.

KavaryNambisan, a surgeon and novelist, combines her medical insights with a strong feminist perspective in her writings. Drawing on psychoanalytic ideas, Sigmund Freud suggested that women's lives are determined by their biological constitution, with their primary role tied to reproduction; society then regulates their work and behaviour around motherhood, often dismissing other ambitions as "unnatural." This restriction denies women the freedom to define their own identities and limits their individuality. As Simone de Beauvoir observes, women have the capacity to define themselves, yet they live in societies dominated by men, which subordinate them. Nambisan's work addresses these gender inequalities, exploring the complexities of women's lives and their limited access to education and social mobility in male-dominated contexts. In *The Second Sex* (2011), de Beauvoir argues that women will achieve equality when granted access to social, economic, and cultural spheres historically reserved for men (75). Similarly, Diane Elam in *Feminism and Deconstruction* (1994) asserts that liberation comes when women develop a conscious awareness of their self-defined sexual identity (43). Reflecting these ideas, Nambisan portrays women as confident, expressive, and conscious of their identities. Her characters pursue their dreams and ambitions, confronting social oppression and striving to realize their goals with determination and resilience.

Studying the works of Anita Nair and KavaryNambisan provides a spectrum of feminist agency, ranging from survival to subversion. Their writings reveal diverse approaches to women's empowerment, showing that feminist agency does not always manifest as overt political action or revolution. At times, it appears as mere survival; at others, it emerges through subtle acts of personal subversion and the redefinition of identity within the constraints of a patriarchal society. Women's liberation often begins with a shift in mindset, the courage to live according to one's own choices rather than conforming to pre-assigned social roles. Such agency frequently expresses itself through



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small yet significant acts that challenge societal expectations, including rejecting imposed roles, pursuing personal dreams, and asserting selfhood.

Women in the contemporary period increasingly demand the freedom to live on their own terms. For this study, one novel from each author has been selected for analysis: Anita Nair's *Ladies Coupe* and Kavery Nambisan's *The Hills of Angheri*. The female characters in these works exercise agency in diverse ways, navigating the constraints imposed by a patriarchal society. By examining the narratives of these novels, this research highlights the multiple forms of resistance and expressions of feminist agency in contemporary Indian English literature.

LITERATURE REVIEW

Harvinder and Dr. A Vijayanand (2025) in their work "Mapping the Inner Landscape: Existential Anguish and Self-Realization in Anita Nair's *Ladies Coupe*", explore Akhila's journey of self-discovery where she realizes how duty and social expectations have limited her life. The novel shows that mental freedom comes before physical freedom, and ends with Akhila choosing to live for herself, symbolizing self-realization and independence.

Richa Langyan, in her work "Women and Society: A Study of Themes and Attitudes in the Novels of Anita Nair", examines how Anita Nair portrays women's lives and societal roles. She analyses the recurring themes of patriarchy, gender inequality, and the struggle for self-identity in Nair's novels.

Dr. Madhumita Basu in her work "Quest for Selfhood: A Study of Anita Nair's *The Ladies Coupe*", observes that patriarchal structures, though often invisible, exert strong control over women's lives. Despite differences in background, education, culture, and age, all the women face similar challenges within this social order. The space of the coupe provides them a platform to share their stories and reflect on gender-based inequalities. Through these exchanges, they gradually discover their paths to selfhood.

Dr. Nisha Thomji Varghese and Ms. Anannya Rajesh, in their work "Eclipsing Oppression: Unravelling the Labyrinth of Patriarchal Hegemony in Anita Nair's *Ladies Coupe*", observe that *Ladies Coupe* presents women not merely as bearers of imposed roles but as individuals with diverse possibilities. The novel depicts women reclaiming their identities and asserting independence through courage and self-realization. It shows that liberation is a gradual, personal process that begins with choosing oneself, celebrating women's resilience and highlighting self-assertion as a powerful form of resistance.

Nisarga M and Dr. Pramod Kumar K S in their work "Tracing the Path of Self-Discovery: A Journey of Exploration in Anita Nair's *Ladies Coupe*", conclude that although women encounter numerous difficulties and face setbacks at every turn—sometimes leaving them in tears—at other times they rise fiercely like a tigress. They confront societal challenges and transform hardships and obstacles into strengths that work in their favor.

Dhanya Pankajakshan and Nandini Nagar in their work "Female Subjugation in Anita Nair's *Ladies Coupe*", conclude that *Ladies Coupe* depicts both an inner and outer journey, leading to life-changing realizations. While society has progressed in areas like property ownership and voting rights, the struggle for true gender equality continues.

Dr. K. Shanmuga Sundara Raj in his work "Feminist Analysis Of *Ladies Coupe* By Anita Nair: Breaking Societal Norms And Empowering Women", analyses *Ladies Coupe* as a powerful feminist text, highlighting women's empowerment, autonomy and agency, where Nair explores how identity, self-discovery and personal agency intersect within a patriarchal society.



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Anjaly Nair M. K., in her work *“Breaking the Bars: Body and Identity in Anita Nair’s Ladies Coupe”*, concludes that each woman in the novel, including the protagonist Akhila, uses her body to shape her identity. She shows how they resist patriarchal control, overcome social and psychological barriers, and reclaim their selfhood and personal freedom.

Dr. Iliyas Ali Shaik, Dr. C KalyanChakravarthy, M. Naga Raja Kumar, and Dr. K. Shaheen, in their work *“Strategic Subversion in Anita Nair’s Ladies Coupe: A Feminist Perspective”*, examine the role of subversion in feminist literature. They show how Nair’s narrative challenges traditional norms, portraying women who subtly resist patriarchal control through quiet, strategic acts, redefining their identities and asserting independence while highlighting the resilience of marginalized women.

G. Vijay and Dr. A. D. Sudha in their study *“Revolutionary Culture of Women against Gender Norms in KaveryNambisan’s The Hills of Angheri”* argues that Nalli’s resistance to discriminatory cultural norms enabled her to achieve her dream of becoming a doctor and build a hospital for her town. It highlights how the courage of a few women in the past transformed restrictive traditions, allowing later generations to access education, careers, independence, and social respect. Through determined, responsible, and nonviolent efforts—especially their commitment to education—women have challenged and weakened male dominance in society.

R. Kaliswari and Dr. K. M. Sumathi in their study *“In Dream vs Reality: A Thematic Analysis of KaveryNambisan’s The Hills of Angheri”* highlight the story of Nalli, a village girl who aspires to become a doctor. Despite family pressure and traditional biases favouring boys, she perseveres and achieves her dream, demonstrating that a woman’s ambitions cannot be held back.

M. DayaBhagyaSherin, in her work *“The Pursuit of Social Justice in KaveryNambisan’s The Hills of Angheri”*, analyses how KaveryNambisan and Amartya Sen view true development as more than wealth—it involves improving education, health, and social equality. The study emphasizes that socially responsible doctors like Nalli can address health disparities in villages and promote social justice.

G. Vijay and Dr. A.D. Sudha, in their work *“Role of Education in Eliminating Gender Biases in KaveryNambisan’s The Hills of Angheri”* highlight how Nalli embodies self-empowerment, encouraging women to pursue their goals despite challenges. Through Nalli, KaveryNambisan stresses that education is crucial for overcoming discrimination and gender bias peacefully. The study advocates prioritizing girls’ education, promoting equality in schools, removing cultural barriers like forced marriage and drawing inspiration from the novel to build a fairer society.

Dr. Raj Kumar Verma, in his work *“Voicing the Unheard: KaveryNambisan’s Creative Expressions as a Platform for Women’s Empowerment in Marginalized Communities”*, shows how KaveryNambisan’s diverse female characters reflect India’s social, cultural, and economic realities, expressing strength and agency. Through their determination and pursuit of personal goals, these women challenge patriarchal norms and assert their voices against longstanding marginalization.

K. Sathiyakala and Dr. K.N. Sharmila, in their work *“Contextualising Environmental Virtue and Struggling Woman in KaveryNambisan’s The Hills of Angheri”*, highlight how *The Hills of Angheri* addresses critical environmental issues like climate change, species extinction, biodiversity loss, and harmful pesticide use. Using an ecofeminist perspective, they show how the exploitation of nature parallels the oppression of women, illustrating how patriarchal control impacts both the environment and the female protagonist.





METHODOLOGY

The selected novels were examined in depth, alongside relevant secondary sources, including scholarly literature and publications related to the authors. This study adopts a qualitative approach, employing a systematic textual analysis of the chosen novels to explore themes of feminist agency and resistance.

Ladies Coupe

Anita Nair's *Ladies Coupe* centres on a train compartment that becomes a space for women to voice their struggles with domestic violence, gender inequality, societal expectations and personal dilemmas, while exploring the assertion of female agency. The story follows six women named Margaret, Prabha Devi, Janaki, Sheela, Marikolunthu and the protagonist Akhilandeshwari (Akhila) whose narratives within the confined space reveal the diverse forms of resistance women employ in Indian society. Their conversations and shared experiences help Akhila confront her central question: "Can a woman live by herself?" This question reflects her pursuit of autonomy and feminist selfhood. Nair portrays agency as a transformative process, showing how women reshape their own lives and pursue happiness despite the constraints imposed by a patriarchal society.

Akhila, the forty-five-year-old protagonist of *Ladies Coupe*, is unmarried and the primary breadwinner for her family. Her life has been defined by sacrifice, compliance, and the absence of personal choice, emotional support or social freedom. Her assertion of agency begins with her bold decision to travel alone to Kanyakumari with a one-way ticket, refusing to remain silent or confined within familial expectations. Her determination is evident when she declares to Padma, "For heaven's sake, I don't need anyone's consent... I will do exactly as I please and I don't give a damn about what you or anyone else thinks..." (Nair 204), asserting her right to self-determination without seeking her brothers' permission. Akhila breaks free from her suffocating existence and the burden of family responsibilities following her father's death. She experiences bodily and emotional liberation through a romantic relationship with the younger Vinod. By the conclusion of the novel, Akhila emerges as a self-possessed woman, no longer merely an extension of her family, but someone who defines her own identity and life.

Margaret Shanthi, a chemistry instructor in *Ladies Coupe*, demonstrates agency in a quiet yet subversive manner. Her husband, Ebenezer Paulraj, embodies patriarchal dominance, having forced her to abort a child. Margaret expresses her anger through a calculated, strategic act. Being aware of Paulraj's health-conscious habits, she gradually overfeeds him, making him physically dependent on her. This clever action reverses the household power dynamic. Her psychological release is evident when she declares, "I hate him. I hate my husband. I hate Ebenezer Paulraj. Hate him. Hate him." (Nair 98). Through this subtle yet deliberate form of resistance, Margaret asserts control over her life, embodying a form of feminist agency that is quiet, strategic, and transformative.

Prabha Devi demonstrates agency in both overt and internalized forms. As a child, she is devalued by her father, dismissed as a "bloody nuisance" simply for being a girl. She initially asserts her autonomy visibly by wearing Western clothing during a trip to the United States. Later, after being sexually exploited by her husband's friend, she shifts to subtle, internalized resistance, choosing to wear saris and traditional attire. This decision is not a surrender but a conscious reclaiming of self, prioritizing emotional stability and inner peace over external validation. It's a quiet yet profound form of agency.

Janaki's agency is primarily expressed within domestic boundaries. Her marriage to Prabhakar is arranged and she grows up pampered and protected. However, she becomes disillusioned by her son's indifference and refuses to define herself solely through motherhood. Her confrontation with her husband, "You just want to control him. You want to control everybody. You want everyone to do your bidding" (Nair 30) marks her refusal to accept patriarchal authority and asserts her identity as an individual, not merely as a wife or mother.



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Sheela, just fourteen and the youngest of six women in the ladies' compartment, demonstrates that agency is not limited by age. She is aware of neglect and the threat of sexual abuse. She is deeply hurt by seeing her grandmother being ignored by her sons. She feels uncomfortable by experiencing inappropriate advances from her friend Hasina's father, Nazar. Though too young to directly protest, Sheela makes a thoughtful decision to protect herself from physical abuse. She begins cleaning her face with a handkerchief before entering Hasina's house and eventually avoids visiting her home altogether. This act of self-protection is evident in the text, "Thereafter, Sheela mopped her face with a hanky each time she entered Hasina's home.... She would never go to Hasina's house again" (Nair 66). Despite her age, Sheela's actions reflect a clear sense of bodily autonomy and agency.

Marikolunthu, a humble woman in *Ladies Coupe*, is treated as a sexual object and her life highlights the intersection of sexual violence, gender, and class. She is raped by Murugesan, yet society blames her while protecting him due to his social status. Despite this injustice, she exercises agency in a subtle yet powerful way. She attains a sense of liberation and control by selling her son, Muthu, as child labour to Murugesan's silk factory, thereby gaining economic independence. Through this act, Marikolunthu reclaims authority over her life, freeing herself from past trauma and asserting her self-determination and resilience. These women demonstrate that agency is not uniform or universally applicable. Rather, it manifests in diverse forms like strategic, internalized, assertive or sometimes as mere survival which shaped largely by their individual circumstances.

The Hills of Angheri

The protagonist of the novel Nalli is a village girl from Angheri, located twenty miles from Mysore. She embodies a revolutionary spirit, breaking traditional barriers to bring modern healthcare to rural India. Nalli acts as an agent of social change and rural healthcare management. Her agency lies in her ability to challenge oppressive societal norms and pursue her dream of benefiting her village independently.

Nalli aspires to become a doctor alongside her friend Jai. While her family opposes her ambition, reflecting the common belief that such professions are unsuitable for women, society readily supports Jai's choice to serve the village. Nalli, meanwhile, is expected to marry at the "appropriate" age. Yet she is deeply aware of her village's urgent need for medical care. The villagers lack awareness of health issues and have little access to healthcare and other essential resources due to their distance from the city. Undeterred by opposition, Nalli remains determined to become a doctor and build a hospital in her village. She asserts, "No child will die of a simple illness like dysentery" (Nambisan 135). By pursuing education and a medical career, Nalli challenges the prevailing belief that women should remain uneducated. She is a liberal feminist deeply committed to individual rights and equality in education and profession. Her struggle against an orthodox society that restricts women's education, along with her family's objections, demonstrates her agency. Defying her family, she pursues her ambition to study medicine.

Nallienrols in Madras for medical education, facing the challenges of adapting to urban life as a village girl and coping with the campus ragging culture. Struggling with her identity, she takes deliberate steps to shed the "village girl" image by studying English, wearing skirts, wearing makeup and shortening her hair. Nambisan writes, "She felt unlucky to be born in Angheri; her origin stuck to her like a stain" (74). Despite these difficulties, she remains steadfast in achieving her goals. Patriarchal society seeks to dominate women, interfering with their personal choices and limiting their resources, but Nalli resists these pressures.

After completing her medical degree, Nalli moves to London to pursue the Royal College of Surgeons Fellowship (FRCS). There, she faces additional obstacles, including discrimination based on nationality and gender in a colonial context. These challenges test her agency further, yet she overcomes them and refocuses on her vision of serving her village.

Nalli's marginalization persists even after she becomes a doctor, as reflected in her words, "Sir, England is a different country. They ruled us for so long, now they resent us going there as equals" (Nambisan 184). Despite her qualifications, she is denied the opportunity to treat foreign patients, as they prefer only British doctors. Her





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poignant question, “Did my credentials start with being Indian, being Hindu, being a woman, a doctor, or as a rustic?” (Nambisan 201) forces a serious reflection on the intersectional barriers she faces.

Even as a trained surgeon, Nalli struggles to gain support to establish a hospital in her village, Angheri. She temporarily joins Keshavan’s ashram hospital, demonstrating her persistence and agency in continuing her mission to serve the community despite disillusionment and lack of backing. Eventually, she returns to Angheri to fulfil her dream, dedicating herself to improving the health and well-being of her people and making quality healthcare accessible to all.

CONCLUSION

Agency involves a change of mindset and the courage to resist oppression. Feminist agency is not uniform, nor is it always overt or loud. A comparison of the two novels reveals that feminist agency can take multiple forms like assertive, strategic, internal or even purely survival-driven depending on individual circumstances and social constraints. In *Ladies Coupe*, Akhila recognizes her right to define her own happiness and make choices for herself after hearing the stories of the other five women in the compartment. She feels empowered by the freedom to pursue what brings her fulfilment. In *The Hills of Angheri*, Nalli’s determination and revolutionary spirit challenge a conservative society, steering it toward modernity. Both characters reshape traditional practices to suit their personal needs. Through these narratives, Anita Nair and Kavary Nambisan redefine agency as the capacity of women to make conscious choices within patriarchal structures. Their female characters reject the myth of the “superwoman” who effortlessly balances home, career and happiness. Instead, they acknowledge their dissatisfaction and suppressed desires as valid forms of self-assertion and empowerment.

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RESEARCH ARTICLE

Partition Wound: A Psychoanalytic Study of Khadija Mastur's The Women's Courtyard

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ABSTRACT

Khadija Mastur's *The Women's Courtyard* provides a compelling analysis of the psychological effects of the Partition of India from the perspective of women imprisoned in domestic spaces. Khadija Mastur is a writer in Urdu language, and she analyzes the process of border-making and vividly brings into focus the gruesome incidents of the Partition. *The Women's Courtyard*, written by Khadija Mastur, which is considered by some to be a Partition novel, is bolstered in its status as a feminist work. In an exquisite and delicate translation, the English rendering of this book by Daisy Rockwell conveys the elegance and power of Khadija Mastur's distinct writing style. The novel is about a young Muslim girl named Aliya and her family living in the peak period of the Independence of India. The protagonist Aliya speaks for the author Khadija Mastur, and despite all the barriers that might limit her to domestic life, she expresses a positive sense of curiosity. By virtue of these characters who are suffering through the female gender role, the author has been able to illustrate how social oppression occurs through the violence committed in the times of the Indian partition period. *The Women's Courtyard* speaks out from the confines of the courtyard in the setting of the independence struggle. In the present paper, the author will adopt a psychoanalytical approach through which the theories of Sigmund Freud, Jacques Lacan, and Cathy Caruth can be employed to explore themes such as repression, subjectivity, and trauma in the novel. The paper posits that partition is a psychological wound that translates into forms of silence, alienation, and fragmented sense of self as opposed to a mere historical incident. The courtyard represents the symbol of unconscious through which repressed emotions move about.

Keywords: Partition, psychoanalysis, trauma, repression, gender, alienation, silence.





INTRODUCTION

The partition of India in 1947 continues even today to be counted among the most significant events in the history of South Asia due to concerns about violence, migrations, and social transformation. Despite the fact that there is much attention paid to violence in narratives of the partition, *The Women's Courtyard* by Khadija Mastur takes the opposite direction by analyzing the psychology of the event. The novel revolves around the story of Aliya, a girl from a Muslim family who finds her identity in the political conflict as well as in the environment of her family life. In contrast to Saadat Hasan Manto and Bhisham Sahni, Mastur approaches trauma as an internal issue. For this research paper, a qualitative interpretive approach will be adopted based on psychoanalytic literary criticism. The text to be analyzed is Khadija Mastur's *The Women's Courtyard* which has been translated into English by Daisy Rockwell. In this process of qualitative textual analysis, the following methodologies have been adopted to apply literary theories to the primary text as follows: This process of interpretive textual analysis is based on three psychoanalytic models. They are the Freudian concept of repression, the unconscious, and the return of the repressed; the Lacanian idea of subjectivity, the symbolic order, and fragmented identity; and Cathy Caruth's concept of trauma.

The approach used in the study involves close textual analysis of the narrative form and point of view, symbolism (including the role of the courtyard as psychic space), characterization (with an emphasis on conflicts involving Aliya), as well as the theme of silence and psychological tension. Psychoanalytical theories will be applied to analyze various themes, including silence, repressed trauma, and detachment. The study is concerned mostly with the psychological and gender aspects of the Partition as depicted in the novel under review. It does not make a comprehensive historical assessment of Partition, as well as does not include comparative works. The approach used in the research (psychoanalytical theory) is rich in interpretations but lacks cultural context since it stems from the Eurocentric tradition.

Scholars have approached Partition literature differently over time, with initial scholarly analysis focused on political history and contemporary work focusing on aspects of memory, trauma, and gender relations. In *The Other Side of Silence* (1998), Urvashi Butalia emphasizes how the lives of women and their marginalization in patriarchal cultures are an example of silence as part of trauma. Gyanendra Pandey in *Remembering Partition* (2001) suggests that Partition should be interpreted from the perspective of memory and individual experiences. Psychoanalytic criticism focuses on repression and unconsciousness and is rooted in Freudian thought. The French philosopher Jacques Lacan interprets psychoanalysis within a linguistic context.

While Partition literature has been extensively studied, Mastur's text has not received much psychoanalytic consideration. Most existing research on the novel tends to be feminist or historical in nature; nonetheless, the psychological insights provided by the novel make it possible for an alternative approach. In order to fill this void, this article will examine the relationship between psychoanalytic theory and Partition literature by incorporating aspects from both fields. Freudian repression refers to how traumas are buried deep inside the psyche and come out in an indirect manner. Lacanian subjectivity involves fragmentation and structure of the self in language. These theories provide an opportunity to read Mastur's novel through the lens of an indirect expression of trauma via silence, memory, and emotional dislocation.

The Courtyard as Psychic Space

The aangan, in its physical and metaphorical enclosures, shapes the psychology of the women who inhabit it. For instance, Aliya sees the aangan as a place that confines her instead of providing solace. "The walls of the courtyard felt like they were closing in on us, silently watching" (Mastur, 2018, p. 34). Such imagery symbolizes not just physical confinement but also the psychological repression of feelings within the characters' minds. Within Freudian theory, a space such as the aangan acts as a container that encapsulates the contents of the subconscious mind. The characters are unable to express their thoughts and emotions freely and directly in their conversations, and they use circumlocution as an indirect means of doing so.





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Lacanian psychoanalysis further explains this space through its relation to the symbolic order. The women internalize societal norms, engaging in roles that do not align with their desires. The idea that “everything that mattered happened outside these walls, but they were alive inside of us” (p. 52) is one way of understanding the irony in the relationship of internalization and reality.

Partition as Psychological Trauma

Aliya's experience in the courtyard brings out this irony. Even as she is trapped physically, she finds herself affected by occurrences beyond the space. Unlike other forms of partition that include physical violence, psychological violence characterizes this form of separation. This separation leads to uncertainty. “Nothing stayed where it was meant to stay; everything seemed uncertain” (Mastur, 2018, p. 119). This brings out the idea of Cathy Caruth on trauma being about disruption of time and emotion. The characters cannot comprehend their trauma in its entirety as it happens. On the contrary, their trauma surfaces through anxiety and emotional isolation. For Aliya, this emotional isolation is an act of self-defense. She says, “I learned to feel less, for feeling too much became unbearable” (p. 143). The statement perfectly reflects the concept of repression, according to the psychoanalytic theory of Sigmund Freud. Therefore, the Partition is a “wound” that remains alive inside people.

Repression and Female Subjectivity

The subjectivity of Aliya is influenced by her suppression and internal conflicts. Her wants remain unexpressed, limited by societal expectations. Aliya confesses, “There were things that needed saying; the words just failed me” (Mastur, 2018, p. 67). The return of the repressed, which is a Freudian theory, can be witnessed in this statement. Furthermore, the fragmentation of the self, as described by Jacques Lacan, can also be witnessed in the subjectivity of Aliya. She oscillates between submission and rebellion without ever finding an agreement between the two poles. The slow process of attaining autonomy from Aliya is also suggested when she says “perhaps freedom was not granted, but quietly appropriated, inch by inch” (p. 198). Tensions and unresolved conflicts characterize the family in *The Women's Courtyard*. Relations between characters are based on frustration, as well as unsatisfied desires. This type of relationship is explained through psychoanalytic theory that sees it as a result of neurosis caused by the suppression of emotions. Specifically, the character of the mother is described as a product of patriarchal oppression, thus continuing to reproduce the mechanisms of women's oppression. Unstable male power creates additional complications for these relationships.

Silence and the Gendered Nature of Trauma

The motif of silence is one of the main motifs used throughout the novel. It symbolizes both suppression and protest against oppression. Suffering experienced by women occurs silently as a response to the need to endure. In addition, this element acts both as a symptom and coping mechanism in the novel. As Aliya notes: “We spoke of ordinary things, as if the extraordinary had never happened” (Mastur, 2018, p. 156). The above idea resonates well with Cathy Caruth's claims about trauma's irreproducibility. The indescribability of Partition is achieved by using narration gaps and restraint in emotions. Silence is normalized in the phrase, “no one asked questions, because no one expected answers” (p. 162). This illustrates the collective repressed experience of trauma. Trauma is unrepresentable, which leads to the development of indirect ways of representation. In addition, from the feminist approach to understanding Partition, the silencing of women indicates their marginalization in the process of forming families and nations.

The Paradox of Liberation

By disrupting conventional relations, Partition gives women like Aliya some level of autonomy. However, the freedom she has obtained comes with ambivalence since “I was free, but there was no one left to share that freedom with” (Mastur, 2018, p. 210). Hence, independence and solitude become associated in her case as means of self-development and psychological liberation from trauma caused by the experience of Partition. Thus, the psychological effects of Partition remain unresolved for decades, proving its character of a wound.



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CONCLUSION

Khadija Mastur's *"The Women's Courtyard"* reinterprets Partition as a psychological trauma inscribed within the subconscious mind of its survivors. In this novel, psychoanalysis becomes instrumental in uncovering the way in which trauma can be internalized by individuals and subsequently manifested in silence, repression, and the fragmentation of one's sense of self. By focusing on the experience of women, Mastur opens up new vistas to Partition writing, underscoring its personal and gendered aspects.

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RESEARCH ARTICLE

Comparing Human and AI-Generated Communication: Implications for Creativity, Authenticity, and Future Authorship

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ABSTRACT

In the present era of rapid digitalization, the exponential growth of Artificial Intelligence (AI) across sectors has raised critical questions regarding authenticity, employment, and the future of human creativity and communication. With the advent of AI, certain existing jobs may become obsolete, while entirely new roles may emerge. Similarly, concerns arise about the future of literature: will it be dominated by AI-generated content, or will there remain meaningful scope for human creativity? This research paper explores the evolving role of AI in human society, focusing on the differences between human-generated and AI-generated literary works. It examines whether AI functions as a replacement for human creativity or as an enabling tool that enhances human potential. The study ultimately investigates the future relationship between AI and human communication in an increasingly AI-mediated world.

Keywords: human, communication, AI, creativity, digitalization





INTRODUCTION

The landscape of human interaction is undergoing a profound transformation driven by advancements in Artificial Intelligence (AI). At the core of these developments lies Machine Learning (ML), a subset of computational science in which algorithms analyse vast datasets to identify patterns. Combined with Natural Language Processing (NLP)—an interdisciplinary field integrating linguistics and deep learning—AI systems are now capable of performing tasks once considered exclusive to human intelligence. These systems operate through various learning paradigms, including supervised, unsupervised, semi-supervised, and reinforcement learning. The convergence of these approaches has led to the emergence of Generative AI, which can produce novel content by learning from historical data. This evolution marks a shift from Computer-Mediated Communication (CMC) to AI-Mediated Communication (AI-MC). In the CMC era, technology functioned as a passive medium for transmitting human thought. In contrast, AI-MC positions technology as an active agent capable of anticipating user responses through predictive analytics. While this enhances efficiency, it also introduces concerns regarding manipulation of behaviour for commercial or political purposes. The integration of AI into communication also raises ethical challenges. One major concern is “hallucination,” where AI systems generate inaccurate or fabricated information with high confidence. Due to their human-like tone, such outputs may be perceived as credible. Moreover, while AI may not threaten purely artistic creativity, it poses significant challenges to professional creativity in fields such as technical writing, journalism, and design. Although AI enhances efficiency, AI-generated communication often lacks the emotional depth, contextual nuance, and lived experience that define authentic human expression.

LITERATURE REVIEW

The study of digital communication has evolved significantly from viewing technology as a passive tool to recognising it as an active participant in human interaction. Traditionally, Computer-Mediated Communication (CMC) was understood as a conduit facilitating human exchange across distances. However, recent advancements in Artificial Intelligence have led to the emergence of Human-Machine Communication (HMC), where machines are no longer mere intermediaries but communicative agents (Guzman & Lewis, 2020; Gunkel, 2020). In this paradigm, AI systems function as interactive partners capable of generating language that closely resembles human expression. This shift challenges conventional notions of authorship, agency, and communication dynamics. Despite these advancements, the extent to which AI can replicate human cognition remains a subject of debate. Marcus and Davis (2020) argue that AI systems exhibit “computational mimicry” rather than genuine understanding, as they manipulate symbols without possessing experiential or social grounding. This distinction highlights a fundamental divide between human creativity, which is rooted in lived experience, and machine-generated output, which is data-driven.

From an economic perspective, generative AI tools have been recognised for enhancing productivity and efficiency (Brynjolfsson et al., 2023). However, this efficiency introduces the risk of linguistic homogenization. As AI systems prioritise probabilistic word selection, they tend to produce standardized outputs, potentially diminishing individual voice and stylistic diversity. Ethical concerns further complicate the integration of AI into communication practices. Floridi (2023) introduces the concept of “artificial reliability,” where AI-generated content appears credible despite potential inaccuracies. This concern is reinforced by studies on AI hallucinations (Ji et al., 2023), which demonstrate how systems may produce factually incorrect information while maintaining a convincing tone. Such tendencies pose significant risks to trust and integrity in academic and professional communication. While existing literature extensively addresses the technical and economic dimensions of AI, there remains a notable gap in understanding its psychological and emotional implications. In particular, the impact of AI-Mediated Communication (AI-MC) on human creativity, emotional depth, and identity formation has received limited attention. Current research often prioritises efficiency and output quality, overlooking the interpersonal and experiential costs of delegating communication to algorithms. This study seeks to address this gap by examining whether the increasing reliance on





AI-generated communication leads to the erosion of creative agency and emotional authenticity in human expression.

METHODOLOGY

This study adopts a mixed-methods approach, combining qualitative textual analysis with quantitative survey data to examine differences between human-generated and AI-generated communication.

Research Design

A comparative research design was employed to analyse variations in linguistic style, emotional depth, and structural patterns between human-authored texts and AI-generated content.

Data Collection

a) Human Literary Samples

Selected texts from established authors such as William Shakespeare, Jane Austen, and T.S. Eliot were used as representative samples of human creativity. These works were chosen due to their richness in emotional expression, thematic depth, and stylistic variation.

AI-Generated Samples

AI-generated texts were produced using contemporary generative AI tools (e.g., GPT and Gemini), based on prompts designed to replicate literary and explanatory writing styles.

Survey Data

A structured survey was conducted among 50 engineering students to capture perceptions of AI-generated communication. The survey included Likert-scale and descriptive questions focusing on:

- Authenticity
- Emotional depth
- Readability
- Personal connection

Evaluation Criteria

The collected data was analysed using the following parameters:

- Lexical Diversity – vocabulary richness and variation
- Sentence Structure – variation in sentence length and rhythm
- Emotional Sentiment – depth and complexity of emotional expression
- Reliability – factual accuracy and coherence

Data Analysis

- Qualitative Analysis was used to interpret stylistic and emotional differences between human and AI-generated texts.
- Comparative Analysis was conducted to identify patterns across both datasets
- Quantitative Analysis of survey responses was used to measure student perceptions, expressed in percentages.

Limitations

This study is limited by:

- A relatively small sample size (50 participants)
- Restricted selection of literary texts
- Dependence on specific AI tools, which may evolve over time





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RESULTS AND FINDINGS

This study presents a comparative analysis of human-authored literary texts and AI-generated content, supported by survey data collected from 50 engineering students. The findings reveal clear distinctions in linguistic expression, emotional depth, structural organization, and user perception.

Comparative Textual Analysis

The comparison between human and AI-generated texts was conducted based on four key parameters: lexical diversity, sentence variation, emotional sentiment, and reliability.

Interpretation of Table 1

The analysis indicates that human-authored texts demonstrate greater **linguistic richness and expressive variability**, while AI-generated texts emphasize **clarity, consistency, and structural coherence**.

Human writing reflects cultural context and individual identity, whereas AI-generated content tends to produce standardized outputs optimized for readability. Furthermore, emotional expression in human writing is complex and layered, while AI-generated content remains relatively neutral and simplified.

A notable limitation of AI-generated text is its susceptibility to **hallucination**, where information may appear credible but lacks factual accuracy.

Quantitative Evaluation

To further support the qualitative findings, both human and AI-generated texts were evaluated using a scoring framework

Interpretation of Table 2

The quantitative results reveal that AI-generated text outperforms human writing in **structural coherence and organization**. However, human writing significantly exceeds AI in **lexical diversity, emotional depth, and authorial voice**.

This demonstrates that while AI is effective in enhancing clarity and structure, it lacks the ability to replicate the individuality and emotional richness inherent in human expression.

Survey Findings (Student Perception)

The perception of AI-generated communication was analysed through a survey conducted among 50 engineering students.

The results indicate that:

- 78% of students perceived AI-generated text as *robotic or overly polished*
- 72% reported a lack of personal connection in AI-generated responses
- 68% preferred using AI for editing and structuring rather than content creation
- 81% found human-authored content more emotionally engaging

Interpretation of Survey Results

The survey findings suggest that while students recognize the usefulness of AI for improving clarity and efficiency, they remain sceptical about its ability to convey authenticity and emotional depth.

AI is primarily viewed as a supportive tool, rather than a replacement for human creativity.

Overall Findings

Based on the combined analysis, the following key findings emerge:

1. Human writing excels in creativity, emotional depth, and individuality, driven by lived experience and cultural context.



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2. AI-generated content demonstrates strength in structure, coherence, and efficiency, making it suitable for technical and formal communication.
3. AI introduces a standardizing effect, which may lead to the reduction of stylistic diversity and personal voice.
4. Users prefer a hybrid approach, where AI is used as an assistive tool rather than a primary creator.

DISCUSSION

The findings of this study reinforce the evolving understanding that Artificial Intelligence (AI) is transforming communication not as a replacement for human creativity, but as a complementary force. The comparative analysis demonstrates that AI-generated content excels in structural coherence and efficiency, whereas human-authored texts retain superiority in emotional depth, lexical richness, and authorial voice. These results align with the concept of Human-Machine Communication (HMC) proposed by Guzman and Lewis (2020), where AI functions as a communicative agent rather than a passive medium. However, the present study extends this perspective by highlighting the limitations of AI in replicating experiential and emotional dimensions of communication.

The findings also support Marcus and Davis (2020), who argue that AI exhibits “computational mimicry” rather than genuine understanding. While AI systems can generate linguistically accurate content, they lack the lived experience necessary to produce authentic emotional expression. This limitation is particularly evident in the observed “emotional flattening” of AI-generated texts. From an economic and functional perspective, the results are consistent with Brynjolfsson et al. (2023), which identify AI as a productivity-enhancing tool. The high score of AI in structural coherence confirms its effectiveness in organizing and refining communication. However, this efficiency introduces the risk of “linguistic homogenization,” where unique writing styles are replaced by standardized outputs. The issue of reliability further complicates AI integration. The presence of hallucinations in AI-generated content supports the concerns raised by Ji et al. (2023) and Floridi (2023) regarding “artificial reliability.” The ability of AI to produce convincing yet inaccurate information poses significant challenges for academic integrity and professional communication. Importantly, the survey findings provide a human-centered perspective. The majority of students perceived AI-generated content as lacking authenticity and emotional connection, reinforcing the argument that communication is not merely a functional process but also an experiential and relational one. Overall, the study suggests that the future of communication lies in hybrid authorship, where AI supports human expression without replacing it. AI is most effective when used for structuring and refining ideas, while humans remain central to generating meaning, emotion, and originality.

CONCLUSION

This study set out to examine the evolving relationship between human creativity and Artificial Intelligence in the context of communication. The findings clearly indicate that while AI has made significant advancements in generating structured and coherent content, it cannot replicate the depth, authenticity, and emotional complexity inherent in human expression. AI-generated communication, although efficient and accessible, tends to produce standardized outputs that may diminish individuality and cultural nuance. In contrast, human-authored texts remain deeply rooted in lived experience, enabling richer emotional engagement and creative diversity. The study highlights that the role of AI should not be viewed as a replacement for human creativity, but rather as an enabling tool that enhances productivity and supports the communication process. The concept of Augmented Intelligence emerges as a sustainable model, where humans retain control over intellectual and creative content while leveraging AI for efficiency. In conclusion, the future of communication will not be defined by competition between humans and AI, but by collaboration, where technological capabilities and human creativity coexist to produce more effective and meaningful communication.





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Table 1: Comparative Analysis of Human and AI-Generated Texts

Evaluated Metric	Human Literary Sample	AI-Generated Sample	Commentary
Lexical Diversity	Rich, context-specific vocabulary with idiomatic expressions (e.g., Shakespeare's "wherefore" or Austen's "countenance").	Vocabulary optimized for clarity and general comprehension.	Human writing reflects cultural depth; AI prioritizes readability.
Sentence Variation	Dynamic structure with varied sentence lengths and rhythms.	Uniform and balanced sentence structures.	Humans use variation for emphasis; AI maintains consistency.
Emotional Sentiment	Multilayered emotional expression (irony, ambiguity, intensity).	Predominantly neutral or positively biased tone.	AI lacks emotional depth due to the absence of lived experience.
Hallucination Rate	Grounded in contextual and experiential knowledge.	Occasional factual inconsistencies (hallucinations).	AI prioritizes plausibility over factual certainty.

Table 2: Quantitative Comparison of Human vs. AI Writing

Metric	Human Writing	AI Writing
Lexical Diversity	9.1	6.8
Sentence Variation	9.3	7.2
Emotional Depth	9.5	5.1
Structural Coherence	7.8	9.2
Authorial Voice	9.4	4.5

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RESEARCH ARTICLE

Reading Against Ourselves: Cognitive Dissonance, Moral Complicity, and Bio-Capitalism in Paolo Bacigalupi's *The Windup Girl*

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ABSTRACT

The paper will discuss *The Windup Girl* (2009) by Paolo Bacigalupi in terms of moral psychology by stating that the novel creates cognitive dissonance in a systematic manner, which has been used to disturb the ethical certainties of the readers. Placed in a future, created as a result of genetic engineering, corporate seed monopolies and environmental destruction, the story creates a world that adheres to bio-capitalism and engineered scarcity. The novel instead lacks a firm division of morality, spreading the use of complicity throughout corporations, state actors, black-market dealers, and those on the fringes. This spreading of responsibility creates psychological tensions because the readers have to face the distorted lines between victimization and involvement. Using cognitive dissonance theory, the paper will discuss how the text plays with the moral alignment. Characters defend predatory systems because they need to survive, be secure, or make progress, and are also the ones exposing how structural violence the systems perpetuate. The character of Emiko, the windup girl, makes the ethical instability even stronger by blurring the line between human life and a manufactured one. The readers are placed in conflicting moral frames that cannot be reconciled and make them reflect on the consumption, biotechnology domination and ecological apathy. This paper claims that the dystopia created by Bacigalupi works as not only a cautionary speculation but, in fact, a psychological experiment of discomfort. Through the enactment of contradictions between belief and action, empathy and self-interest, the novel forces the readers to acknowledge their own involvement in the global systems of extraction and scarcity. Climate dystopia, therefore, comes forward as a place in which moral thought is induced by dissonance instead of instructive certitude.

Keywords: Cognitive dissonance, Climate dystopia, Bio-capitalism, Moral psychology, Ethical ambiguity



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INTRODUCTION

Climate dystopia has become a key thread of twenty-first-century speculative fiction, in response to the intensifying ecological instability, biotechnology and corporate integration of the systems of life. In this discipline, the discourses are becoming more and more indicative of not only the ecological breakdown but also the emotional and ethical fabrications that come with such a breakdown. The *Windup Girl* by Paolo Bacigalupi shows the future that is monopolized by calories, genetics and artificial scarcity; the ecological crisis in the context of bio-capitalist regimes [3]. Instead of creating a naive dichotomy between the offenders and the victims, the novel disperses the blame among corporations, state authorities, merchants, refugees, and artificial life. The diffusion creates a story world where ethics are undermined. Interdisciplinary engagement with affect theory, new materialism and cognitive approaches to narrative has become the focus of such instability so that the same ethical ambiguity can operate both at the textual and the readerly level. The collective feeling shared by Ahmed emphasizes that emotions spread socially, and it is the collective impressions that make a person ethically oriented, not the personal thinking [1]. Likewise, Anderson understands affect as being distributed between bodies, environments and infrastructures and not being in individuals [2]. Such distributed affect is particularly acute in climate dystopia. Ethical conflicts of bio-capitalism are not the prerogative of character psychology, but they permeate markets, food systems and urban spaces. These tensions are fueled in the staging of *The Windup Girl* in a Bangkok under the threat of rising waters and corporate control of seed, entwined in material conditions as well as in the abstract principle [3]. The new materialism also theorizes these tensions. The concept of material-discursive entanglement by Barad criticizes the strict separation between matter and meaning and highlights the importance of relational intra-actions as agencies are formed [4]. Coole and Frost also anticipate the significance and the vitality of material processes [10]. Backgrounds, in place of active forces as to ethical possibility, in Bacigalupi's novel, are seeds, plagues, genetically modified bodies [3]. Material ecocriticism builds upon this understanding by considering matter as narratively expressive, and hence able to express ecological violence and systemic injustice [13]. In that sense, bio-capitalist scarcity is not merely an empirical issue of thematic interest, but a structuring fact which defines the way moral perception is formed.

In addition to these materialist methodologies, cognitive and enactive narratology approaches provide methods of explaining how ethical ambiguity influences the reader. The narrative worlds presented by Gergig accentuate the point that a reader psychologically transports to the story worlds where events happen through imagination projection [11]. The fact that immersion can transform beliefs and attitudes further is proposed by Green and Brock's idea of narrative transportation, which proposes that, by engaging in immersion, counter-argumentation is prevented [12]. Such transportation can create not moral reassurance but dissonance in the dystopian fiction. As recognition changes between ethically corrupt characters, the readers are placed in opposing judgmental structures. The experience is perhaps less about taking a definite ethical position and more about bargaining against discomfort [6]. This analysis is further enhanced by the enactivist approach of narratives put forward by Caracciolo, which focuses on experience and embodied reconstruction [6]. He claims that narrative space is recreated by the imaginative involvement of the reader, which entails affective and sensorimotor activity [5]. This field of experience is informed by mood, point of view, and focalization, and either leads the reader near or away empathy [7]. The intermingling focalization on Anderson Lake, Emiko, Hock Seng, and Jaidee as applied in *The Windup Girl* results in the creation of wavering ethical alliances [3]. Both characters make their rationalizations based on their survival, loyalty or corporate responsibility. These justifications welcome tentative insight despite the way they reveal structural violence. It is when the reader experiences the embodied process of these changes of heart that the psychological tension is created.

This is also explained by emotion theory. The enactive view of emotion proposed by Colombetti puts it in the context of bodily interaction, engagement with the environment [8]. In contrast, the dynamic co-constitution of affect and cognition is highlighted by Colombetti and Thompson [9]. The morality of stories is therefore generated not through dispassionate thinking but through passionate evaluation. The degradation of Emiko, the business choices of



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Anderson Lake, and the nationalistic passions of Jaidee produce intuitive responses that coincide with reasoning [3]. This embodied ambivalence is exacerbated by the fact that moral categories are not stabilized in the novel, although the ecocritical and political-economic interpretations of the novel have been abundantly developed. The particular processes by which narrative form brings psychological discomfort to readers have received little focus. Kortekallio anticipates that an anthropocentric norm is destabilized by the contemporary speculative fiction through his work on mutant stories and ecological science fiction, which operates on the assumption of the alteration of the anthropocentric bodily experientiality of readerhood [14]. However, the issue of cognitive dissonance as an organizing dynamic has not been studied in depth. Although ecocriticism usually focuses on the environmental representation and political commentary, it has not always focused on how the readers are situated in the opposing moral framework. This paper thus fills a major gap. The *Windup Girl* has been discussed as a criticism of neoliberal biotechnology and global capitalism. Yet, the emphasis has been on this too little.

In contrast, the nature of the narrative strategies forming the backbone of this work produces ethical instability at the level of the reading experience. The novel creates a conflict between sympathy and condemnation by spreading out the complicity and denying a moral judgment. Characters justify exploitative systems as important to survive or move on, and simultaneously, the narrative exposes the systemic damage that those systems are causing [3]. This tension corresponds to the observation of the cognitive dissonance theory, according to which contradictory beliefs and actions create a state of psychological uneasiness that will have to be addressed. Instead of providing a resolution, however, Bacigalupi maintains contradiction in his dystopia. The main questions that regulate this inquiry are thus: How does *The Windup Girl* create cognitive dissonance on the level of character and reader? How does bio-capitalist scarcity organize the moral compromising? What are the disruptions that ethical ambiguity causes in the firm's moral alignment? And is climate dystopia a moral experiment in discomposure? By uniting affect theory, enactivist narrative theory, and material ecocriticism, the given paper holds that the novel in question serves not only as an attempt at speculative foretelling but also as an experience device. By means of distributed agency and focalization and embodied engagements, the text locates the readers in ethically ambiguous situations where belief, sympathy, and judgment come into conflict. Climate dystopia is, therefore, a venue where ethical thinking is provoked not by moral clarity but by dissonance maintained.

METHODS

The proposed study uses a qualitative and theoretically integrative approach aimed at analyzing the way attachment of moral discomfort to the narrative structure in *The Windup Girl* is created. The methodology is based on cognitive literary research, enactivist philosophy, phenomenology of mood and posthuman material thinking. Instead of seeing the novel as a clear manifestation of the ecological crisis, the approach examines the process of readerly engagement as a dynamical process that is determined through embodied simulation, environmental sensitivity, and affective instability. It is not an empirical aim but an interpretive one: to clarify how the form of a narrative creates the conditions of cognitive dissonance without subjecting fiction to psychological experiment. The reading material is Paolo Bacigalupi, *The Windup Girl* [3], and the focus of the analysis is made up of scenes that pre-empt bodily vulnerability, environmental precarity, and moral compromise. These are sequences that illustrate the humiliation of Emiko in public and her limited embodiment, corporate rationalizations of Anderson Lake, nationalist imposition of trade boundaries by Jaidee, and the flooding of the city of Bangkok as the climax. The rationale behind the choice of these narrative sites lies in the fact that they enact ethical conflict in terms of material spaces designed by scarcity and biotechnological disciplines. The methodology is not a chronological presence in the novel. Still, it isolates nodal points, where there is an ethical justification, bodily exposure and environmental instability, converging.

The theoretical basis of the methodology is the account of the cascades of cognition in an embodied reader [15]. This means that under this framework, the readers create expectations that are constantly updated in regard to the narrative developments. This dynamic offers the perspective through which the change in ethical alignment in the novel can be analyzed. Predictive models of moral judgment are brought to their knees as the reader is introduced to



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opposing rationalizations and contradictory views. This interpretation strategy is thus followed through analysis of the instances in which the narrative point of view, the storytelling, beckons tentative sympathy and then breaks it. The work by Kuzmicova regarding presence in literary reading continues to inform this interpretive practice by highlighting the crucial roles of motor enactment and the spatial reconstruction as the main components of the narrative experience [16]. Descriptive text used in *The Windup Girl* is analyzed in its own ability to produce the desired sensorimotor images, especially in such instances as the heat, the crowd, or the physical susceptibility. The approach presupposes that these images enhance emotional appeal and increase moral risks. Moral ambiguity is something that will be experienced when readers imaginatively enter the worlds of scarcity or humiliation. The subsequent investigation of the physical situatedness of reading by Kuzmicova thereby highlights the interaction of the narrative environment with the embodied perception [17]. Even though physical states of reading are not measured in this study, it embraces the theoretical understanding that the narrative space is a field of experience that defines evaluative reaction.

Another dimension to the methodology is posthuman phenomenology. The entangled nature of the body as described by Neimanis in relation to the ecological systems prefigures the permeable nature of the human and nonhuman material [18]. According to this view, water, disease and genetic modification in the text by Bacigalupi are put into play as powers of conditioning ethical possibility. The material space of Bangkok is therefore not seen as the backdrop setting but as an active participant in the narrative meaning. In this regard, the approach is consistent with the enactivist philosophy proposed by Noë, who claims that perception is based on active-oriented participation, but not passive representation [19]. This perspective, when applied to literary interpretation, redefines reading as a form of exploratory moral tourism. The resulting ethics of discomfort in the active navigation through conflicting frames of evaluation, instead of passive reflection, is further developed in the idea of the double vision of fiction by Polvinen [20], whereby this idea is used to develop a more analytical perspective on the circumstance of reading. The paper thus takes care of those instances in which the readers are asked to side with a morally compromised, and at the same time acknowledge structural injustice. This swing between immersion and critique is considered one of the central mechanisms of the analogical performance of cognitive dissonance. Narrative form keeps the tension that is not resolved in the stable moral hierarchy. Phenomenology of mood gives the ultimate theoretical stratum of the methodology. Ratcliffe also views mood as a background orientation that realizes the field of significance on which judgments are made [21]. The endless effect of heat, decay, and looming downfall, in the case of *The Windup Girl*, acts as an orientation. The approach thus examines how environmental circumstances determine an affective grounding, which defines the choices made by characters and the interpretations of the reader. The discussion of mood patterns affected by environment presented by Rohan and Rough proves the more general statement that the conditions of climate do moderate the affective states [22]. Even though their interest lies in the clinical, the conceptual acumen that the rhythms in the environment determine emotional orientation enhances the interpretation of the repressive climatic setting of the novel. Close reading is used to determine the passages of the explicit moral justification and change in the narrative alignment. Linguistic indications of necessity and inevitability, and survival logic are investigated to follow the logic of complicity rationalization of characters in bio-capitalist systems. These textual results are then viewed from the perspective of embodied presence and gauging the way of descriptive detail to recruit sensorimotor imagery and increase affective responsiveness. Lastly, there is the enduring mood of ecological precarity, which is assessed as a structuring condition influencing interpretive orientation. The integration of these approaches is summarized in Table 1.

The logic behind such a methodological set-up is based on the assumption that literature is a form of experience where ethical conflict will be acted out, but not purely presented. The combination of embodied cognition, phenomenology of mood, and posthuman ecological thought enables the method to capture the affective and evaluative instability generated by narrative environments. The strategy does not resort to reductionism by considering psychological theory as an analogical resource instead of an empirical assertion. In this interdisciplinary approach, *The Windup Girl* is explored as a place where bio-capitalist scarcity and ecological precarity create the perpetuated moral tension at both the character and reader levels.



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RESULTS

Through the analysis, it is evident that *The Windup Girl* creates moral discomfort not just by plot events but by multifaceted affective and embodied processes that also coincide with the social affect, attention, and enactive cognition theories. Instead of using the ethical conflict as a direct debate, the novel creates an atmosphere of tension distributed and existing on the lower level of expressed judgment. The findings indicate that this tension is created by three processes that are interrelated and that include the circulation of social affect through networks of scarcity, the modulation of attention and background experience in the perception of the reader, and destabilized anthropocentric moral structures through posthuman affect. In the description of social affect, Seyfert argues that affective intensities circulate within the social systems and can not be reduced to personal feeling [23]. Fear of contagion, economic anxiety, and nationalist hostility in Bangkok are collective moods and not individual responses, as the author, Bacigalupi, employs them. The calorie companies, the environmental ministries, and the refugee populations have an effective economy in common, which is organized as a Scarcity. This spread effect determines moral logic by making suspicion normal and defensive aggression right. The use of violence and exploitation is justified as a safeguarding measure by the characters in an already highly charged environment. Ethical instability, as can be seen in the novel, is therefore not due to an abrupt emotional outburst but rather due to a long-term social mood of precarity. The reader is exposed to this atmosphere as permeating the novel and not intermittent, creating an uncomfortable experience that serves to represent systemic involvement as opposed to personal moral deficits. Second, the findings reveal that the novel deploys the reader's attention in a manner that compares to philosophical explanations of background experience. Schwitzgebel's thoughts about the concept of attention and the unnoticed tactile experience point to the fact that much of lived experience exists outside of the focal awareness [24]. Translated into the analysis of narrative, this observation explains the functionality of the environmental details of the novel. The repressive heat, the surging water, and the artificial plagues are often kept in the background of the story as the political intrigue takes up the foreground. However, it is these environmental factors that keep on influencing interpretation. Ecological references are not necessarily something that readers pay conscious attention to, yet the overall effect preconditions evaluative response. Scarcity is a tacit frame that justifies compromise. Moral dissonance can thus arise in part because of the conflict between the explicitly considered and the ambient.

This foreground and the background interaction conforms to the enactive theories of cognition. The biological and phenomenological process of mind as described by Thompson underlines the fact that cognition occurs as a result of embodied interaction with the environment [25]. Varela, Thompson, and Rosch are more or less of the same opinion that knowledge is practiced in terms of structural coupling between organism and world [26]. The characters in the novel do not discuss abstract ethical principles that are not connected to material conditions. Their choices are played out in the context of immediate body and setting limitations. Corporate strategies of Anderson Lake are influenced by the disease epidemics and seed monopolies, and the vulnerability of Emiko is encoded into her artificial physiology. The circumstances of the embodiment cannot be separated from the ethical reasoning. It is the reader who, in turn, acts by bringing understanding through imaginatively playing out of these confined positions. Moral uneasiness comes when the reader makes simulated decisions in the face of pressure, realizing that judgment is not easily divorced from its survival circumstances.

The discussion also indicates that the novel upsets anthropocentric ethical structures with posthuman affect. The idea of posthuman affect by Vermeulen emphasizes the shift in human-centered emotional disposition in modern literature [27]. In *The Windup Girl*, the stable categories of human and nonhuman are broken by genetically modified organisms, viral plagues and bioengineered bodies. The fact that Emiko is a manufactured, yet sentient being, questions the traditional compassion. The readers might not fail to react to her humiliating moment with defensive anger, but her commodification as an object makes this reaction complicated. The writing does not entirely incorporate her into the human identity and does not deprive her of the human experience. Such ambivalence increases dissonance. Ethical consideration should address hybrid versions of life, which are opposed to inherited moral patterns. This destabilization is increased with social affect. According to the theory proposed by Seyfert, the



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affective intensities might be higher than the conscious interpretation, and they determine the collective orientation without any direct expression [23]. It is not enough that the aggression towards Emiko is perpetuated with the help of rational argumentation, but also through the spread of disgust and fear. These influences are social controls that strengthen hierarchies of the bio-capitalist order. The interaction of the reader with these dynamics proves that ethical boundaries are created or even created effectively, not logically. Uncomfort is caused by the realization of being a part of the like affective economies outside of the text.

The theory of attention also explains the process of this discomfort. The discussion of unnoticed experience by Schwitzgebel suggests that awareness is partial and unstable [24]. The shifting focalization of the novel redirects the attention of the readers to the various moral frames at the expense of some others. As a narrative direction shifts away to the calculating of corporations to the suffering of the body, violence that was assumed as a background in the narrative is brought to the fore as a foreground. The wavering of the focus is reflective of the lack of moral conviction. There are cases when the evaluation has to be reset by the readers after each new detail on the experience is revealed. Enactive philosophy expands on this description through the focus on relational interdependence. Bio-phenomenology by Thompson and embodied action by Varela and others put cognition in terms of emergent in organism-environment interaction [25] and embodied action in terms of knowledge [26]. Ethical positions in the novel form as a result of relational mirroring in food systems, water networks and genetic manipulation. The symbolic device of the flood that overcomes the city of Bangkok is a material force that restructures the social hierarchies. The reader feels this restructuring as structural dislocation and not narrative convenience. Moral dissonance is, therefore, demonstrative of changing relational structures other than a solitary character flaw.

The result of these processes is perpetuated ethical instability. In Posthuman affect as explained by Vermeulen, entanglement and vulnerability outside the human subject are resistant to closure by foregrounding [27]. The last scenes of the novel fail to bring about moral sanity. They instead heighten the reality of systemic vulnerability. Social affects are in circulation, the pressures of the environmental landscape are still in place, and the hybrid life forms are still precarious. The reader is not given any safe moral resolution. Collectively, the outcomes prove that *The Windup Girl* creates cognitive dissonance by practicing embodied interactions with social and material systems. Distributed affect normalizes compromise, environmental background forces control attention, and posthuman entanglement introduces instability in anthropocentric ethics. The novel is an experiential practice where the reader plays a game of moral reasoning in restriction. Instead of providing pedagogical teaching, it maintains a conflict between sympathy and criticism. This internal conflict is one of the ways climate dystopia may serve as an experimental space to investigate the affective and embodied principles of moral judgment.

DISCUSSION

The conclusions of this paper indicate that *The Windup Girl* must not be viewed as a piece of hypothetical critique of bio-capitalism, but rather as an embodied system of instability, which enacts ethical instability by way of embodied and attentional relations. The novel mobilizes enactive and phenomenological cognition by foregrounding ecological insecurity, hybrid subjectivity and systemic scarcity. The moral discomfort in the text is not caused by abstract ideological conflict per se, but by the involvement of the reader in changes of fields of attention, embodiment simulation and relationship entanglement.

The author offers a fruitful framework for understanding the ethical order of the novel by analyzing the background experience of Schwitzgebel. The fact that he says that much of conscious life functions beyond focal attention upsets the belief that moral awareness is continuous and transparent [24]. Ecological degradation, engineered disease, and infrastructural collapse have been used as an ambient condition, as opposed to a dramatic focus, in *The Windup Girl*. They exist almost in every scene, though not necessarily premeditated in thought. This is a narrative approach that is similar to the fact that Schwitzgebel points out that even invisible aspects of the experience can influence the orientation and judgment. The neediness and environmental disruption turn into the equivalent of the unrecognized



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sense of touch in his example: constantly training action, and at the same time, existing partly outside conscious perception. The moral unease of the reader is thereby the comprehension of the background forces that have arranged the compromise of ethics, even without making any noise.

The figure proposes a stratified conceptual framework whereby embodied moral dissonance is placed within concentric cells of cognitive as well as affective processing. The deepest field is the foreground's background attention, which is the pre-reflective field of experience. The second level is enactive cognition, which puts focus on the organism-environment interaction of meaning-making. At the third layer, structural coupling is the dynamic interaction between body, world and narrative environment. These processes are placed in the outermost ring and thus positioned in the posthuman affect where ethical response is not based on anthropocentrism. The concentric form shows that there is an integration instead of hierarchy, pointing out that moral dissonance is created by a recursive interaction between embodied, cognitive, and affective systems.

This relationship is more evident in the description of cognition as embodied and relational, presented by Thompson [25]. Thompson states that the mind is not a detached processor of representations but an emergent process based on biological and phenomenological involvement with the environment. This view applied to the dystopia of *Bacigalupi* is that the moral choices of characters cannot be seen outside of the entanglement that they possess with food systems, disease ecologies and political infrastructures. The abstractability of the corporate calculations of Anderson Lake, such as those, is not independent of the material conditions of resistance to the plague and seed monopolies. The physically engineered vulnerability of Emiko is marked on her own physiology. Balancing of ethical reasoning in the novel is thus performed within limited material relations.

This relational structure is reflected in the interest of the reader. Cognition, according to Varela, Thompson, and Rosch, is the result of structural coupling between the organism and the world as opposed to being detached contemplation [26]. Reading is a performed experiment of limited possibilities. The moral aspect of the novel is not seen in the exterior but explored in the creative simulation. As the readers shift positions of relationality when assuming various positions, such as corporate agent, engineered being, nationalist enforcer, they are engaging in changes of relational positioning. The reason that makes moral judgment unstable is that it is dependent on the embodied standpoint based on which it emerges. The unease created by the narrative is therefore an expression of the fluidity of the performed point of view as opposed to mere confusion about what is right and what is wrong.

This instability of relations overlaps with the description by Vermeulen of the posthuman affect that focuses on the destabilization of solid human-based emotional patterns in modern literature [27]. By making the engineered bodies and genetically modified organisms the main protagonists of its moral field, the *Windup Girl* challenges the anthropocentric assumptions. The life of Emiko defies inherited gender divisions of compassion and moral duty or responsibility. The audience can first react to her misery with the more common humanitarian interest, but she is a manufactured commodity, which makes this reaction more complicated. Posthuman affect disrupts moral recognition. What makes the discomfort is that ethical norms do not fade away, but there is an insufficiency in handling hybrid forms of life. Combined, these theoretical approaches explain why the novel is so powerful because it is able to maintain unresolved tension. The focus on shifting attention, as highlighted by Schwitzgebel, highlights the way ecological forces in the background slowly creep into focal awareness [24]. The enactive framework proposed by Thompson puts ethical deliberations in the context of embodied constraint [25]. According to the description by Varela and others of structural coupling, moral navigation is participatory in nature [26]. The posthuman affect of Vermeulen demonstrates the manner in which the hybrid subjectivities of the anthropocentric empathy become unstable [27]. These dynamics intersect to create a type of cognitive dissonance that is more of an experience than a theoretical idea.

Notably, the novel does not solve this dissonance by moral elucidation. Rather, it leaves the reader in an instability of relations. The last sequences make more people conscious of systemic weakness instead of being redemptive. The forces of the environment are still defining the social organization, hybrid bodies are still vulnerable, and corporate





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logic still exists. Ethical reflection is not a decision that is made but rather a continuous process. This argument thus redefines climate dystopia as a platform where embodied cognition and posthuman affect meet to disturb moral certitude. Instead of being a warning allegory on its own, *The Windup Girl* is more of a laboratory experiment to explore the process of the creation of ethical judgment through the intertwined relationships between bodies, infrastructures, and environments. Its painful effect can no longer be seen as a failure of narrative sense but rather as a deliberate revelation of the restrictions of anthropocentric ethical systems in the circumstances of ecological crisis.

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Table 1. Interdisciplinary Methodological Integration

Theoretical Domain	Core Concept	Analytical Application	Interpretive Function
Embodied Cognition	Predictive cascades	Tracking shifts in ethical expectation	Models readerly dissonance
Motor Enactment	Sensorimotor simulation	Analysis of bodily and environmental description	Intensifies moral immediacy
Situated Narrative	Environmental framing	Bangkok as an experiential field	Structuring ethical perception
Posthuman Phenomenology	Bodily entanglement	Agency of water, disease, and genetics	Destabilizes anthropocentrism
Enactive Perception	Action-based cognition	Participatory reading dynamics	Frame's moral navigation
Double Vision	Immersion and critique	Empathy–distance oscillation	Sustains ethical instability
Mood Theory	Background attunement	Climate-induced atmosphere	Conditions evaluative stance
Environmental Affect	Climate–affect linkage	Heat and scarcity as pressure	Amplifies discomfort

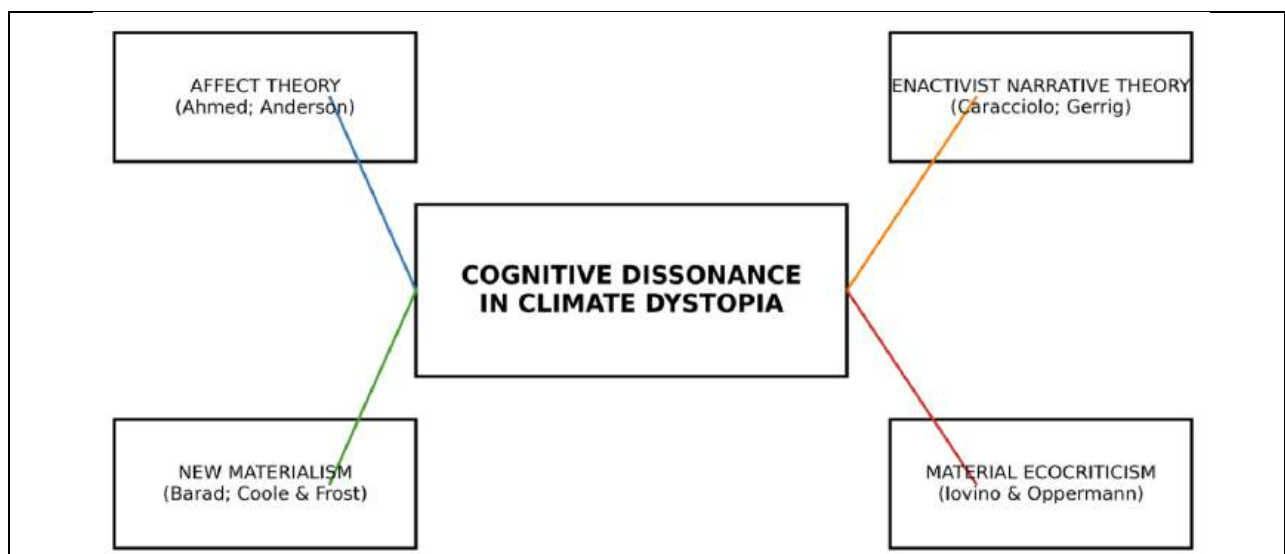
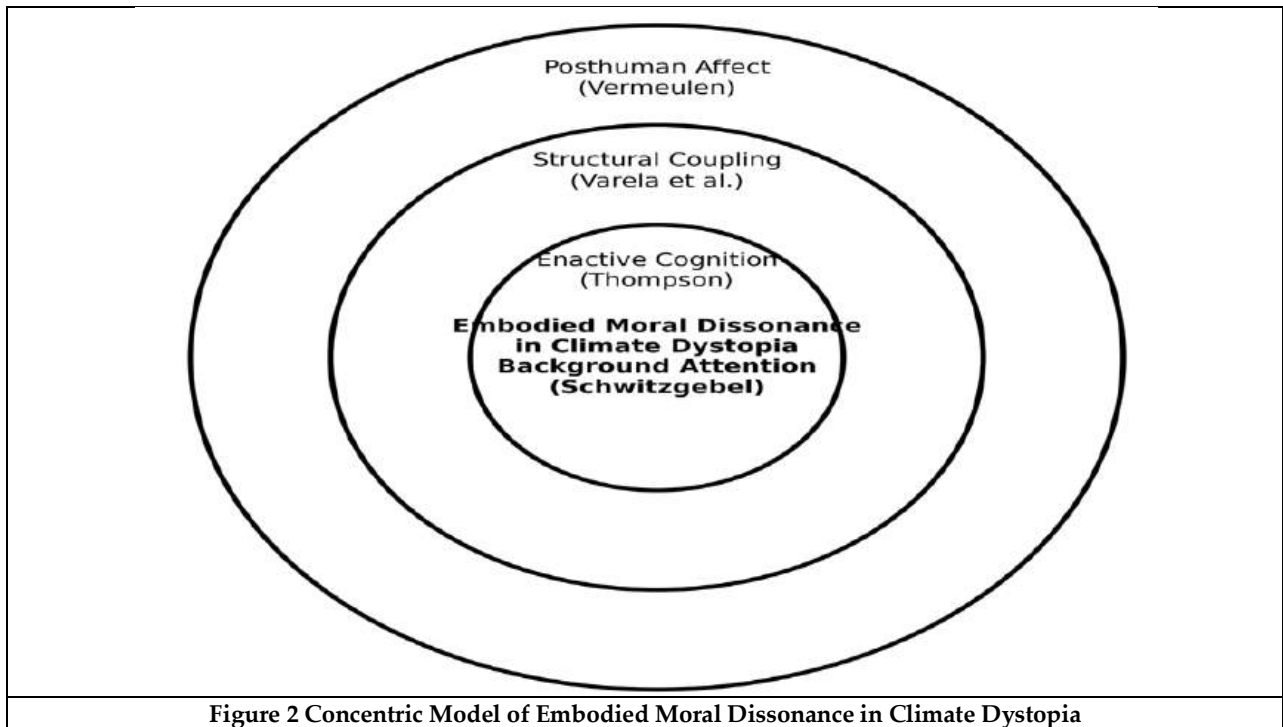


Fig 1 Theoretical Integration





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RESEARCH ARTICLE

A Freudian Reading of Trisha Raje's Character Development in *Pride, Prejudice, and Other Flavors*

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ABSTRACT

The character development in modern diasporic fiction tends to explain complex psychological negotiation which combine individual desire, rationality, and social expectations. This study explores the character development of Trisha Raje in the novel, *Pride, Prejudice, and Other Flavors*. The psychoanalytic reading of Trisha is examined through the lens of the psychoanalytic model developed by Sigmund Freud, namely the Id, Ego and Superego. The analysis maps the role of these three psychic elements in harmonizing the temperament, internal frictions, and emotional transformation of Trisha throughout the narrative. The repressed emotional desires and instinctive responses of Trisha exemplify the functions of the Id. Her suppressed emotional needs include her desire to be loved, to be accepted and to have personal freedom. Her professional identity, epitomized by her strict discipline as a neurosurgeon, reflects the Ego and its strict control over impulses. Simultaneously, the moral expectations internalised by her prestigious Raje family serve as the Superego. The study demonstrates how the constant negotiation between these psychic structures contributes to the gradual evolution of Trisha's character.

Keywords: Diaspora, Ego, Freud, Id, Superego

INTRODUCTION

Human mind is quite complex, and this complexity is often reflected in literature. Literature reflects this complexity through characters whose thoughts, emotions, and actions mirror the intricate mechanisms that are involved in



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human psychology. “Sigmund Freud, in his “Structural Model theory of personality”, states that each individual’s personality is made of three parts: The Ego, the Superego and the Id” (Niaz et al., 2019). The psychoanalytic model of Sigmund Freud has always been considered as a valuable tool for analysing the motives of characters, the inner conflicts, and the emotional existence in literature. The tripartite model of the Freudian psyche which includes id, ego and superego is used to understand how the unconscious desires, rational thought, and moral prohibitions act together in a person. The contemporary diasporic novel, *Pride, Prejudice, and Other Flavors* (2019) by Sonali Dev portrays a psychologically complex portrait of Trisha Raje. Dev’s novel is the modern retelling of Jane Austen’s classic *Pride and Prejudice* (1813/2003) in the contemporary Indian-American setting. It also provides a deep psychological analysis of guilt, obligation, and emotional suppressions. Dev restages the classic canons of social division, emotional vulnerability, and personal transformation within a diasporic context

Trisha is a renowned neurosurgeon who belongs to a well-known, powerful Indian-American family. She is acknowledged for her exceptional intelligence and composure. However, there lies an emotional detachment, an unresolved guilt, and a constant need for validation, beneath her professional brilliance. She is extremely confident in the medical field, but she is uncertain in handling interpersonal relationships and emotionally charged situations. Her professional competence juxtaposes with her inability express her vulnerability. Her stern attitude is due to her guilt, familial expectations, and pressure to maintain perfection. These elements create a psychological conflict which can be effectively analysed through Freud’s tripartite model of the psyche. The paper further argues that Trisha’s psychological journey represents a process of self-realization, where she learns how to reconcile these conflicting aspects of her personality.

LITERATURE REVIEW

According to the review of Niaz et al. (2019), the psychoanalytic theory of Sigmund Freud is a significant approach in literary criticism. It highlights how the notions of the id, the ego, and the superego can be used to discover the unrepressed wishes and suppressed feelings in literature. The paper also examines how the elements of symbolism, repression, and the unconscious are used in the development of characters and construction of plot. The study proposes a hypothesis that the psychoanalysis acts as an interdisciplinary framework for analysing literature, and human behaviour. (Azmi, 2023) provides a literature review on the psychoanalytic approach in understanding the individual behaviour, which is based mostly on the theory of Sigmund Freud. It explains the role of the dynamic interaction of id, ego, and superego in shaping the human behaviour and internal struggle. The study summarizes the existing literature, where the unconscious processes, defense mechanisms, and past experiences are highlighted as the factors that determine the human behaviour. It also traces the development of the psychoanalytic theory and its persistence, in relevance with the fields of psychology, education and personal growth.

Marcelina and Juanda (2025) analyse the character arc of John Wick based on the tripartite model of Freud, and anticipates the dominance of the id in driving his quest for vengeance. The Id is evident in Wick’s anger and in his desire to get revenge after suffering a personal loss. The ego on the other hand mediates these impulses and coordinates the strategic and calculated actions while the superego reflects moral codes. The paper, therefore, assumes that the psychological development of Wick would depend on a dynamic balance between these forces, despite the dominant nature of the id. Eventually, his development echoes behavioural patterns of trauma where the loss of emotions throws off the balance but does not entirely eliminate moral consciousness. Loway et al. (2023) explores the personality profile of Kat Stratford which shows that the domination of the id is strong and dictates her emotional instability, anger, and rebellious behaviour. Her ego appears in her practical behaviour and the superego occasionally guides her through morality. This paper argues that the character of Kat has been shaped by emotional impulsivity instead of moral reasoning. The salient id dominance depicts how personality determine behavioural trends and interpersonal relations in the narratives.



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Sitohang et al. (2025) examines a psychoanalytic reading on Macbeth. The paper emphasizes on how id-driven ambition dominates his personality and causes his moral decline. The ego becomes evident only in his hesitation and tactical planning. The superego appears here as guilt and remorse after murdering Duncan. The study reveals that the imbalance between these elements causes psychological deconstruction. The domination of ego by the superego and id causes an outcome of destructive behaviour and identity disintegration. Shah et al. (2025) discusses the psychological breakdown of the protagonists using the theoretical framework of Freud. It portrays the process of character development as collapse instead of growth, due to the lack of balance between the three structures, which leads to a mental breakdown and crime. Iqbal et al. (2025) explores Flynn's *Gone Girl*, comparing Freudian and Lacanian psychoanalysis and demonstrates how unconscious desires, trauma, and social pressures define the identity of Amy and Nick, highlighting their fragmented and reconstructed personality. Almas et al. (2024) applies Freudian theory to Amir in Hosseini's *The Kite Runner*, showing how guilt, trauma, and paternal expectations shapes him through the conflicts between id, ego, and superego. Mutyarani et al. (2024) employs Freud's model to illustrate how desire, morality, and repression lead to emotional conflict, which shapes actions, relationships, and identity struggles of characters. Lapsley et al. (2011) states that id, ego and superego focusing on unconscious drives, moral regulation and internal conflict act as a key to personality and human behaviour. The existing study has largely applied Freudian psychoanalytic models to characters who are controlled by extreme impulses or moral conflict. But less research has been done on ambivalent but internally conflict characters such as Trisha Raje in *Pride, Prejudice, and Other Flavors*. This study addresses that gap by examining how repression, professional self, and family expectations influence delicate interactions among id, ego, and superego.

RESEARCH FOCUS

The primary focus of the paper is to analyse how Freud's structural model of the psyche, the id, ego, and superego is employed in character development of Trisha Raje. The analysis examines the influence of these psychic structures on her self-concept, and interpersonal relationships. The study aims to

- Trace the instances of the id, ego, and superego in the personality of Trisha.
- How the interaction between these aspects in a dynamic manner drives her character development?
- How Freud's model of the psyche functions as a tool in understanding the inner conflicts, emotional repression, and psychological evolution of Trisha Raje?

Theoretical framework

Freud's psychoanalytical theory suggests that the human mind is composition of three mutually dependent components namely the id, the ego, and the superego. Each of these elements have their own psychological functions, which together determine complexities of human personality, motivation, and internal conflict. In literary studies, this framework provides a powerful lens through which the thought process of a character, their behaviour and emotional struggles can be meticulously decoded. According to Freud, the id is the most primitive portion of the psyche. It is a system that runs purely on the principle of pleasure and represents the appetites of the instinct, such as emotional gratification, affection and personal satisfaction. The id strives to get immediate gratification of desires such as hunger, sexuality, aggression, and instinctual impulses. The id lacks logic, ethics, or social norms. It requires instant satisfaction regardless of the consequences. In literature, the id is represented in the character's impulsive action, outburst of feelings and emotions, and desire. The ego on the other hand is the conscious and rational part of the psyche. It functions according to the reality principle. The ego lies between the two elements, the id, and the superego. It balances the desires of the id and the restrictions imposed by the superego, allowing people to negotiate the social worlds in an efficient way. It tries to satisfy the desires raised by the id in the realistic and socially acceptable ways without causing psychological imbalance. The ego uses reasoning, problem-solving, and decision-making to balance the conflicting forces. In literary criticism, the ego can be found among the inner thoughts of a character, compromises, and adaptive strategies. It is a negotiating force that prevents an individual from completely acting on impulse or morality. The third one is the superego. It is a bundle of internalized moral and ethical ideals that are influenced by parents, culture, and societal norms. It functions as a moral conscience that supervises the behaviour of the individuals through socialization and parental control. It also imposes the feelings of guilt, shame, or anxiety as penalties when those norms are violated. The superego is further divided into two, one of them is the



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conscience, which punishes the actions that are wrong, and the other one is the ego-ideal, which rewards good behaviour through a sense of pride. The superego manifests through the moral dilemmas of characters, their self-criticism and following the social norms. It often creates conflict with the id, when instinctual desires contradict the ethical standards. All of these three components interact together to form a human psychological conflict. When desires of id are too strong, the ego might break down in controlling them. This may lead to impulsive or destructive behaviour. When the superego dominates, people may experience excessive guilt, repression, or psychological distress. Therefore, the ego is supposed to maintain a balance between these conflicting forces. In literary analysis, this framework helps to analyse how characters struggle between personal desires and societal expectations. In the case of Trisha Raje, there is a psychological tension between emotional desire and societal pressure which propels her character development.

The Superego of Trisha Raje

The superego, in the Freudian psychoanalytic theory represents the moral conscience, the internalized societal norms and the pressure to achieve perfection. The superego, seems dominant and controls the personality of Trisha. She belongs to the powerful Raje family and brought up in a world of privilege, prestige and unceasing demands. Her character was formed by aristocratic backgrounds, family norms, and internalised standards of excellence. It controls her behaviour, restrains her emotional reaction and continuously drives her toward a quest of excellence and accountability. The Raje family is a classic social establishment which values achievement, reputations and power. Since she is a very young child, Trisha is taught that being excellent is not an option but a necessity. She can no longer define herself without her accomplishments, particularly her career as a neurosurgeon. Though she excelled as a neurosurgeon, her family still sees her as a less accomplished person. This is evident when her mother says, "I think you might be the first simpleton in the Raje family... No one said you aren't good at what you do" (Dev, 153).

The narrative frequently highlights how her superego demands perfection. "Trisha had spent every waking moment for the past five years thinking about how to operate on tumors growing on brain tissue...it wasn't just her waking moments; she spent most nights dreaming about her work too." (Dev, 8) These lines show her perfectionist mindset where less concentration or any distraction is unacceptable. It also shows that her perfectionism is subconscious. She strives to eliminate all possibilities of errors. This commitment alienates her emotionally. Her inner world is entirely engulfed by professional excellence leaving a very little room to have relationships, and emotions, which create internal conflicts. Her superego allows her to take pride on her career. "I dare to take pride in my work, in knowing I'm excellent at it." (Dev, 319). The superego comes in the form of guilt and feeling of failure and particularly the mistake she did in the past in connection with Julia and the way it affected Yash. Trisha carries this psychological burden which is never-ending. She believes that she is the reason that provided a chance for Julia to negatively impact the life, the career and image of her brother. She feels guilty of nearly ruining the life of her brother. She started to suppress vulnerability and personal desires after that incident. She thinks expressing her emotions will weaken her image of strong person, and may also give others to destroy the name of her family. Her superego is a vehicle of strength and power that drives her to achieve excellence, be responsible. It also sets high expectations that promote feelings of guilt, depression, and isolation.

The Id

The id as interpreted in Freudian psychoanalysis is the most primitive and instinctual part of the psyche, which follows the principle of pleasure and is motivated by instant gratification. Her id is not dominant yet suppressive. It occurs when she experiences emotional intensity, desire, anger, and vulnerability. The id is shaped by the internal desire for validation, intimacy which is constantly regulated by the ego and is repressed by the superego. Her id can be traced through her emotional reaction towards her patients, particularly Emma Caine. She projects a clinical detachment but her inner responses reveal emotional agitation. She remembers the blind girl from her childhood and experiences "an empty, hungry restlessness that had knocked her completely off-balance" (Dev, 4). The words hungry and restlessness indicate the raw and unrefined emotional energy, a characteristic of id. She desires to have an emotional attachment with Yash after the Julia incident. A sudden rush of emotions hits her when she comes to meet him at the dinner. "Trisha was tempted to grab his arm and apologize for missing years...She wanted to tell



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him that Julia was in town and HRH was hiding it from him. She wanted to do it so badly” (Dev, 39). However, these urges are suppressed by the ego and the superego.

The id of Trisha is mostly overshadowed by her strong superego. But it comes out occasionally when she is overwhelmed by sexual desire, emotion, and sensory delights, particularly in her relationships with DJ and her food. The id represents instinctual needs like pleasure, attraction, and emotional longing, which disrupts her controlled persona. Her id is clearly visible in her sensory reaction to the cooking of DJ. When she tastes his food, her response is immediate, “Oh my God...You cannot possibly feed this to people” (Dev, 184). This spontaneous expression of pleasure reflects the momentary relief from her self-control, permitting her instinctual pleasure to dominate. Her attraction to DJ also throws more light on the mechanisms of her id. Despite her conscious hate, she feels a deep instinctual pull towards him. “The craving for his food had been rolling in waves across her taste buds, tangling her thoughts up inside her” (Dev, 195). This analogy of craving goes beyond the food and stretches to the emotional and physical attraction, highlighting on how her id operate at a subconscious level to influence thoughts and desires. These affective conditions are natural results of spontaneous impulses that challenge her carefully constructed identity. The id is reflected in her emotional outbursts and unplanned reactions. She is sharp and defensive during her interactions with DJ. It is evident when she sarcastically responds, “it’s not like you need a photographic memory to cook food” (Dev, 174). It is just a reaction of wounded pride and emotional agitation, which shows her id can gain control over her normal composure. Her id functions as a suppressive yet powerful dynamic in her psyche, which appears in sensory pleasure, emotional response, and unconscious desire. Though her superego tries to limit and tone down these forces, the id still comes out eventually. The id of Trisha is not chaotic, but is repressed and internalized. It is expressed in of anger, desire, longing and vulnerability.

The Ego

The ego of Trisha is characterised by efficiency and common sense, especially in her profession as a neurosurgeon. The textual lines, “so much about the world baffled Dr. Trisha Rajee, but she was never at a loss for how to do her job” (Dev, 1) defines the nature of her ego. She resorts to logic and competency even when she feels overwhelmed. The ego in Trisha’s character acts like an interpreter between the overpowering superego and the repressed id. It attempts to make a balance between her instinctual urges on the one hand and the practical demands of the world on the other. Being a successful neurosurgeon, her ego is aligned with logical reasoning, control, and decision-making processes, which makes her prepared to deal with complex professional and personal situations. Unlike the impulsive id or the judgemental superego, her ego works on rational thought and circumstantial awareness.

The character has a strong ego in her work environment where she is capable of make decisions under pressure. She faces an issue in communicating a life-changing diagnosis to a patient at the beginning of the novel. “Telling a patient her tumor was not fatal should have been the easiest thing, but Trisha had no idea how she was going to manage it. How on earth did one tell an artist that she was going to go blind?” (Dev, 1). These textual lines highlight her perception of reality. She tries to balance the medical facts with emotional delicacy. Her ego realizes the complexity of the situation and tries to respond accordingly, rather than reacting on impulse or moral rigidity. Her ego also acts as a stabilizing mechanism while informing Emma about her impending blindness. Though she struggles emotionally, her ego drives her to be straightforward in saying, “Removing the tumor is the only way to save your life. And we can’t remove the tumor and also salvage your optic nerves” (Dev, 15). Her ego prioritizes reality over providing emotional comfort. She lives life as she approaches surgery, in a structured, calculated, and focused manner. Her internal response is controlled, when she learns about approval of a huge grant of research. “It made her want to pump her fist in vindication and shout...instead, she took the hand he held out and thanked him for being such a great boss and mentor” (Dev,16). Her ego matches her action with the expectation of the society in terms of professionalism.

Trisha knows her interpersonal limitation, yet she justifies and distances herself. Her ego balances her desire to be emotionally connected (id), and her fear of being vulnerable (superego). She initially resists her feelings towards DJ, but gradually starts to get involved with him. Although the superego encourages restraint and the id drives desire,





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the ego strives to reconcile these two conflicting forces that resonates with reality. The ego in Trisha's character acts as a rational centre which balances the instinctual desires and the moral expectations. It provides her competence to live in the real world while navigating internal conflicts. She gradually learns how to balance and control her vulnerability through the ego, which plays an important part of her psychological growth.

The interaction of Id, Ego and Superego leaves a constant psychological conflict in the personality of Trisha. The Id drives her to emotional sincerity while the Superego simultaneously compels her to be discipline, and be morally accountable. The Ego attempts to balance these hostile forces, by means of a rational control. However, the tension is unbearable. Later, Trisha begins to question the rigid standards that have conditioned her behaviour. Her interaction with DJ encourages her to rethink her understanding of success, responsibility, and personal satisfaction. Through this process, she gradually learns to integrate the different aspects of her psyche rather than allowing one element to dominate the others. This integration is the final stage of her psychological development. She learns to reconcile the emotional needs with moral responsibility, instead of suppressing her desires or blindly following the moral expectations. The Ego eventually creates a strong balance by recognizing the validity of both moral values and instinctual desires. The Id, Ego and Superego still exists but they function in a symbiotic and harmonized manner.

CONCLUSION

The continuous interaction of the Id, Ego, and Superego has an influence on the overall personality and behaviour of an individual. The Freudian model of psyche provides a strong framework for analysing the complex character arc of Trisha Raje in Sonali Dev's novel, *Pride, Prejudice and Other Flavors*. The Id in Trisha emerges in her suppressed desire of emotional connection and personal freedom. The suppressed Id is revealed on occasions of involuntary desire, anger and need of association. Her Ego is expressed in her strict professional character and dependence on rational decision making. However, the same process leads her towards emotional self-distancing and inability to build effective relationships. In the meantime, her Superego represents the effective power of family demands, social values, and the demands of moral conscience. This makes her focus on responsibility, accomplishment, and control at the cost of individual satisfaction and emotional outlets. The three forces create a continuous psychic struggle which drives the plot and shapes her character. The development of Trisha's character proves that the true fulfillment requires the harmonious combination of desire, reason, and morality. She learns to balance these dimensions by putting the feeling of guilt and self-denial behind her and discover the path toward a more authentic sense of self. This study highlights how the Freudian theory illustrates the richness of Trisha's psychological development and emphasizes the universal human conflict between responsibility and desire. Her growth indicates that the real satisfaction of life in finding a balance between reason, emotion, and the moral obligation.

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RESEARCH ARTICLE

Gamification as Cognitive Scaffolding: A Psycholinguistic Study of Working Memory Load and Attentional Control in ELT

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ABSTRACT

This study discusses the concept of gamification in English language teaching in the psycholinguistic context of how game mechanics can be used as cognitive scaffolding to demonstrate pedagogical change. The text presents a smaller working memory load and greater attentional control as key indicators of knowing the mental effects of digital learning environments. The dynamics between gamified components and learner processes will be analyzed in the paper to examine the themes of engagement, psychological optimization, and the relationship between motivation and linguistic acquisition. The study emphasizes how gamification is instituting organized forms of play to overcome frail attention and the immediate demand of a concise answer to overload in learning environments. In addition, the paper explores how technology and knowledge are used to deal with educational crises, how the diversity of learners is intertwined with psychological needs, and why it is critical to adopt pedagogical views. Simply put, this research paper advocates that gamification increases awareness of the effects of mental load on language acquisition and urges consideration of a comprehensive approach to educational design. It highlights how a group of teachers has a common role in ensuring the future of language education through the harmonization of the instructional approach with mental architecture to achieve sustainable academic development. The equilibrium of the mind in the digital distractive age is at risk in the absence of such scaffolding; therefore, it warrants the implementation of interventions to maintain resources to conduct effective communication and global competency in the 21st-century classroom. The present research adds to the debate regarding the necessity of a collective reaction to the crisis in the area of education and its impact on society.

Keywords: Gamification, Cognitive Scaffolding, Working Memory, Attentional Control, ELT, Psycholinguistics, Language Acquisition, Cognitive Load, Pedagogical Design, Digital Learning



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INTRODUCTION

Cognitive overload has become one of the most pressing problems of the 21st-century classroom, with broad-reaching implications for the learning environment, society, and the global economy of education. The increasing consequences of digital distraction, an increase in information temperatures, extreme events of multitasking, rising data levels, and the loss of focus by biodiversity states the fact of an ever more unstable ecological equilibrium of the mind. Central to this difficulty is the notion of the cognitive equation, the term applied to explain the complicated and interrelated interactions that exist between the mental ecosystems of the learner, pedagogical actions, and the linguistic resources on which we depend (Sweller, 2011). This paper investigates the language learning process in terms of the cognitive equation, which is the process by which human-controllable variables, such as instructional design, digital interference, and curriculum density, interfere with the fragile balance of working memory (Baddeley, 2000). One of the most topical problems of our epoch is cognitive load, and the literature has become a significant instrument for studying and increasing awareness of its extensive effects. Among pedagogical concepts, there is gamification, which is a strategy that intertwines complex issues of engagement, mechanics, and the human experience (Deterding et al., 2011). This discussion focuses on the way in which gamification utilizes game mechanics as a core emblem to investigate the cognitive implications of instructional transformations. The classroom mechanic turns out to be a point of departure for cognizing the interdependence of the mental world and how changing digital circumstances break down the fine line of attention. Given that we have an unstable future in perspective, it is essential that we evolve an all-encompassing appreciation of the cognitive equation to inform the world towards educational resilience, sustainable development, and learning justice.

The literature on gamification demonstrates how cognitively and attentional control relate to the experiences of learners. Structured play is an influential metaphor for general cognitive interference by information flow that is not managed, reflecting the principles applied in multimedia learning systems (Mayer, 2009). The discipline not only makes one think about how learners perceive and react to changes in pedagogy but also encourages more people to be more conservative when it comes to mental resources. The aforementioned studies and research in the review reveal the ambiguity of memory patterns and attention behavior with a shifting digital climate, which provides the urgency of further educational studies and practices to avoid deteriorating delicate learning outcomes (Hanus & Fox, 2015). The description of changed interactions in gamification is an influential metaphor for global environmental shifts due to cognitive overload. This methodology not only makes one think of the manner in which human beings interpret and react to environmental changes in the classroom but also compels them to conserve the environment more significantly. This paper hopes that through this exploration, it can contribute to the current debate on the dire need for a collective global action to the cognitive crisis in the educational field as well as the implications of such a crisis on society.

RESEARCH FOCUS

The main purpose of this study is to examine how gamification mirrors cognitive and psycholinguistic narrative based on symbolic encoding of game mechanics, their effect on memory patterns, and the consequences that it may bring to natural learning ecosystems and human societies. The decrease in memory load was significant. The research questions were as follows:

How do gamification mechanics (in terms of points and badges) exploit the more general cognitive implications of scaffolding?

- How does the study point to a lack of natural learning cycles and cognitive balance?

How do the learner experiences, as represented in ELT, reflect the larger cognitive crises represented by shifting patterns of attention?



**Gifto David and Muhammedali Chalikandy Puthiyapurayil****Gamification and Cognitive Themes in ELT**

Gamification in English language teaching is woven around a captivating story that examines the interplay between game mechanics and language systems. The domain is framed with the dynamic digital world, and the impacts of cognitive load destabilize local learning environments. The cognitive imbalance and attentional strain themes are central not only to the strategy but also provide insights into the entire societal repercussions of educational degradation. Gamification is structured around the life of the learner, who, after an experience with some mysterious mechanics, realizes that she is going through a series of significant cognitive crises that are taking place in her environment. The entry of points, which typically drive in particular ways, is interrupted because of modifications in the design because of overload (Sweller, 2011). This interruption is an extension of general themes that run through the classroom, as the mental world is depicted as being frail and open to human influence.

When considering the cognitive and gamification elements in ELT, this research paper will look into the description of human-instruction relationships and the effects of cognitive disruption. By examining the developing concept of memory and symbolic expression of the badge system by learners, this paper will serve to show how designers employ mechanics to bring out the urgency of cognitive action (Mayer, 2009). Gamification can be viewed as an engaging critique of the necessity of sustainable practices and overall responsibility in overcoming the cognitive challenges of our age, with its vivid representation of the effects of distraction on an individual and global level (Deterding et al., 2011). Literature on the subject of gamification demonstrates profound interrelationships between load, control, and experience. The research papers emphasize the complication of memory patterns under the conditions of evolving digital climate and emphasize that further research is obligatory to maintain the threatened learning results (Baddeley, 2000; Hanus and Fox, 2015).

Game Mechanics as a Symbol of Cognitive Scaffolding

In science and literature, game mechanics are commonly employed as symbolic representations of the frailty and strength of cognitive mechanisms. In ELT, designers refer to the interrupted attention of the learner as a metaphor for the mental systems that have become more and more disrupted because of cognitive overload. Digital intrusion, which results in a change in the classic inspirational direction of the points and badges, is used to symbolize the vulnerability of natural systems and the implications of instructional alterations by human factors (Deterding et al., 2011). It is a symbolic employment of the mechanic that not only emphasizes the short-term effects of load on learning but also represents the systemic effects of destabilization in the delicate balance of working memory (Sweller, 2011). The gamified aspect, which is characterized by engagement, plays a key role in the classroom because it focuses attention on the alteration of cognitive patterns that interfere with natural processes. Traditionally, the learners give instructions to acquisition of specific patterns. In the digital world, however, attention lies in a trough of distraction, which is otherwise an unaccounted route. This unaccountable change in behavior is a symbol of a larger environmental transformation in the world, which alters the regular cycles of nature (Baddeley, 2000). The entry of learners was first understood to be a miracle. However, later in the course, one realizes that their existence is not a natural occurrence but an outcome of an educational crisis. Such a change in the focus of learners is a wake-up call to the educator that makes them face less observable disturbances that take place in the mind world (Mayer, 2009).

The change in the behavior of the learners is similar to the internal changes as the characters understand the intensity of cognitive load and challenges. Mechanics are also manifestations of personal and global issues. The symbol of the badge as something weak but able to travel the world portrays the urgency of dealing with cognitive disruptions before they cause irreversible damage. This essay explores the symbolic meaning of the mechanic in ELT as a symptom of cognitive breakdown by drawing parallels between the disrupted course of the learner and the educational crises at a larger level brought about by overload. Finally, the mechanic in gamification is a powerful prompt for connectedness and urgency to bring cognitive balance back before it is too late (Hamari et al., 2014).

Gamification as a Reflection of Learner Lives

As the story unfolds, the learner begins to see the mechanisms of gamification as a reflection of their own struggles. Because the badge system is a launchpad to personal enlightenment and greater community-wide social



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and cognitive challenges, personal change follows teaching change (Deterding et al., 2011). This connection between humans and computers evidences that intrinsic drive is not an abstract idea but one that affects human beings in all their backgrounds and financial statuses (Ryan and Deci, 2000).

- Waking up on a Personal Level: The engagement with the mechanics is a turning point for the learner, showing the criticality of addressing cognitive load. Referring to the experience of transferring to a native country and another one, they begin to understand the effects of the global educational crisis on their own lives (Hamari et al., 2014). Human Ignorance and Denial: To start with, some members of the community perceived the gamification as an outlier or supernatural intervention. This is a prime illustration of the widespread ignorance and unacceptance of education change. Cognitive pressure is something many individuals have to deal with in reality, and throughout the course, the student becomes skeptical and later realizes it (Hanus & Fox, 2015; Sweller, 2011).

The Role of Technology and Knowledge in Understanding Cognitive Load

The discipline is very keen on the use of technology to explain and comprehend cognitive phenomena. The researcher is the work of the scientific community to understand the impact of distraction on the learning ecosystem. The formation and sharing of scientific knowledge are extremely significant in the development and interpretation of cognitive load (Sweller, 2011). In recent decades, scientific progress has furnished empirical data on the existing global cognitive crisis and has also provided paradigms for explaining its occurrence. Cognitive load would demand interdisciplinary scientific work, including research in psycholinguistics, social sciences, and other sciences, to understand all the complexities involved (Baddeley, 2000).

The significance of science and knowledge in understanding memory is discussed in this study. Data collection and processing are important aspects of scientific work. It is through the use of observational records and the cognitive models that the researchers can predict the way in which people will learn in future and this is crucial to any policy maker in their attempt to seek solutions to the problem (Mayer, 2009). The consequences of the load on ecosystems are outlined by the information provided by the scientific community. The contribution of cognitive strain, which can be in the form of multitasking and ineffective teaching tools, may be better understood through scientific data. Paas and Van Merriënboer (1994) state that the investigation of gamification can assist in reducing stress, which is why the development is essential.

Conversely, scientific knowledge is essential for addressing the interpersonal side of education. Misinformation has persisted despite the best efforts of scientists to raise public awareness of cognitive science, which is essential for promoting collective action. Clark and Mayer (2016) claim that science communication is highly important in the dissemination of scientific knowledge to more people. Cognitive load should be conveyed in an understandable, clear, and precise manner so that people can be prepared to make informed judgments in the event of an educational crisis.

Scientific investigation is important in the identification and response to disruptions in education through research on changes in learners' memory and attention, which also displays cognitive load and scientific observations. The teacher embodies intuitive knowledge, and the researcher's presence highlights the need to integrate scientific analysis with local, experienced knowledge.

Cognitive Load, Learner Diversity, and Educational Equity

Cognitive load has an uneven distribution in English language teaching, targeting marginalized working-class groups. Economically disadvantaged students are given the chance to appreciate the onset of intricate mechanics, which is an eye-opener regarding social disparity coupled with educational degeneration in society. Educational equity is a new field of study that investigates the nexus of cognitive sustainability and social justice, which involves a fair distribution of mental profits and costs in societies and across generations. As vulnerable communities are affected more by instructional degradation, digital distraction, and resource depletion, the notion of educational equity is crucial in the context of balancing human and environmental needs in the quest to achieve a just and



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sustainable future (Freire, 1970). Intergenerational equality is an important concept in the sustenance of development that aims to create a fair bond between the current and future generations through the safekeeping of knowledge and skills. John Rawls, an academic, has added his voice to this argument, explaining why it is our moral obligation to conserve educational resources to benefit future generations (Rawls, 1971). Two issues addressed by environmental justice theory include disparities in exposure to environmental hazards and environmental degradation. Environmental justice, whose roots are in the civil rights movement, aims to ensure that vulnerable groups of people are not disproportionately affected by environmental risks by facilitating an equitable redistribution of such risks (Bullard, 1990).

The main postulate of ecological modernization theory is that technological advancement is the key to realizing economic growth and environmental sustainability. This was conceived by Joseph Huber in 1982 and offers a timely perspective on how technology can help create an ecological equilibrium. Ecological modernization does not necessarily address social inequities directly, but rather relates to ecological fairness by suggesting that green technology investments can be a solution to ecological issues. Educational Justice: This study criticizes the response to the cognitive crisis for the most vulnerable students. The presence of cognitive load enhances existing social disparities, and rural inhabitants are particularly impacted because of educational degradation and economic changes (Warschauer, 2004).

Rural vs. Urban Divide: This highlights the conflict between rural and urban attitudes towards cognitive load, in which the former was the first to question scientific warnings. The rural environment offers a platform to address the issue of how ecological changes pose a challenge to traditional ways of living (Sweller, 2011).

Attentional Control and the Future of Language Learning

Cognitive load interferes with the attentional control of the learner, demonstrating the dependence of all cognitive processes and the vulnerability of the classroom setting. The future of all species, including human beings, is in a world where technology is increasingly affecting learners at the micro-level. The fact that attentional processes have an extraordinary long-distance migration is not a recent discovery in conventional education (Schmidt, 1990). Their regular movement between teaching and acquisition has been used to represent natural cycles and ecological stability. The distractor of the normal line of thought, as represented by the entrance of attention in a valley of distraction characterized by being away from the natural process, symbolizes the interference with the natural systems in digital ELT. Not only are human beings' lives influenced by cognitive load, but also the migration and survival of species (Baddeley, 2000). The result of this is abnormal behavior due to an increase in information temperature.

The changed focus of the students, which was initially perceived as a magic phenomenon, ultimately indicates the collapse of the educational system. As the locals attempted to find meaning in all the attention, the story depicts how ecosystems are either forced to adjust or perish due to climatic change. This disruption serves as a wake-up call to endangered animals and future generations who depend on unchanging, predictable weather (Sweller, 2011). The attentional migration of ELT is a microcosm of the larger issues and the need to take urgent action to safeguard biodiversity. Mayer (2009) and Deterding et al. (2011) also discovered that the development of complex interactions between species necessitates that the latter adapt to them in such a way that may not be sustainable in the long term as a result of the break in the environmental situation.

The Disruption of Natural Learning Cycles and Its Implications

The consequences of the digital interference on the complex cognitive processes involved in language acquisition reflect on the attention of ELT learners. Teachers and learners are experiencing the impact of disruptions in instructional patterns in the wake of rising data temperatures due to human factors such as multitasking and constant connectedness. This shift in environmental conditions forces pedagogical agents to change in a manner that may not be sustainable in the long term because their complex relationships are disrupted (Gee, 2003). Increasing information temperatures due to human activities such as uncontrolled screen time and broken curriculum have





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disrupted both inputs and outputs. According to Squire (2011), changing environmental conditions are forcing species to adapt in ways that might not be viable in the long run because they have disturbed the complex interactions that the species have. When the students walk in the classroom, it creates a commotion of conversation and research. The cognitive load is a fact that community individuals and, in particular, teachers are experiencing in understanding the implications of the altered courses of students and how this could pose a danger to the environment and their lives (Prensky, 2001). The impact of this disruption on a familiar natural phenomenon is an austere notification that the state of the psychological ecosystems is more vulnerable to the residual of human actions. This concentration of the students is therefore the precariousness of school life and the urgency of taking action to solve educational disasters, such as the destruction of habitats and resource shortages (Cowan, 2001). Therefore, attentional migration through gamification is a microcosm of the larger question of education and why we desperately need to act on the issue promptly to safeguard cognitive biodiversity (Kapp, 2012).

The Role of Gamification as a Harbinger of Change

Being provocative to traditional knowledge and bringing radical changes to the context, gamification is a harbinger of ELT pedagogical revolution. Teachers face greater issues of cognitive overload and disproportion when pressured by mechanical forces to be cognizant of the occurrences taking place around them. The mechanics make the student reassess their identity and place in the universe, consequently bringing about drastic changes in the character of the student (McGonigal, 2011). Similar to the point of no return that humankind is currently confronting in its fight against stagnation in educational processes, the mechanics signify a turning point in the discipline. The classroom is going through a turning point in the course of its education, just as the butterflies are going through a trip towards the end. The interruption highlights the essential importance of prompt pedagogical intervention to cure cognitive strain prior to irreversible damage (Landers, 2014).

The future of gamified elements is inextricably linked to the future of all learners within the system. This is a call to action that highlights the need to address educational issues in an integrated manner (Fullan, 2007). The kings are unable to leave their homes alone, just as teachers cannot solve the cognitive issues that afflict us individually. The play aspect of cultural history leads us to the fact that change is at the core of human development (Huizinga, 1955). The support offered when undertaking this transition is referred to as scaffolding, which ensures that learners are not abandoned in the process of the same transition (Vygotsky, 1978). Finally, gamification can be used as a powerful reminder of connectedness and the necessity to reinstitute cognitive harmony as soon as possible, before it is too late. It can be seen as an alert to the radical changes that do occur in the world and in global competency.

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RESEARCH ARTICLE

Digital Diaspora and Cultural Memory: Identity Formation and Self-Representation in Diasporic Narratives

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ABSTRACT

In the contemporary era of globalization and digital connectivity, diasporic communities maintain strong cultural ties with their homeland through both literary narratives and digital platforms. This paper examines how cultural memory contributes to identity formation in diasporic narratives and how these representations resonate with contemporary forms of digital self-representation. Drawing on theories of cultural identity and memory proposed by Stuart Hall and Jan Assmann, the study explores how migrants negotiate their identities between homeland and hostland cultures. Through a textual analysis of novels such as *Brick Lane* by Monica Ali and *The Lowland* by Jhumpa Lahiri, the paper highlights how memories of homeland traditions, language, and family practices shape diasporic identity. These narratives demonstrate that cultural memory functions as a bridge connecting migrants to their cultural roots while enabling them to adapt to new social environments. The study also connects these literary representations with contemporary digital practices, where migrants share experiences, traditions, and everyday life through platforms such as YouTube and Instagram. These digital spaces act as virtual communities where diasporic identities are performed and preserved. By linking literary texts with digital expressions of diaspora, this paper argues that digital media extends traditional cultural memory and creates new avenues for identity construction in transnational contexts.

Keywords: Digital diaspora, cultural memory, diasporic identity, self-representation, transnational narratives.





INTRODUCTION

The transgression of individuals across national boundaries has emerged as a fundamental characteristic of the contemporary globalized landscape. Migration, whether it occurs willingly or under duress, has resulted in the formation of myriad diasporic communities that engage in a complex negotiation of their identities between the cultures of their countries of origin and those of their host nations. For numerous migrants, the experience of displacement engenders feelings of cultural disintegration, yearning, and a persistent pursuit of belonging. Throughout history, literature has functioned as a vital conduit through which diasporic authors articulate their experiences related to migration, memory, and identity. In recent years, the advent of digital technologies and social media platforms has facilitated novel avenues for diasporic communities to express and preserve their cultural identities. Consequently, the notion of digital diaspora underscores the interplay among migration, cultural memory, and digital self-representation.

Diasporic literature frequently delves into the intricate dynamics of identity formation among migrants straddling multiple cultural realms. These narratives depict individuals grappling with the challenge of preserving ties to their cultural heritage while simultaneously adjusting to unfamiliar social and cultural landscapes. Within these contexts, cultural memory is pivotal in shaping the identities of diasporic individuals. Memories of traditions from their homelands, linguistic practices, familial values, and quotidian rituals serve as symbolic markers that enable migrants to sustain a sense of belonging, despite the physical distance from their origins. Through narrative and storytelling, diasporic authors reconstruct these memories and illustrate their impact on the psychological and cultural experiences of migrants.

Theoretical frameworks concerning cultural identity and memory are essential for comprehending these processes. Cultural theorist Stuart Hall posits that identity should not be regarded as a static essence; rather, it should be viewed as an evolving process informed by historical, cultural, and social contexts. According to Hall, identities within the diaspora are shaped through ongoing negotiations between recollections of the past and current realities. In a similar vein, cultural memory scholar Jan Assmann emphasizes the importance of collective memories, preserved through cultural practices, traditions, and narratives in sustaining cultural identity across successive generations. These theoretical insights suggest that the formation of identity within diaspora is inextricably linked to the preservation and reinterpretation of cultural memory.

Contemporary diasporic novels often portray how migrants reconstruct their identities through memory and storytelling. Notable works such as *Brick Lane* by Monica Ali and *The Lowland* by Jhumpa Lahiri offer profound insights into the characters' navigation of the tensions between tradition and modernity, their homelands and host cultures, as well as personal aspirations and cultural expectations. These narratives reveal the ways in which memories of home influence the emotional and social dimensions of diasporic lives. Through representations of family dynamics, cultural practices, language, and culinary traditions, these novels illustrate how migrants maintain connections to their cultural heritage while adapting to new surroundings.

Beyond literary depictions, the digital age has profoundly altered the means by which diasporic communities sustain cultural connections. Platforms such as YouTube, Instagram, and various digital networks enable migrants to share their lived experiences, cultural practices, and daily realities with global audiences. These platforms serve as virtual arenas where diasporic identities are articulated, negotiated, and preserved. Through digital storytelling, culinary vlogs, travel narratives, and cultural discourses, migrants create online collectives that reflect their hybrid identities. Thus, the concept of digital diaspora broadens the traditional understanding of diaspora by integrating technological forms of communication and self-representation.



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The relationship between literature and digital media is particularly consequential for comprehending contemporary manifestations of diasporic identity. While novels offer narrative insights into migrant experiences, digital platforms empower individuals to actively participate in crafting and circulating diasporic narratives. Migrants can document their daily lives, cultural customs, and personal recollections through digital content, thereby transforming individual experiences into shared cultural expressions. These practices illustrate that cultural memory is no longer confined to literary texts or oral histories but increasingly transcended through digital technologies.

Recent scholarship in diaspora studies has widely explored themes of migration, identity, and cultural belonging in literary narratives. However, most studies primarily focus either on literary representations of diaspora or on the role of digital media in shaping contemporary migrant identities. There is comparatively limited research that examines the relationship between diasporic literature and emerging forms of digital self-representation. In particular, few studies analyze how cultural memory represented in literary texts resonates with the ways migrants construct and express their identities through digital platforms such as YouTube and Instagram. Therefore, this study attempts to bridge this gap by connecting literary representations of diaspora with contemporary practices of digital diaspora, highlighting how cultural memory continues to shape identity formation in both narrative and digital spaces.

This paper seeks to investigate how cultural memory informs identity formation within diasporic narratives and how these literary representations resonate with modern manifestations of digital self-representation. By analyzing *Brick Lane* and *The Lowland*, the study explores how memories related to homeland traditions, language, familial relationships, and cultural practices shape the identities of diasporic characters. Additionally, this paper connects these literary expressions to the growing phenomenon of digital diaspora, wherein migrants utilize online platforms to forge cultural ties and construct hybrid identities.

Moreover, this research highlights how digital media enhances traditional forms of cultural memory by enabling diasporic communities to develop new networks of belonging. The intersection of literature and digital culture illustrates that identity formation within diaspora is not limited to physical displacement but also encompasses symbolic and virtual connections that transcend geographical confines. Through this interdisciplinary approach, the study contributes to conversations in cultural studies, diaspora studies, and literary criticism by analyzing how migration narratives interact with contemporary digital practices.

Ultimately, diasporic narratives underscore that identity is neither a fixed nor stable construct but a fluid process shaped by memory, culture, and social interactions. By bridging literary texts with digital forms of self-representation, this paper asserts that cultural memory continues to play a vital role in shaping diasporic identities while accommodating the technological realities of the twenty-first century.

LITERATURE REVIEW

Diaspora studies have emerged as a significant area within cultural studies and postcolonial literary criticism, concentrating on the phenomena of migration, displacement, and identity construction among transnational communities. Researchers have explored how diasporic individuals navigate their cultural identities amid societies that often contrast starkly with their countries of origin. The definition of diaspora has gradually evolved from its conventional association with forced displacement to encompass voluntary migration, globalization, and transnational cultural exchanges. Current scholarly endeavors increasingly focus on the importance of memory, identity, and cultural representation in shaping the experiences of diasporic communities. A pivotal contribution to the discourse on diaspora and identity originates from cultural theorist Stuart Hall, whose analysis of cultural identity provides a vital lens for comprehending diasporic subjectivity. Hall posits that cultural identity should not be seen as a static or intrinsic attribute anchored in the past; instead, it is a fluid and developing phenomenon influenced by historical, cultural, and social contexts. He contends that identities are perpetually constructed through processes of representation, discourse, and cultural practices. In diasporic contexts, individuals frequently encounter



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what Hall refers to as a “double consciousness,” necessitating a negotiation between their inherited cultural legacies and the realities of their new environments. Hall’s framework underscores that diasporic identity emerges from a continuous process of interaction between past memories and present circumstances. Another critical theoretical contribution comes from cultural memory scholar Jan Assmann, who elucidates the concept of cultural memory as a means of understanding how societies preserve and transmit collective memories across generations. Assmann differentiates between communicative memory, which encompasses everyday recollections exchanged through interpersonal interactions, and cultural memory, which is maintained through cultural institutions, texts, rituals, and traditions. In diasporic communities, cultural memory plays a pivotal role in fostering connections with the homeland. Literary narratives, cultural rituals, linguistic practices, and culinary traditions serve as essential conduits through which migrants sustain their collective identity despite geographical dislocation.

In the field of diaspora studies, scholars have further investigated the interplay between migration and transnational identity. Sociologist Robin Cohen has broadened the concept of diaspora by highlighting its various forms, such as labor diaspora, imperial diaspora, trade diaspora, and cultural diaspora. He asserts that contemporary diasporas are marked by profound emotional and cultural bonds to the homeland while simultaneously adapting to the host culture. This dual orientation often leads to hybrid cultural identities that amalgamate elements from both cultures. Similarly, theorist Avtar Brah introduces the notion of “diaspora space,” which refers to the social and cultural milieu where migrants, locals, and other communities interact and negotiate their identities. Brah’s framework emphasizes that diaspora should be understood not merely as a condition of displacement but also as a dynamic environment where new forms of cultural identity may emerge.

Within literary studies, researchers have scrutinized how diasporic authors depict themes of migration, belonging, and cultural memory. Diasporic literature frequently portrays characters caught in emotional struggles between their cultural heritage and the demands for assimilation within the host society. These narratives often illuminate the significance of familial traditions, language, and quotidian cultural practices in the preservation of cultural identity. Elements such as food, clothing, religious observances, and festivals are commonly represented as symbolic links that tether diasporic individuals to their cultural origins. Through these portrayals, literature serves as a potent medium for examining the emotional and psychological dimensions of migration.

The works of contemporary diasporic authors like Monica Ali and Jhumpa Lahiri have garnered significant academic attention for their intricate representations of migrant experiences. In her novel *Brick Lane*, Monica Ali explores the life of a Bangladeshi woman residing in London who wrestles with adapting to a new cultural landscape while safeguarding connections to her homeland. Scholars typically interpret the novel as a depiction of the challenges faced by immigrant women in reconciling identity, tradition, and modernity. Similarly, *The Lowland* delves into the emotional and political ramifications of migration through the narrative of two brothers whose lives are influenced by both personal choices and historical developments. Academic discussions surrounding Lahiri’s work often emphasize themes of memory, displacement, and intergenerational identity.

In recent years, researchers have begun to investigate how digital technologies impact the formation of diasporic identities. The concept of digital diaspora underscores the ways in which migrants utilize digital platforms to engage with their cultural heritage and interact with transnational communities. Social media platforms facilitate the sharing of personal experiences, cultural practices, and everyday life narratives with audiences across geographical boundaries. These digital interactions facilitate new forms of community that transcend traditional physical spaces. Digital media scholars contend that online platforms serve as arenas of cultural representation where individuals actively craft and enact their identities. Through digital storytelling, migrants are able to document their memories, traditions, and cultural practices in manners reminiscent of literary narratives. For instance, numerous migrants share cooking videos, cultural dialogues, and travel experiences via online platforms, thereby preserving and disseminating cultural knowledge within diasporic communities. These digital expressions illustrate how cultural memory continues to adapt in response to technological advancements.



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Moreover, scholars highlight that digital diaspora fosters the emergence of hybrid identities that intertwine elements of homeland culture with global influences. The accessibility afforded by digital communication enables migrants to remain connected to their homeland while concurrently engaging with the cultural life of their host society. Consequently, identity formation becomes a multidimensional process molded by both physical migration and virtual engagements. Despite the expanding corpus of research on diaspora and digital culture, there remains an urgent need for scholarly inquiries that bridge the gap between literary representations of diaspora and contemporary forms of digital self-representation. Existing studies frequently concentrate on either diasporic literature or digital communities, yet few attempts have been made to explore the intersections of these two domains. By analyzing literary narratives alongside digital practices, researchers can achieve a more profound understanding of how cultural memory manifests across diverse modes of representation. Accordingly, this study contributes to the existing body of scholarship by investigating how cultural memory influences identity formation within diasporic narratives, all while considering the role of digital media in extending these phenomena. By synthesizing insights from diaspora studies, cultural memory theory, and digital media studies, this research elucidates the evolving nature of diasporic identity in the contemporary globalized landscape.

Theoretical Framework

This research investigates the interplay between cultural memory, diasporic identity, and digital self-representation by employing theoretical frameworks from cultural studies and memory studies. Notably, the ideas put forth by Stuart Hall, Jan Assmann, and Avtar Brahmin offer critical insights into the processes of identity construction and representation within diasporic settings. These theories elucidate how migrants navigate their identities between the cultures of their homeland and their host country, emphasizing the essential role of memory in preserving cultural belonging across geographical divides.

Cultural Identity and Representation

Stuart Hall's conception of cultural identity is pivotal for understanding the development of diasporic identity. Hall contends that cultural identity should not be regarded as a static or inherent trait originating solely from history. Rather, identity is a fluid and evolving construct, continually influenced by historical events, cultural exchanges, and social contexts. According to Hall, identity is formed through modes of representation and discourse, suggesting that individuals cultivate their sense of self through cultural narratives, language, and social practices. In diasporic communities, the formation of identity often entails a negotiation among various cultural influences. Migrants typically encounter a sense of dislocation as they transition from their homeland to a new cultural landscape. This dislocation necessitates that individuals adapt to unfamiliar social norms while striving to retain elements of their cultural legacy. Hall articulates this process as an ongoing negotiation between past and present, resulting in a diasporic identity that embodies a hybrid character, merging facets of both the homeland and host culture.

Hall further underscores the significance of representation in molding cultural identity. Forms of cultural expression such as literature and film are instrumental in conveying the experiences of diasporic communities. Through narrative techniques, authors can express the emotional and cultural intricacies tied to migration. Such representations enable individuals and communities to comprehend their experiences and forge collective cultural meanings. In the context of this analysis, diasporic literary works such as "Brick Lane" by Monica Ali and "The Lowland" by Jhumpa Lahiri serve as narrative realms where diasporic identities are articulated and examined.

Cultural Memory and Diaspora

Jan Assmann's concept of cultural memory offers an additional crucial theoretical framework for the exploration of diasporic narratives. Assmann posits that cultural memory encompasses the collective recollections that are preserved and communicated within a community through cultural practices, traditions, and texts. These shared memories nurture a sense of continuity and identity within the group, even over extensive periods. Assmann differentiates between two types of memory: communicative memory and cultural memory. Communicative memory pertains to everyday recollections exchanged through interpersonal communication within families or communities, whereas cultural memory is maintained through cultural institutions such as literature, religious



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ceremonies, festivals, and historical recounting. In diasporic contexts, both forms of memory significantly contribute to the sustenance of cultural identity. For migrants residing far from their homeland, memories associated with cultural customs, language, familial bonds, and daily practices often serve as vital sources of emotional attachment. Literary narratives frequently portray characters who recall their homeland through sensory details, such as cuisine, music, attire, and cultural festivities. These recollections assist diasporic individuals in preserving a symbolic link to their cultural heritage while adapting to new social settings. Within diasporic literature, cultural memory acts as a conduit between past and present. Authors frequently recreate scenes from the homeland to demonstrate how memories influence the identities and emotional journeys of migrants. Through narrative, literature safeguards cultural memory while transmitting it to subsequent generations. This theoretical approach is particularly valuable for evaluating how diasporic figures within novels reconstruct their identities through reflections on their cultural histories.

Diaspora Space and Hybrid Identity

AvtarBrah's theory of diaspora space further enriches the understanding of diasporic identity by highlighting the social and cultural interactions that transpire within multicultural societies. Brah asserts that diaspora should not merely be perceived as a state of dislocation but also as a space where diverse identities and cultural histories converge. Brah defines diaspora space as the social atmosphere in which migrants, native populations, and other communities interact and negotiate their identities. This environment is characterized by cultural exchange, adaptation, and transformation, wherein individuals frequently develop hybrid identities that embody influences from various cultures.

The notion of diaspora space holds particular relevance in contemporary globalized societies, where migration has led to the emergence of multicultural communities. In such contexts, cultural identities are continually reshaped through interactions among disparate cultural groups. Diasporic individuals may concurrently identify with their homeland culture while engaging in the cultural life of their host society. Literary portrayals of diaspora often illustrate this cultural negotiation process, with characters navigating social settings in which traditional cultural values intersect with modern lifestyles and global influences. These narratives emphasize the fluidity of identity in diasporic environments.

Digital Diaspora and Self-Representation

While the theories articulated by Hall, Assmann, and Brah primarily address cultural identity and memory within social and cultural frameworks, the advent of digital technology has introduced new dimensions to the construction of diasporic identity. The concept of digital diaspora pertains to the manners in which migrants utilize digital platforms to sustain connections with their homeland and articulate their cultural identities. Digital platforms such as YouTube, Instagram, and various social media networks empower migrants to share their experiences, cultural practices, and everyday lives with audiences across geographical borders. These platforms serve as virtual arenas where diasporic individuals construct and express their identities. Through digital storytelling, migrants archive elements of their culture, encompassing culinary practices, festivals, language, and familial traditions.

From a theoretical standpoint, digital diaspora can be regarded as an extension of cultural memory and diaspora space. Online communities foster new forms of cultural interaction, enabling diasporic individuals to connect with others who share similar cultural backgrounds. These digital engagements contribute to the preservation and dissemination of cultural memory within contemporary society. Furthermore, digital media empower migrants to actively participate in the representation of their identities, as opposed to relying solely on literary or cultural institutions. Individuals have the opportunity to create and share their narratives, thereby broadening the ways in which diasporic experiences are recorded and understood.

Relevance of the Framework to the Study

The amalgamation of these theoretical frameworks establishes a robust basis for the analysis of diasporic narratives. Hall's notion of cultural identity elucidates the manner in which migrants navigate their self-conception across



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varied cultural landscapes. Assmann's framework of cultural memory underscores the significance of collective recollections in maintaining cultural identity within diasporic communities. Brah's interpretation of diaspora space accentuates the social contexts wherein cultural exchanges and hybrid identities materialize. Collectively, these theories lay the groundwork for exploring how diasporic figures in literary works reconstruct their identities through the interplay of memory and cultural practices. Additionally, the notion of digital diaspora broadens these theoretical perspectives to encompass contemporary modes of digital self-representation. By integrating literary analysis with digital cultural studies, this research endeavors to illustrate the enduring influence of cultural memory on diasporic identity within both traditional narratives and present-day digital arenas.

METHODOLOGY

This study adopts a qualitative textual analysis to examine the relationship between cultural memory and identity formation in diasporic narratives. The research focuses on two contemporary diasporic novels: *Brick Lane* by Monica Ali and *The Lowland* by Jhumpa Lahiri. These texts were selected because they provide rich representations of migrant experiences and explore themes such as displacement, cultural memory, and identity negotiation within diasporic contexts. The study analyzes narrative elements including character development, representations of homeland memories, cultural practices, and social interactions within migrant communities. Particular attention is given to how memories of homeland traditions, family relationships, and cultural rituals influence the identities of diasporic characters. The analysis is guided by theoretical perspectives from cultural studies and memory studies, particularly the concepts of cultural identity proposed by Stuart Hall, cultural memory developed by Jan Assmann, and diaspora space introduced by Avtar Brah. In addition to literary analysis, the study also interprets the idea of digital diaspora by examining how migrants use social media platforms to share cultural practices and personal experiences. These digital practices are discussed in relation to the literary representations of diaspora in order to highlight the continuity between traditional narrative forms and contemporary digital self-representation.

Through this interdisciplinary approach combining literary analysis and digital cultural studies, the research aims to demonstrate how cultural memory functions as a central element in the formation of diasporic identity across both textual narratives and digital environments.

Analysis of Brick Lane

Monica Ali's novel *Brick Lane* offers a profound exploration of diasporic existence and the development of identity within the Bangladeshi immigrant community in London. The narrative centers around Nazneen, a young woman who relocates from Bangladesh to England through an arranged marriage. Through her journey, the novel illustrates the emotional, cultural, and societal obstacles that migrants confront as they navigate their identities amid the interplay of their homeland and hostland cultures. This work is particularly noteworthy for demonstrating how cultural memory influences the identities of diasporic individuals and the ways in which migrants gradually reconstruct their sense of belonging in a new cultural context. Initially, Nazneen's identity is deeply entwined with the cultural traditions and societal expectations of her homeland. Raised in a rural Bangladeshi village, she is conditioned to accept her circumstances, adhering to the belief that fate governs human destiny. Upon her arrival in London with her husband Chanu, she grapples with cultural alienation and dislocation. The unfamiliar surroundings, language barriers, and social disparities exacerbate her sense of estrangement. Her early experiences in London are largely confined to her apartment, a setting that epitomizes the restricted social mobility commonly faced by immigrant women. During this phase, her memories of Bangladesh are pivotal in preserving her emotional ties to her cultural heritage.

Cultural memory frequently manifests in Nazneen's reflections on her family and childhood. Her recollections of her mother, village life, and traditional values act as emotional stabilizers, aiding her in coping with the strange landscape of London. These memories resonate with Jan Assmann's theory that cultural memory enables communities to maintain their collective identity across generations. Within the novel, reminders of her homeland



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culture serve as significant symbols of Nazneen's origins and inform her self-perception as a diasporic individual. Furthermore, the novel examines cultural identity through quotidian practices such as food, clothing, and language, which serve as identity markers connecting characters to their homeland. The act of preparing traditional Bangladeshi dishes, for instance, becomes an avenue for Nazneen to uphold her cultural legacy within her London home. Culinary traditions depicted in the narrative signify a continuity of heritage, illustrating how migrants recreate elements of their homeland culture within a foreign backdrop. Such rituals exemplify that cultural identity is preserved not only through memory but also through everyday practices.

Chanu's character introduces another dimension of diasporic identity. In contrast to Nazneen, he is well-educated and harbors ambitious aspirations for success in Britain. Yet, he encounters persistent obstacles to social mobility due to systemic discrimination. His experiences underscore the frustrations that many migrants face in their quest for recognition and acceptance within society. Chanu's continual references to Bangladeshi culture and history signify his endeavor to maintain a sense of pride and identity despite his marginalization in British society. The novel thus delineates the conflict between aspiration and reality in the migrant experience through Chanu's characterization. As the plot unfolds, Nazneen gradually begins to reassess the conventional beliefs that previously dictated her identity. Her encounters with a broader social environment in London foster a burgeoning sense of independence. The city emerges as a critical setting where diverse cultures converge, encapsulating AvtarBrah's concept of diaspora space. Within these multicultural contexts, migrants confront new societal influences that challenge their prior notions of identity and community belonging.

Nazneen's evolution becomes increasingly apparent through her relationship with Karim, a young Bangladeshi activist engaged in local political endeavors. Karim epitomizes a younger generation of migrants who proactively negotiate their cultural identity within the host society. His activism reflects the collective struggles of immigrant communities seeking acknowledgment and representation. Through her interactions with Karim, Nazneen begins to engage more actively with the socio-political realities of her diasporic community. This narrative arc highlights the fluidity of cultural identity, as articulated by Stuart Hall, who posits that identity is not a static essence but a dynamic process shaped by historical and social contexts. Nazneen's journey exemplifies this maturation, as she transitions from passive acceptance to active self-determination. Her choice to remain in London instead of returning to Bangladesh signifies her embrace of a hybrid identity that encompasses aspects of both cultures.

The novel also reflects on the experiences of the broader Bangladeshi community in London. Through illustrations of neighbourhood dynamics, social events, and communal organizations, the narrative showcases how migrants forge collective spaces that sustain their cultural practices. Such community interactions reinforce the importance of cultural memory in nurturing diasporic identity. Observances of festivals, religious customs, and social gatherings enable migrants to retain their sense of belonging, despite being distanced from their homeland.

Moreover, the letters from Nazneen's sister Hasina in Bangladesh serve as an essential narrative element linking the homeland with the diasporic narrative. These correspondences illuminate the socio-economic realities in Bangladesh while simultaneously revealing the emotional chasm between the sisters. Through this dual narrative framework, the novel underscores how diasporic identity is molded by the ongoing interplay between experiences in the homeland and the host country. Towards the conclusion of the novel, the theme of self-realization emerges as a focal point. Nazneen eventually declines Karim's proposal and opts to forge an independent life for herself and her daughters in London. This decision exemplifies her evolving confidence and autonomy. Instead of returning to Bangladesh or depending on patriarchal authority, she embraces a new identity shaped by both her cultural roots and her experiences in Britain. Her transformation signifies the development of a hybrid diasporic identity that transcends conventional cultural and geographical confines. In this context, *Brick Lane* illustrates the intricate process through which migrants navigate their identities within multicultural societies. The narrative emphasizes that cultural memory is instrumental in maintaining connections to one's homeland while simultaneously enabling individuals to adapt to novel social settings. Nazneen's trajectory from isolation to empowerment resonates with the broader experiences of numerous diasporic individuals who progressively redefine their sense of belonging. Ultimately, the



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novel conveys that diasporic identity is not exclusively characterized by displacement or nostalgia but is informed by the continuous dialogue between memory, culture, and social change. Through its rich depiction of migrant life, *Brick Lane* offers a compelling analysis of how cultural memory and quotidian practices contribute to the formation of hybrid identities in contemporary diasporic communities.

Analysis of The Lowland

Jhumpa Lahiri's novel *The Lowland* provides a nuanced examination of migration, memory, and identity within the framework of the Indian diaspora. The story focuses on the lives of two brothers, Subhash and Udayan, who are raised in Calcutta amidst significant political turmoil. While Udayan engages with the Naxalite political movement in India, Subhash ultimately relocates to the United States to further his academic pursuits. Through the experiences of these characters, the novel scrutinizes the ways historical events, individual decisions, and cultural recollections contribute to the development of diasporic identity across generations. Central to the narrative is the theme of displacement. Subhash's migration marks the onset of his journey as a diasporic individual. Initially, he grapples with feelings of isolation and cultural estrangement in an unfamiliar setting. The challenges posed by foreign social customs, linguistic barriers, and the absence of family create an emotional disconnect from both his native land and the new society in which he finds himself. Such experiences resonate with a recurrent motif in diasporic literature, where migrants often navigate the complexities of existing between two cultural realms. Despite the physical distance, the memories of India are profoundly ingrained in Subhash's psyche. His recollections of childhood, familial bonds, and cultural rituals continue to inform his identity. These memories act as emotional ties that link him back to his homeland. This depiction aligns with Jan Assmann's theory of cultural memory, which posits that collective memories preserved through cultural narratives and practices enable communities to sustain a sense of continuity across time and space. Within *The Lowland*, memories of India serve as symbolic touchpoints of Subhash's cultural origins even as he acclimatizes to life in the United States.

Another significant aspect of the novel is the impact of political history on personal identity. Udayan's involvement in the Naxalite movement encapsulates the tumultuous political landscape of India during the late 1960s and early 1970s. His activism ultimately culminates in tragic outcomes that deeply affect his family members. Following Udayan's death, Subhash marries Gauri, Udayan's pregnant widow, and brings her to America to offer her stability and support. This decision introduces an additional layer of diasporic experience, as Gauri herself embarks on the journey of navigating a new cultural terrain. Gauri's character embodies a distinct response to the challenges of diasporic displacement. In contrast to Subhash, who endeavors to sustain ties to his cultural heritage, Gauri progressively detaches herself from her past. She immerses herself in academia and philosophical inquiry, seeking intellectual autonomy and personal liberation. Her evolution illustrates the intricate processes of identity formation within diaspora, where individuals may respond to cultural dislocation in myriad fashions. For Gauri, migration emerges as an opportunity to reconstruct her identity beyond the societal expectations imposed by her familial and cultural background in India. The generational aspect of diasporic identity is further examined through Bela, the daughter of Udayan and Gauri, who is nurtured by Subhash in the United States. Bela's upbringing is influenced by a blend of Indian cultural elements and American societal values. Nonetheless, her grasp of her cultural heritage remains fragmented due to the emotional divide between her and her mother. Bela's identity epitomizes the challenges encountered by second-generation migrants, who often contend with a sense of cultural ambiguity.

Bela's experiences personify the dynamic nature of cultural identity articulated by Stuart Hall, who argues that identity is continuously shaped by historical and social contexts, rather than being static or predetermined. As a second-generation diasporic individual, Bela constructs her identity through her unique experiences rather than solely relying on inherited cultural practices. Her ultimate choice to lead an independent and socially conscious life reflects the interplay of both her familial legacy and her American environment. The symbolic significance of *The lowland* itself plays an integral role within the novel's thematic structure. *The lowland*, a marshy region near the brothers' childhood residence in Calcutta, serves as a site of their formative years. It later becomes the scene of Udayan's demise, evolving into a powerful symbol of memory, loss, and historical trauma. For the characters, the



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lowland signifies a physical and emotional space where personal and political narratives converge. The persistent references to this locale throughout the narrative underscore the enduring impact of memory on the characters' lives. The novel additionally emphasizes the emotional ramifications of migration and displacement. Subhash's existence in the United States is characterized by a quiet sense of obligation as he strives to provide stability for Bela and Gauri. However, his roles as a surrogate father and husband introduce emotional intricacies that shape his sense of self. The narrative navigates his experiences with subtle introspection, illustrating how migration can yield both opportunities and emotional complexities.

Another critical element of the novel is the depiction of cultural hybridity. As the characters oscillate between India and the United States, they encounter diverse cultural expectations and social norms. These experiences gradually reshape their identities, fostering hybrid cultural perspectives that amalgamate elements from both societies. This phenomenon aligns with AvtarBrah's concept of diaspora space, in which migrants negotiate their identities within multicultural environments influenced by a variety of cultural backgrounds. Through its multi-generational narrative framework, *The Lowland* illustrates the evolving nature of diasporic identity over time. The experiences of Subhash, Gauri, and Bela exemplify the notion that identity formation within the diaspora is not a singular event, but rather a continuous process shaped by memory, history, and personal decisions. The novel posits that migration not only transforms individuals but also reconfigures familial relationships and generational connections. Furthermore, the narrative accentuates the importance of storytelling in the preservation of cultural memory. By chronicling the histories of the characters along with the political events that influenced their lives, the novel itself serves as a form of cultural memory, documenting the experiences of migrants and their families. Literary works such as *The Lowland* thus function as cultural archives that safeguard the emotional and historical dimensions of diasporic existence.

In conclusion, *The Lowland* offers a profound examination of migration, memory, and identity within the context of the Indian diaspora. Through its depiction of multiple characters across various generations, the novel elucidates the interplay between cultural memory, historical occurrences, and personal experiences in shaping diasporic identity. The narrative conveys that identity within the diaspora is fluid and perpetually evolving, influenced both by memories of the homeland and the realities of life within the host society.

Digital Diaspora and Social Media: Cultural Memory in Online Spaces

In the contemporary globalized world, digital technology has significantly transformed the ways in which diasporic communities maintain connections with their homeland and represent their identities. With the rapid expansion of social media platforms such as YouTube and Instagram, migrants are no longer limited to traditional forms of communication such as letters or telephone calls. Instead, digital platforms have created new virtual spaces where diasporic individuals can share experiences, memories, and cultural practices with global audiences. This phenomenon is often described as digital diaspora, a concept that highlights how online networks enable migrants to construct and perform their identities across geographical boundaries. Digital diaspora can be understood as an extension of the cultural and social processes traditionally associated with diaspora. While earlier diasporic communities relied on literature, oral storytelling, and community gatherings to preserve cultural memory, contemporary migrants increasingly use digital media to document and circulate their cultural experiences. Through videos, photographs, blogs, and social media posts, migrants create digital narratives that reflect their hybrid identities and transnational lifestyles.

One of the most visible aspects of digital diaspora is the sharing of everyday cultural practices through online platforms. Migrants frequently produce content related to cooking traditional food, celebrating festivals, speaking their native languages, and documenting family traditions. These digital expressions function as forms of cultural preservation, allowing individuals to maintain connections with their cultural heritage even while living far from their homeland. For example, many diasporic content creators upload cooking videos that demonstrate traditional recipes from their home countries. Such videos not only preserve cultural knowledge but also introduce global audiences to diverse culinary traditions. Food-related digital content is particularly significant in the context of diasporic identity because food often functions as a powerful symbol of cultural memory. Preparing and sharing



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traditional dishes can evoke memories of childhood, family gatherings, and homeland environments. When migrants upload cooking videos or share food photographs online, they transform these personal memories into collective cultural experiences that can be accessed by other members of the diaspora. In this way, digital media becomes a tool for transmitting cultural memory across generations and geographical boundaries. Digital platforms also enable migrants to construct narratives about their everyday lives in the host society. Through vlogs, travel diaries, and lifestyle content, diasporic individuals share their experiences of adapting to new cultures while maintaining connections to their cultural roots. These narratives often highlight the challenges and opportunities associated with migration, including language barriers, cultural differences, and the search for belonging. By documenting these experiences online, migrants create digital archives that reflect the evolving realities of diasporic life.

The process of sharing personal experiences online can be understood as a form of self-representation. Unlike traditional media, where narratives about migrants are often produced by external institutions, digital platforms allow individuals to represent their own identities and experiences. This shift in representation is particularly important for diasporic communities, as it enables migrants to challenge stereotypes and present more nuanced portrayals of their cultural identities. The concept of cultural identity proposed by Stuart Hall is highly relevant in understanding these digital practices. Hall emphasizes that identity is not fixed but continuously constructed through representation and cultural interaction. Social media platforms provide new spaces where such representations can occur. Migrants can experiment with different aspects of their identities by sharing content that reflects both their homeland culture and their experiences in the host society. This process often results in hybrid cultural expressions that combine traditional practices with global influences.

Digital media also plays an important role in strengthening transnational connections within diasporic communities. Migrants can communicate with family members and friends in their homeland through online platforms, reducing the sense of distance created by migration. In addition, digital communities allow individuals with similar cultural backgrounds to connect with each other regardless of their geographical location. These virtual networks create a sense of belonging that extends beyond physical borders.

From the perspective of cultural memory, digital media functions as a new medium through which collective memories are preserved and shared. The theory of cultural memory developed by Jan Assmann suggests that communities maintain their identities through cultural narratives and symbolic practices. In the digital age, online platforms serve as new cultural spaces where these memories can be recorded and transmitted. Photographs, videos, and personal stories posted on social media become digital records that preserve aspects of cultural heritage. Another important feature of digital diaspora is the creation of online communities centered around shared cultural experiences. Migrants often follow content creators from similar cultural backgrounds who share relatable experiences of living abroad. These interactions generate discussions about identity, culture, and belonging. Through comments, messages, and collaborative content, individuals participate in collective conversations about diasporic life. Such interactions contribute to the formation of virtual diaspora spaces where cultural identities are continuously negotiated and redefined.

The concept of diaspora space introduced by Avtar Brah can also be applied to digital environments. While Brah originally described diaspora space as a physical social environment where different cultures interact, digital platforms extend this concept into virtual realms. Social media networks function as digital diaspora spaces where migrants and non-migrants interact, exchange ideas, and engage with cultural narratives. These online spaces reflect the multicultural interactions that characterize contemporary global societies.

Digital storytelling also allows migrants to challenge dominant narratives about migration. In many traditional media representations, migrants are often portrayed through simplified or stereotypical images. However, social media platforms provide opportunities for individuals to share more complex and personal perspectives. By documenting their achievements, struggles, and everyday experiences, migrants present alternative narratives that highlight the diversity of diasporic identities.



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Furthermore, the accessibility of digital technology enables younger generations of diasporic communities to engage with their cultural heritage in new ways. Second-generation migrants who may have limited direct experience with their ancestral homeland can learn about their cultural traditions through online content produced by other members of the diaspora. Digital platforms therefore play an important role in bridging generational gaps within diasporic communities. The relationship between digital media and literature is also noteworthy. While novels such as *Brick Lane* and *The Lowland* provide narrative representations of diasporic experiences, digital platforms allow individuals to actively participate in the creation of similar narratives. Through videos, blogs, and social media posts, migrants document their personal journeys in ways that resemble literary storytelling. This interaction between literature and digital media demonstrates how diasporic narratives continue to evolve across different cultural forms. In conclusion, digital media has transformed the ways in which diasporic communities preserve cultural memory and represent their identities. Platforms such as YouTube and Instagram provide virtual spaces where migrants can share their experiences, traditions, and personal stories with global audiences. These digital practices extend traditional forms of cultural memory and create new opportunities for identity construction in transnational contexts. By connecting literary representations of diaspora with contemporary digital expressions, it becomes clear that the formation of diasporic identity is an ongoing process shaped by both cultural memory and technological change.

CONCLUSION

The exploration of diasporic narratives illustrates that migration encompasses far more than merely relocating; it represents a multifaceted cultural and emotional journey that profoundly influences identity in various respects. Individuals within diasporas often find themselves in a continual negotiation between the culture of their homeland and the social fabric of their host country. This paper has investigated the role of cultural memory in shaping identity within diasporic narratives and how these literary portrayals resonate with modern forms of digital self-representation. By examining the novels *Brick Lane* by Monica Ali and *The Lowland* by Jhumpa Lahiri, this work elucidates the impact of recollections of homeland traditions, familial bonds, and cultural practices on the experiences and identities of diasporic individuals.

The analysis of *Brick Lane* reveals how migrants reconstruct their identities through the lens of memory and daily cultural practices. Nazneen's transformation from isolation to autonomy encapsulates the broader experiences shared by numerous diasporic individuals who progressively redefine their identities within multicultural contexts. The novel articulates cultural memory through elements such as familial customs, culinary traditions, and community interactions, which serve as symbolic connections to the migrants' homeland. These portrayals underscore the ways in which cultural memory fosters emotional ties and assists migrants in upholding their cultural heritage while adapting to new societal landscapes. Conversely, *The Lowland* offers a multigenerational lens on diasporic identity, highlighting the experiences of characters straddling the cultural divides between India and the United States. Through the narratives of Subhash, Gauri, and Bela, the book illustrates how historical events, personal decisions, and familial relationships shape the evolution of identity across generations. The narrative affirms that cultural memory continues to sculpt diasporic identity, even as individuals strive to dissociate themselves from their pasts. The symbolic significance of the lowland connotes that memory and history remain intricately woven into the lives of migrants.

The theoretical frameworks proposed by Stuart Hall, Jan Assmann, and Avtar Brah offer essential perspectives for interpreting these literary depictions. Hall's concept of cultural identity underscores that identity is not static but is perpetually molded by historical and social interactions. Assmann's theory of cultural memory elucidates how collective recollections, maintained through narratives and cultural practices, sustain a sense of cultural continuity. Brah's notion of diaspora space emphasizes the multicultural settings in which migrants negotiate and reinvent their identities. In addition to literary narratives, this study also investigates the influence of digital media on the formation of contemporary diasporic identities. Platforms such as YouTube and Instagram have forged new virtual avenues for migrants to share their experiences, cultural traditions, and personal memories with a global audience.





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These digital arenas serve as modern extensions of cultural memory, enabling diasporic communities to maintain ties to their homeland while engaging in transnational cultural networks. Through digital storytelling, migrants actively construct and articulate their identities, expanding the modalities through which diasporic experiences are recorded and comprehended. By linking literary narratives to contemporary digital practices, this study underscores the fluid and evolving nature of diasporic identity in the twenty-first century. While traditional diasporic literature captures the emotional and cultural nuances of migration, digital media presents new avenues for individuals to convey their experiences and sustain cultural connections across geographic divides. Both forms of representation affirm that cultural memory remains a pivotal element in the formation of diasporic identity. Ultimately, diasporic identity should be regarded as a dynamic and multifaceted process influenced by memory, culture, and social interactions. The experiences depicted in *Brick Lane* and *The Lowland* illustrate that migrants incessantly negotiate their sense of belonging in relation to multiple cultural spheres. Concurrently, digital media has broadened the venues for these negotiations, allowing diasporic communities to preserve and reshape their cultural identities in innovative ways. By examining the intersection of literature, cultural memory, and digital self-representation, this study contributes to a nuanced understanding of how diasporic identities are constructed and expressed in an increasingly interconnected global milieu.

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RESEARCH ARTICLE

Undergraduate Students' Perspectives on Artificial Intelligence in Task-Based Language Teaching

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ABSTRACT

The emergence of Artificial Intelligence (AI) has transformed all domains of education including English language teaching and learning. AI is integrated in English language classrooms including TBLT Classrooms. Task Based Language Teaching (TBLT) emphasizes authentic tasks, learner interaction, and meaningful language use. Negotiation and exchange of meanings are central in the task-based learning since the focus is on communication while completing a given task. Task Based Language Teaching (TBLT) focuses on real-world tasks designed to meet individual learners' needs and to develop their communicative competence, requiring learners' active involvement and participation in completing the tasks. This paper examines undergraduate students' perspectives on using AI in TBLT classrooms. An open-ended questionnaire was administered to ten undergraduate students in order to collect the data and the data was analysed and interpreted thematically. The result demonstrates that AI scaffolds the learners during all the stages of TBLT, provides the learners with numerous learning opportunities and there are some challenges that AI poses in TBLT classrooms.

Keywords: Perspectives Task-Based Language Teaching (TBLT) Artificial Intelligence (AI) Opportunities Challenges

INTRODUCTION

English language teaching and learning have been revolutionized since the advent of Artificial Intelligence (AI) in language education and AI technologies have become an integral part of teaching and learning processes. Task-Based Language Teaching (TBLT) prioritizes meaningful interaction through authentic tasks rather than teaching isolated grammatical items. In other words, the learners have to do a particular task and the focus of the lesson is on tasks not



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on structures. TBLT works in a language learning classroom focusing on providing opportunities for real life meaningful communication. Language acquisition occurs most effectively when learners engage in meaningful negotiation during interaction.

Task-Based Language Teaching

Task Based Language Teaching (TBLT) refers to language teaching which enables learners to acquire language by doing a task without focusing on language elements. According to Nunan (1989) “Task Based Teaching and Learning is teaching and learning a language by using language to accomplish open ended tasks. Learners are given a problem or objectives to accomplish but left with some freedom in approaching this problem or objective” (49). Willis and Willis (2001) elaborated the term by adding communication to it and termed as, “Task Based Learning (TBL) involves the specification not of a sequence of language items, but of a sequence of communicative tasks to be carried out in the target language” (173). Ellis (2003) views that “TBL is mostly about the social interaction established between learners as a source of input and means of acquisition, and involves the negotiation of meaning, communicative strategies, and communicative effectiveness” (p. 65). In short, tasks have become central in the TBLT classroom (Brown, 2007). According to Williams and Burden (1997) a task is “any activity that learners engage into further the process of learning a language” (p.168). Tasks can be activities that range from simple and brief exercises to complex and lengthy activities like problem solving and decision making (Breen, 1987) and they create meaningful contexts for language use (Stern, 1992). Willis (1996) believes that “tasks are always activities where the target language is used by the learner for a communicative purpose (goal) in order to achieve an outcome” (p. 23). In short, TBLT is a learner centred approach and it recognizes learners’ experience in learning

Background of the Study

A number of studies have focused on Artificial Intelligence in English language classroom (e.g. C P, 2025; Yan et al., 2024; Zhang et al., 2024) and several studies investigated TBLT in learning English (e.g. Bryfonski & McKay, 2019) across the world. Since AI integration in TBLT is a recent development, very few studies have focused on the use of AI in TBLT Classrooms. Furthermore, the few studies that were done on AI in TBLT investigated its impact on learners in TBLT (e.g. Nissa et al., 2025), how AI enhances English proficiency and students’ engagement (e.g. Xiaojing et. Al., 2024), and effectiveness of AI in TBLT (e.g. Simatupang & Heryono, 2025; Amir et al., 2025).). Nevertheless, students’ perspectives on the use AI in TBLT Classroom have not been explored. Therefore, this paper is an attempt to fill the gap found in the literature as it explores undergraduate students’ view on using AI in TBLT Classrooms.

Purpose

The purpose of this study was to explore undergraduate students’ beliefs about the use of AI in TBLT Classrooms: the role that AI play in TBLT, opportunities that AI provide the learners with in TBLT classrooms and the difficulties that the use of AI cause in TBLT classrooms. As a result, the following questions guided the study.

- What roles does AI play in TBLT classrooms?
- What are the opportunities that AI provide for TBLT classrooms?
- What challenges does use of AI create in TBLT classrooms?

Context, Participants and Methods

This study was done in one of the higher education institutions in Chennai, India. The participants were 10 undergraduate students from the English department. This study used a qualitative approach as the focus was on students’ perception of Artificial Intelligence in Task Based Language Teaching and collected “open-ended, emerging data with the primary intent of developing themes from the data” (Creswell, 2003, p. 18). In addition, an open-ended questionnaire was used to collect the data for this study since open-ended questions collect opinion, feeling and evaluation (Wellington, 2000).

The data analysis was done using the framework given by Miles and Huberman (1994) and thematic interpretation was used to analyze the open-ended questionnaire. Since the data was primarily “textual data”, it employed



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“interpretative analysis” (Croker, 2009, p. 5). Different levels of analysis were done by “moving deeper and deeper into understanding the data and making an interpretation of the larger meaning of the data” (Creswell, 2003, p. 190). In short, the data went through four stages such as data reduction, data display, data conclusion and data verification.

RESULTS AND DISCUSSION

This section discusses the findings of the study. The findings are classified into three sections: AI and task stages, use of AI in TBLT Classrooms and the challenges of using it in TBLT Classrooms.

AI and Stages of Tasks

The data demonstrate that AI plays a significant role in TBLT classrooms and supports learners in the classrooms. All the participants believe that AI is instrumental in all the three stages of TBLT like pre-task, while task and post task stage (Willis, 1996). For instance, according to Participant 3 “AI is integrated into TBLT and used in the three stages of tasks.”

Pre-Task Stage

In the Pre-Task Stage, AI “helps students understand instructions” (participant1), the “background and purpose of the task” (participant8), “clear initial doubts” (participant10), “find meanings of new words” (participant 5), and “generate contextual prompts and helps” (participant 7). Moreover, it can “adapt preliminary and introductory exercises according to learners’ level and proficiency” (participant 9) and the requirement of the tasks. In short, in this stage “AI enhances learners’ readiness” (participant 10) to do the task effectively. The main functions of AI in the pre- task stage are to prepare the students for the task and to lead them in the task by clearing doubts, explaining unknown words, the context and purpose of the task and making sure whether they understand what they are supposed to do in the task.

While Task

During the task, AI is a great help for students. To demonstrate, “AI can assist students in providing instant solutions for task-based language activities. It can give the correct structure of sentences, and examples related to the task” (participant2). Artificial Intelligence “can generate ideas for writing and help organize answers (which) makes easier for students to complete tasks with more confidence and less confusion” (participant1). Similarly, Participant 3 points out “AI gives simple explanations during tasks” and Participant 4 argues “It guides learners with step-by-step suggestions and guidance while completing activities.” Furthermore, “while students are engaged in language tasks, AI applications detect mistakes, provide clues, hints, and explanations, allowing students to make corrections instantly” (participant7). The participants believe that the support that AI provides during the task “makes language tasks easier and helps students learn new words, improve sentences, and complete their work with better understanding” (participant4) and assists students “to complete tasks with more confidence and less confusion” (participant1). The findings indicate that learners use AI while doing their tasks to get ideas and vocabulary, clear doubts, do grammar checking, edit and refine their tasks.

Post Task

The participants believe that AI has profound impact on their learning and it has effects even after the completion of tasks. For instance, “we found that AI also assists us after we finish our tasks” (participant2). AI is a great help for learners in the post task stage through its “automated feedback systems” (participant4). AI enables learners to “reflect on their task performance and revise output systematically” (participant 9) and helps them to practice “structures, grammar items and vocabulary items” (participant 8) generated from the task. All the participants believe that AI has improved their confidence and helped them prepare task report and other post task activities like presentation and writing.



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AI enhances independent learning as it enables them to generate ideas, edit, revise and polish their work independently and engage with AI interactively during all the stages and collaborate with AI to complete tasks. The findings underline the increasing use of AI in language learning in general and task-based learning in particular.

Use of AI in TBLT Classrooms

According to the participants AI is used multiple ways in TBLT Classrooms. To begin with, Artificial Intelligence develops learner autonomy as Participant7 claims “Students become autonomous learners as AI “helps them perform language tasks independently” and Participant 2 argues “By providing hints to students instead of answers, AI applications encourage students to think independently and complete tasks on their own.” Another use of AI is that it “creates interactive contexts for role-play and problem-solving tasks” (participant 8) and “AI applications such as chatbots can assist students in planning role plays, dialogues and presentation of the task” (participant1). Furthermore, tasks make learning interactive, collaborative and communicative as they provide meaningful real time communication opportunities and “authentic communicative practice in diverse contexts” (participant3) where AI acts as a prompter and “simulates conversations” and AI helps learners “practice speaking” (participant8) accurately and “confidently” (Participant7) by “giving real time pronunciation prompt, appropriate words, grammatical and structural suggestions” (participant6). Additionally, AI aids learners’ language acquisition since they nudge learners through the language learning process and its “formative evaluation of the task” (Participant3). Notably, AI can provide the learners with “personalized learning by adapting the complexity of the tasks suitable to learner needs and level” (participant1) and providing personalized practice. As a consequence, learners can “repeat tasks, get extra exercises and additional practice without being embarrassed in front of their classmates” (participant2).

AI provides immediate feedback on tasks and “instant feedback on grammar” (participant7) as it can “quickly check spelling, grammar and sentence structure” (participant1). AI can point out mistakes and suggest better words through its “instant responses” (participant2) which enables learners to improve continuously and “provide personalized feedback on tasks, recommend more appropriate vocabulary or sentence structures without putting learners down” (Participant 2). Consequently, “they can correct themselves as they understand their errors and improve their work without waiting for the teacher” (participant1). In short, “instant feedback from AI enables learners to build their confidence” (participant2), motivate them to do tasks, “develop their language faster” (participant5) and learn how to use the language more accurately” (participant4). Above all, using AI develop skills like “critical thinking” (participnat10), “digital literacy, and problem-solving skills” (participant 4) and improve their accent as “AI tools help learners with pronunciation” (participant8).

In conclusion, AI work as a “scaffold that supplements, but does not substitute, human and peer interaction” (participant1). They believe that AI reduces the teacher’s workload by correcting learners’ errors. Thus, teachers can now focus “more on guiding, supporting, and designing meaningful tasks rather than correcting their routine work” (participnat5). In other words, teachers’ roles have been changed from task provider to task facilitators, designers, and evaluators as AI help them as a tool. AI can make tasks more engaging as the students can interact with AI anytime and it makes learning more fun and enjoyable. Consequently, learning becomes quicker and more efficient.

Challenges of Using AI in TBLT Classrooms

The study also sheds light on the challenges that AI poses in TBLT classrooms. The participant pointed out the issues like overdependence, hallucination, reliability, loss of creativity, critical thinking skills and authenticity of the work. To demonstrate, the participants fear that the learners will depend on “excessively on AI-generated content” (participnat1) which will reduce learners’ “authentic task engagement” (Participant2). As a result of learners’ “overdependence on AI” (participnat6), their “cognitive and mental effort and critical reflection” skills will be weakened. Similarly, Participant 7 points out “Too much reliance on AI tools such as ChatGPT could lead to a lack of critical thinking, creativity, and autonomous language production.” Overreliance on AI in TBLT classroom will make students stop thinking independently as they copy answers without understanding, which can reduce real learning and creativity. Another problem is that there will be “technological inequality” (participant9) as some of the students who are from remote areas cannot access to AI. Furthermore; students will commit plagiarism and misuse AI



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unethically as they submit AI-generated work as their own. To illustrate, “Students may resort to copying answers from AI tools without comprehending them, which could lead to a lack of effective communication skills and a poor development of language skills in the long run” (participant7). “Privacy is another concern, and personal data should not be shared carelessly. Ethical use means learning honestly and responsibly” (participant2). They also point out that AI can give “false information” (participant8) because the content that AI give is “not always true” (participant9). Therefore, they think that AI content is not “reliable” (participnat3) and it needs to be verified.

In order to contain this problem, the participants suggest some measures like creating clear rules, teaching proper use of AI, and designing tasks that require personal opinions and creativity not the one that force the students merely copy from AI. The participants suggested that the learners “must use AI only for help and learning” (participant1) “not for cheating” (participant3) and use it “as a learning aid, not a shortcut” (participant2). Since “respecting rules and being honest is very important” (participant1) in this digitalized world, “it is essential to be honest, respect academic rules, and use technology responsibly” (participant3). To put it another way, students should use AI ethically and avoid copying answers directly. “They must focus on learning rather than just finishing tasks” (participant9); “giving original responses, and using AI only as a learning tool are important ethical responsibilities” (participant4). The results demonstrate the important roles that AI plays in TBLT Classrooms, the numerous opportunities that AI provides for learners and the challenges that the learners face while doing tasks. Effective use of AI in TBLT classrooms require careful guidance and management, critical digital literacy, and ethical and responsible use of AI.

CONCLUSION

The findings of this qualitative study demonstrate that integration of AI in Task Based Language Teaching marks a drastic change in English language teaching. AI offers transformative opportunities for personalization, feedback, and engagement. It is found that AI functions as a scaffolding which stimulates learners’ interaction and increases communication during the tasks and it does not replace teacher expertise or authentic peer interaction. The challenges show us that it is necessary to manage AI use carefully, judiciously and balanced way. Since this study is qualitative in nature and context bound, the result cannot be generalized. Therefore, a longitudinal mixed study would be preferred.

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RESEARCH ARTICLE

Remnants from Earlier Generations: Intergenerational Trauma and the Psychology of Inheritance in Michael Ondaatje's *Running in the Family*

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ABSTRACT

Running in the Family by Michael Ondaatje does not appear to be a memoir but a form of intergenerational trauma reconciliation. In *Blind Faith*, the narrator explains the current generation as mere remnants of the older generation that was destroyed, but mentions the legacies of the chaos that existed in the past. This instability is discussed in this paper as Mervyn Ondaatje portrays it in his extreme intoxication, his fascination with poisonous gas, and the instability that had distorted the whole family set-up. According to family systems theory, the dispersal of the siblings all over the world was not by chance; it was life-saving. As it is written, the magnetic fields would be mad when together with three or more Ondaatjes, or physical distance was a physical coping mechanism of inherited dysfunction. Ondaatje, in the acknowledgements, admits that the book is a portrait or gesture, not a history, and the more the lie is well told, the more the thousand facts. This fact and fiction combination is an effective form of therapeutic reconstruction, a coping system for suppressing childhood trauma. This family disintegration is compounded by the tropical scenery of Ceylon, which is very similar to the removal of the psyche from the house, as affirmed by the heat and the land. The special focus is on children who are subjected to the volatility of parents, including the naked jungle escapades of the father, as well as the psychological disintegration. Finally, the memoir is applied as an exorcism. The writing of the legacy of a fractured lineage is the tool of negotiation, the expression of how the literature may act upon the psychological handicap, and how it may use the narrative reconstruction to heal the family trauma.

Keywords: Intergenerational Trauma, Alcoholism, Memory, Narrative Reconstruction, Family Systems, Inheritance, Psychology





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INTRODUCTION

Intergenerational trauma is not only a professional term but also an experience that is transmitted to generations as family heritage, unwanted by its carriers. Psychologists refer to the concept of transmission of trauma in explaining how unresolved parental and grandparental wounds get imprinted on the psyche of a child. This legacy has an impact on actions, memory, and identity and in most cases, resulting in a trend that is not realized until one takes action to discover it [1]. This heritage can be explored in literature uniquely. It may contain imprecision and articulate silence, and it may pick up the subtlety lost in clinical definitions. Trauma is not an experience, as Cathy Caruth reminds us, but rather it revisits us and insists on being narrated when we are speechless [2].

The dynamic of the family is reflected in the work of Michael Ondaatje *Running in the Family*. Ondaatje writes of the book as less of a memoir than a portrait or gesture a collage of memory, gossip, and invention about a family characterized by disorder, alcoholism, and what the narrator refers to as ruined generations [3]. The question that is posed in this paper is a very simple yet very deep question; how do children manoeuvre in a legacy of such instability? What do you do when you need to write about ancestors that existed on the brink of control without making them caricatures and absolving them of their evil?

This paper, already on the border of psychology and the study of literature, has examined how it is possible that narrative itself can be utilized to process trauma. The blend of fact and fiction done by Ondaatje is not purely a style. This mixture is based on a Sri Lankan culture, in which a well-told lie is good as a thousand truths, and a survival strategy. It helps the writer to deal with some painful truths without being overpowered by them [3]. Within the frame of the theory of trauma, the writing process becomes a sort of exorcism- a manner in which the narrator cajoles with a broken heritage. The article is presented in four movements. First, it discusses how the text comprises the passing of trauma between generations, in which the narrator feels that he is a remnant. Second, it examines the father's alcoholism as an individual pathology and disruption of the family system. Third, it considers how the siblings' global dispersion is a coping strategy. Finally, it ponders on the work of remembering and healing as reflected by the narrative strategy adopted by Ondaatje, which is fragmentation, lyrical, and purposefully unreliable.

Research Focus

This study analyzes the manner in which *Running in the Family* traces the psychological history of inheritance through the use of family tales, alcoholism, and memory as symbols. In the acknowledgments, Ondaatje refers to the memoir as a portrait or gesture rather than actual history, and this study does not ignore this important distinction. It explores the effects that parents' disorders have on their children and how the family forms a family lineage known as remnants by the narrator, as the ruined ones of earlier generations. Using the prism of intergenerational trauma, this paper reveals the importance of rewriting history as a form of therapy. The framework is able to connect certain events, such as train escapades and the Family Hold Back code, to psychological theory, thereby demonstrating how personal behavior is indicative of family health.

The key issues that will promote this analysis are as follows:

1. What does Ondaatje mean by his father's alcoholism as a symbol of the increased psychological consequences of intergenerational trauma?
2. How does the novel demonstrate the loss of family cycles and psychological balance?
3. How do human experience and broader psychological crises reflected in the memoir relate to the transforming dynamics in the family?

These questions address the problem of memory versus fact that is present between memory and fact in both "Blind Faith" and "Final Days." Dipsomania of the father is not regarded as individual failure but as a social interference that has broken the global distribution of siblings. The study examines the role of magnetic fields that the family had to move apart as a survival measure, similar to the displacement of ecology. It also considers the narrator's





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acknowledgement that a well-told lie is a thousand times better than a thousand facts, which places the flexibility of narratives as a survival mechanism. According to Ondaatje, fact and fiction are intertwined to cope with the suffering of inheritance, as storytelling is the key to psychological survival in the chaos of the ancestors. This is in line with more general discourse on the ways in which literature works through trauma and the strengths needed to negotiate disrupted ancestry.

Intergenerational Trauma Themes in *Running in the Family*

Michael Ondaatje in *Running in the Family* is not dealing with historical record as much as the weight of the ancestry. The narrator does not describe his generation as heirs but rather as survivors of a broken lineage. In "Blind Faith," he confessed that certain events expose them as the remains of the previous generations that were annihilated [8]. This kind of feeling can be associated with the theory of trauma, whereby unresolved traumas present themselves in the future in the form of unclaimed past experiences [3]. Instead of a normal household, the Ondaatjes are an ecosystem of their own, stressed, poisoned by alcoholism, paranoia, and colonial displacement. The degradation of one part of the system negatively affects the entire system, a phenomenon that is in line with family systems theory [7]. In this case, the family unit cracks with instability passed down through the years, and the children are left to walk through a world that is the result of the blunders of the past.

Instability is a direct flow between grandparents and children. The home atmosphere was unstable, with the whimsicalness of Lalla Gratiaen and the strict regulations of Philip Ondaatje. This reached its apogee with the extreme dipsomania of Mervyn Ondaatje and the dramatics of Doris Gratiaen. Similar to ecological imbalance, in which a single species causes havoc in the habitat of all others, the activities of the parents destabilized the children. This is the toxicity that was answered by Christopher, Janet, Gillian, and Michael as they dispersed across the world. Ondaatje notes that "Magnetic fields would go crazy in the presence of more than three Ondaatjes," survival required physical distance to succeed [8]. This dispersion was no more than a migration for defense. Separation in narratives of trauma usually keeps individual identity in collective dysfunction. By emigrating to Canada, England, and America, the brothers and sisters played the role of a shield, preventing the collusion of the magnetic fields of their inherited trauma.

This balance is restored by the very structure of the book. It is a form of therapy as the narrator is able to heal his or her suppressed memories and heal a fractured heritage that they have. The realm of trauma fiction usually demands the re-creation of history to create sense out of the fragmented experiences [3]. In the case of Ondaatje, it is not merely a style that is mixed between fact and fiction but it is vital to the healing. This style will help the family to face the debris of the past generation without being engulfed by it. In connecting personal narrative to the rest of the themes of displacement, the memoir demonstrates that recovery requires a joint effort. Reading promotes the knowledge of intergenerational inheritance as being imperative in protecting the future. The family, similar to the environment, needs to be carefully brought back on track to heal the wounds of previous disturbances.

The Father's Alcoholism as a Symbol of Psychological Disruption

In *Running in the Family*, the problem of Mervyn Ondaatje, not only consuming alcohol but also his weakness, is a disruptive system, such as ecological instability in Kingsolver's work. Similar to shifts in climate disorienting migration paths, the dipsomania that characterizes Mervyn upsets the family path and makes the landscape one of uncertainty and terror [8]. The best manifestation of this psychological disturbance is the train escapades. In *Travels in Ceylon*, Mervyn halts a train with a gun and later dashes into the Kadugannawa tunnel naked, believing that it has bombs planted there. In this case, it is a trauma reaction; that is, the person starts playing a game of rehearsing the disorder, not knowing what is safe and what is dangerous [4]. The nudity in the tunnel takes away social decorum and brings out the crude nakedness beneath the colonial patriarch. His insistence that the train was mined is similar to the loss of the butterfly on its usual route; both are lost in a land that has been hostile because of outside influence.

In the "Final Days / Father Tongue" section, paranoia reappears, bringing out the fragmentation of the psyche. Mervyn sees the friends in the shape of poisonous gas and breaks eggs in terror of the same being true. This is



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indicative of hypervigilance, which is typical in survivors of complex trauma, as the environment itself becomes dangerous [1]. The chapter, “The Bone,” creates a vivid image of this weight. Mervyn is spotted in the jungle with a chain of five dogs on ropes, and he has supernatural strength. This picture implies that he is literally keeping the lineage of evil or disorder at bay, preventing it from swallowing the children, but turns himself into a monster in the process [4]. The dogs symbolize the vagrant wickedness of the area, and his hold on them is symbolic control in a battle against internal disintegration.

The family system has been negatively affected, and this has been difficult to overlook. According to family systems theory, addiction upsets all members who are compelled to adapt or disperse [7]. This psychological climate change is directly related to the scattering of the siblings around the globe; the magnetic fields would go wild in the company of more than three Ondaatjes. In the book, *Dialogues*, the children tell about the frightening car journeys in which the father drives drunk on the edges of the cliffs, falls asleep, and the car continues on its way. This physical threat is a reflection of the emotional uncertainty of their upbringing. The children are not able to stay in the home ecosystem, just like butterflies are unable to complete their migration. The life of the father, who was shattered by alcohol, is used as a representation of the instability of the family. His personality determines a mood of emotions, turning charming to violent without any notice. This haphazardness causes the children to resort to survival tactics, like the species to a hostile environment. The role of alcoholism in Mervyn is comparable to the carbon emissions in the family, a toxic by-product that pollutes the air that all people inhale. Ondaatje does not justify these things by re-creating them, but to map the scope of the damage. The reading shows that individual addiction leads to the intergenerational trauma that the new generation must live in, picking up the pieces of the crumbled domestic ecosystem. It is a dynamic that resonates with ecological disruption theory which demonstrates the application of systemic collapse at the universal level.

Narrative Reconstruction as a Reflection of Human Lives

The blurring of fact and fiction in *Running in the Family* serves as a reflection of human psychological survival, as the model shows when describing the behavior of butterflies as a reflection of ecological change. Ondaatje, like the broken migration of the monarch, is an indication of psychological trauma. In the Acknowledgments, Ondaatje states that “the book is not a history, but a portrait or a gesture, adding that in Sri Lanka,” a good story is better than a thousand facts” [9]. This statement is in line with the theory of trauma that argues that memory after a disaster is usually not linear and is rebuilt and never documented [10]. The fact that the narrator realizes that memory is not reliable can be used as a personal awakening, similar to how Dellarobia realizes that there is climate change. The mechanism to deal with this instability is writing, which makes sense of chaotic memory into an orderly narrative [11].

The text tells different stories concerning the main events, such as the drowning accident of the mother or the train rides of the father. In the lunch conversation, various family members give different versions of the same story of how the grandmother Lalla almost drowned while moving between being a hero and inaction [12]. Similarly, the adventurous escapades of the father during train travel differ between halting the engine and running naked inside a tunnel that is thought to be mined. Such contradictions are not mistakes but indications of how families work with shame and trauma through myth-making. This is a reflection of the theme of the model on human ignorance and denial, in which the community first rejects ecological anomalies. In this case, the family rejects the painful facts to embrace simple narratives. The narrator is a skeptic who later realizes that these differences shield the mind from too much pain [13].

Storytelling is a form of therapeutic intervention. The process of narration enables the speaker to bargain the heritage of a broken ancestry, just as scientific research bases ecological knowledge. Ondaatje focuses more on the subjective experience of trauma than on hard facts by adopting the well-told lie. This leads to the consideration of the way in which the family history is fade away so easily, and the importance of the personal and community memory. The story indicates that the healing process involves counterattack on the fractured self. The memoir suggests that to restore harmony within a family, one must accept the lack of stability in memory itself, as the memoir urges the



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reader to recognize the larger implications of inherited pain. In this view, the text shows that truth in trauma stories is not based on factual faithfulness but rather on emotional appeal, so that the story can survive when history is so harmful that it cannot be told without endangering the narrator.

Colonial Context and Family Systems Equity

In *Running in the Family*, Ceylon serves not as a fixed location but rather as a compounding agent to the psychological disintegration of the family. The deterioration of the colonial plantation, Rock Hill, is a reflection of the breakdown of the Ondaatje family, suggesting that political and environmental stressors contribute to a higher incidence of domestic instability. Ondaatje refers to the Karapothas—the foreigners who come, plunder the material resources, and leave—as an allegory of the impermanence of colonial power and the consequent cultural displacement [14]. This impermanence trickles into the family setup where alcoholism of the father leads to the equivalent cycle of presence and absence. The weather is even oppressive; the heat and monsoons increase the tension and reflect the instability of political life of the postcolonial period.

The corrosion of the Rock Hill is an indication of the corrosion of family equity. The family loses its ground as the estate is subdivided and sold to pay for the shortage of money. This lack of resources is directly associated with the father's addiction, which consumes resources that should be used to stabilize the children. The F.H.B. Such rationing can be reminiscent of the unfair allocation of resources in colonial economies, where the pressure of scarcity is disproportionately placed on the vulnerable.[15] Triangulation and resource hoarding in family systems theory interfere with the emotional balance necessary for healthy development. Triangulation and resource hoarding in the family systems theory interfere with the emotional balance necessary for healthy development.

First, the novel is a criticism of the impact of environmental and economic crises on the most vulnerable members of the family. The scattering of the children across the world is a direct reaction to the toxic atmosphere generated by the instability of parents, such as communities running away to escape ecological dangers. In addition, the text highlights the conflict between the settler colonialists, the Karapothas, and the indigenous people. The lack of family self-establishment is the way the colonial experience failed to sustainably establish itself on the land, which created a legacy of displacement [16].

Finally, the crash of the colonial disintegration into the family crises reveals a clear injustice in the household. There is a similarity here to ecology: as the environmental loads have to be distributed equally, so do the families have to get equal share of emotional and material resources to operate. It is the survival strategy that enabled the Ondaatje kids to escape this ascending terrain despite being caught in the magnetic fields of an addicted and baggage-ridden family. The memoir indicates that without identification of such systemic imbalances, be they political or personal, then there is no healing possible. Harmony can only be restored to the broken lineage by simply recognizing them.

CONCLUSION

The family fractures in the Ondaatje family are indicative that trauma is not normally a one-time event and is more of a systematic continuation of trauma through the generations. The dysfunction that characterizes the family in *Running in the Family*; be it the alcoholism of Mervyn or the strangeness of Lalla is not a individual pathology, but is rather an indication of a greater imbalance in the family unit [7]. The children perceive themselves as survivors of a family that was already destroyed, and they are not only inheriting the memories, but also a large burden of the instability in their minds. According to this conveyance, unless the cycle is broken, the turbulences of the past are sure to spill over into the present and leave future generations with the task of maneuvering around a world that was created by the errors they have not made [1].

But Ondaatje does not only give a diagnosis of such a breakdown in his memoir; he also suggests storytelling as a method of restoration. The fact mixes with fiction enables the author to do not merely document his history but, on





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the contrary, to rewrite it to render the trauma manageable. This is in agreement with the trauma theory which implies that the survivors have to re-construct their disintegrated memories to seek some form of coherence [4]. When Ondaatje implies that good lie can indicate more than a thousand facts, he does not deny the reality. Rather he is employing a survival strategy which enables him to face some ugly facts without being devoured by them [5]. Writing is the way of grounding the disorganized vitality of the family, transforming the dull silence of painful experience into a communal narrative that is subject to analysis, not mere experience. The book does not provide a well-tied conclusion, just sticks around in the olfactory aspects of a last morning. The narrator is lying in the dark where he can hear the rain on the wall and the fan running above him. The pictures of the slow light, the anxious rain birds, and the shinning fan blades indicates that there is no cure of the traditional meaning. Rather, the process of healing is only present in being awake and in the present. The rain has not stopped, the fan is still rotating, and the past has not vanished; the narrator never feels paralyzed by it anymore. He is inside the storm, where he recognizes the connection of continuity with the environment and lineage.

Just as the model paper tackles the issue of the future of the planet, the urgency of ensuring the future of the Lineage is highlighted in the current research. Similarly to ecological equity, which requires a just sharing of the environmental burden, psychological health means that familial history ought to be fairly processed. According to Ondaatje, the solution to protecting the future is to break the silence cycle through which trauma can spread. The author documents the destroyed generations to provide his children and readers with a map that would help them understand the root cause of their instability. The memoir is an ode to the strength needed to overcome a divided heritage and call for a shared duty to mend the damage of the past in order to have something better than ashes in the future. Finally, the book is not simply a portrait of a family but a gesture of survival in the context of inevitable rot.

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RESEARCH ARTICLE

Resilience and Self-Realization in the Female Protagonists of Selected Novels by Sudha Murty

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ABSTRACT

Sudha Murthy supports women and encourages them to exhibit resilience throughout challenging circumstances through her efforts. The primary aim of this study is to examine the challenges encountered by the female protagonists in Sudha Murthy's selected novels, *Gently Falls the Bakula*, *House of Cards*, and *Mahaswetha*, and how they transcend their quotidian lives in pursuit of a more meaningful existence and the attainment of their aspirations. A comprehensive assessment of the research literature was conducted to achieve the study's objective. Three works, namely '*Gently Falls the Bakula*,' '*House of Cards*,' and '*Mahaswetha*,' have undergone critical analysis. We also examined the research articles published in peer-reviewed journals. We examined the challenges faced by women and their strategies for overcoming them to achieve a fulfilling life, as presented in the literature. The study's findings reveal the brutality, degradation, and exploitation faced by female protagonists in books such as *Anupama*, *Mridula*, and *Shrimati*. The principal themes of "*Gently Falls the Bakula*," "*House of Cards*," and "*Mahaswetha*" encompass the dynamics of male-female relationships, societal norms, and the pervasive sense of isolation in contemporary existence. The female characters in the books *Mridula*, *Srimati*, and *Anupama* are shown as uncomplicated, diligent, and innocent. Conversely, the male characters—Sanjay, Srikant, and Anand—are profoundly swayed by the allure of luxury, comfort, and consumerism, ascending the corporate hierarchy while neglecting the significance of familial bonds. The man's avarice for power, fortune, and social standing has adversely affected the women in the narrative. The ladies in the narrative recognize that deceptive ideals and financial gain do not equate to genuine achievement. They strive diligently to surmount the obstacles presented by a patriarchal culture to attain meaning in their life. The selected books for analysis address ethical and societal ideals. Life is shown as a journey characterized by the processes of learning and unlearning, confronting many issues and obstacles



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that evaluate one's tenacity and motivation. The figures depicted by Sudha Murthy illustrate how these issues facilitate decision-making. Despite the difficulty of their decisions, they discovered bravery, purpose, and significance in forging a new future. Comprehending our true worth is challenging; nonetheless, achieving this fortifies our convictions and fervor. Discovering one's identity is a challenging journey that encompasses both suffering and insight. The characters exhibit resilience and confront a fresh commencement.

Keywords: Sudha Murthy, Social & Ethical Values, Trust, Relationship. Marriage, loneliness.

INTRODUCTION

Mrs. Sudha Murthy, an Indian social worker and author, has composed several short tales and novels that compellingly portray social challenges, women's empowerment, identity crises, and the need of ethical ideals for a meaningful existence. Her value-centric novels emphasize commonplace living, allowing readers to recognize themselves in many characters. Her works are entrenched in Indian culture, with situations derived from quotidian reality, events, and experiences. These circumstances demonstrate that women are unable to articulate their rightful entitlements. Passive pain, stoic sacrifice, familial bonds, quiet, social apathy, denial, loneliness, fear, isolation, rejection, acceptance of failure, individuality, vociferous protest, and the transgression of social standards have remained latent. The women in the studied works, including Shrimati, Mridula, and Mahashweta, become victims of their own circumstances. In a subsequent phase of their lives, they see their potential and recover. A woman should not confine herself to societal limits and rigid notions; she must transcend these boundaries and awaken to other alternatives to fulfill her own aspirations. She must begin a new inward adventure. The aforementioned notions prominently feature in the vivid representation of the female characters illustrated by Sudha Murthy.

To quote from Simone de Beauvoir's book titled *'The Second Sex'* wherein she asserts that:

"Once she ceases to be a parasite, the system based on her dependence crumble, between her and the universe there is no longer any need for a masculine mediator".

In all her publications, Sudha Murthy asserted that a woman must transcend the confines of psychological confinement inherent within herself. The confinement of household restraints stifled women's life and exploited female subjectivity, serving as the foundation in all these works.

A woman is shown as an emblem of sacrifice. She contends that women must liberate themselves from their patriarchally built social connections. To restore her identity, she undergoes a transformative journey, ultimately emerging as an individual. The woman, the pinnacle of divine creation, need protection and a connection that allows her to express her refined feminine attributes, unimpeded by malevolent self-serving tendencies, while unveiling her multifaceted nature in the pursuit of self-discovery. We have instances of assertive, powerful, and opinionated women who have shaped their attitudes and behaviors, demonstrating their strength by advocating for themselves and resisting societal preconceptions.

"Feminism isn't about making women strong. Women are already strong. It's about changing the way the world perceives that strength" (G.D. Anderson)

This scenario evokes the narrative "In Search of Myself" by Indian activist Chhaya Datar. The narrative illustrates the unfortunate situation of an educated lady who liberates herself from patriarchal societal conventions. The tale explores a woman's dilemma between pursuing her passion and adhering to the constraints imposed by her traditional family. She tries to convey her experience as a social worker and a member of the union for agricultural workers. living in a tribal society. She gets a letter from her spouse requesting her return to partake in a family rite. The pivotal aspect of the whole narrative is her potential reaction, to paraphrase the lyrics of *Gautama Buddha* 'Not to



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get upset with people and situations because both are powerless without our reactions'. This novel helps a woman to discover herself and overcome social fear and uncertainties.

Remarkable women who have significantly advanced in several disciplines, altering the conventional feminine archetype, deserve recognition. Cleopatra, Marie Curie, Queen Victoria, Indira Gandhi, Mother Teresa, and others served as archetypes, illuminating the many personas depicted by several Indian women authors. This is particularly accurate for the female characters in Sudha Murthy's writings. To quote Wilma Mankiller, the American leader in community building, particularly among the Cherokee Tribe.

"The happiest people I've ever met, regardless of their profession, their social standing, or their economic status, are people that are fully engaged in the world around them. The most fulfilled people are the ones who get up every morning and stand for something larger than themselves. They are the people who care about others, who will extend a helping hand to someone in need or will speak up about an injustice when they see it".

"There is no force equal to a woman determined to rise" (William Edward Burghardt Dubois - An American sociologist, historian, writer, and editor). Has the journey culminated in self-actualization? Amelia Earhart has affirmed our belief that females can attain significant success in male-dominated areas, encouraging them to persevere in their aspirations despite financial challenges, gender prejudice, and other impediments. Emmeline Pankhurst was the founder member of a women's organization known as the Suffragettes. This organization valiantly fought for women's suffrage in the United Kingdom. Margaret Thatcher was instrumental in implementing reforms in contemporary British politics. Queen Elizabeth reigned for 66 years. She is the longest-reigning queen in the world. She held the positions of head of the Commonwealth, head of the Church of England, and head of the Armed Forces. Mother Teresa dedicated herself to mankind with fervor, while Florence Nightingale, the Lady with the Lamp, exemplified service despite her privileged upbringing. Rani Laxmibhai embodied courage in the face of adversity and upheld self-respect. The passionate queen unequivocally demonstrated that females cannot be restrained but may be exuberant and fervent. The emergence of a new concept posits that women's empowerment entails the liberation of women from social, economic, political, caste, and gender-based discrimination, aiming to replace patriarchy with equality. The notions of personal autonomy, feminist emancipation, and the interdependence among women are pertinent to the female protagonists in Sudha Murthy's works.

To quote – Mark Victor Hansen (An American native, enthusiastic speaker and the author of the bestselling book "Chicken Soup for the Soul").

"Don't wait until everything is just right. It will never be perfect. There will always be challenges, obstacles and less than perfect conditions. So what, get started now. With each step you take, you will grow stronger and stronger, more and more skilled, more and more self-confident and more and more successful".

Consequently, the above introduction clearly demonstrates that women are integral to the development of both society and country. Sudha Murthy's works clearly concentrate on the many issues encountered by women. The primary objective of the research is to illuminate a woman's endeavor to surmount societal shame and worries, as well as the strategies she employs to enhance the significance of her existence. The selected books of Sudha Murthy have been assessed to fulfill the objectives of the study. The books include 'Gently Falls the Bakula,' 'House of Cards,' and 'Mahaswetha.'

DISCUSSION

The gist: This was Sudha Murthy's debut book. The narrative centers on two people, Shrimati and Shrikant. They reside next to one another. Their residences are encircled by a Bakula tree. The two families harbor animosity towards one another. Despite familial discord, they fall in love and marry. Shrimati makes significant sacrifices as Shrikant advances in his professional life. His avarice for power and achievement obscures his judgment. He



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disregards her, prompting her to resolve to leave him permanently in pursuit of her aspirations. The narrative starts in a modest setting in Hubli, depicting the lives of Shrimati and Shrikant. Shrimati, an exceedingly fragile child, is raised by an unemployed father, a domineering grandmother, and a timid but kind mother. Robust values are the foundation of Shrimati's existence. Shrikant is a member of the Smartha community. They were both classmates. Shrimati consistently outperforms Shrikant in examinations. They were competitors in the class, engaging in little egotistical conflicts.

A Bakula tree (Fragrant flower) delineates the two residences. The Bakula tree, characterized by its dark green foliage and peculiar, unappealing blossoms like a crown but exuding a wonderful smell, covered the ground like an ethereal carpet, standing proudly with dignity. It was regarded with reverence. It was not exceptionally attractive nor fragrant, but it had an unfathomable allure and was a symbol of legendary love. Shrikant is captivated by Shrimati's simplicity and subsequently falls in love with her. Shrimati also develops romantic feelings for the attractive and affable Shrikant. The Bakula flowers symbolize her love letters, signifying that the essence of their affection would endure indefinitely. They enter into matrimony.

Shrikant was ambitious and committed to his work. He enters an IT firm, ascends the corporate hierarchy swiftly, and achieves success, forsaking Shrimati and her educational ambitions. Shrimati dutifully performs her responsibilities as a compliant wife during her prime years. She eventually recognizes the void inside herself. The narrative culminates with Shrimati departing the residence to pursue her ambition. 'Gently Falls the Bakula' narrates the tale of a marriage that deteriorates due to the avarice of the husband.

The dialogue between the two upon their departure is profoundly poignant and very moving. Shrimati informs her husband that she can no longer endure the solitude. She also conveys to him that her affection for him surpassed her achievements. She explicitly indicates her dissatisfaction with the comfort he offered her. He saw her as an adornment rather than as a sentient individual with emotions and feelings. Upon her departure, Shrikant reflects and acknowledges his cruelty towards his wife, seeing himself as the primary catalyst for her exit. The Bakula Tree, a symbol of their love, had tragically fallen.

The House of Cards

The gist: (Mridula, a youthful and passionate lady, originates from a hamlet in Karnataka. She meets Sanjay, develops romantic feelings, marries him, and establishes her residence in Bangalore. She experiences disillusionment while seeing the self-serving, materialistic society. She exits the marriage.....)

Materialistic factors have undermined our ideals, diminishing our familial connections. True love, comprehension, and forbearance are fundamental principles essential for maintaining the significance of any relationship, as articulated by Antoine de Saint-Exupéry, the French writer, poet, aristocrat, journalist, and pioneering aviator. "Love does not consist of gazing at each other, but in looking together in the same direction"

'The House of Cards' is a concise familial drama that illustrates the simplicity of rural existence, the complexities of urban life, and the cultural conflicts that have disrupted their marital relationship. The author examines human interactions in depth. Mridula consistently embodies the qualities of a diligent and compliant spouse, but Sanjay is swayed by the allure of opulence. Mridula, an intelligent young lady, relinquishes her aspirations and vitality to ensure her husband Sanjay's success and popularity.

"Soon, Mridula and Sanjay settled into a comfortable routine. Mridula got up early in the morning, cooked and gave Sanjay breakfast. He carried a lunch box to the hospital and returned home at night. After Sanjay left, Mridula went to school; she cleaned the house in the evenings". (Sudha Murty 2013)



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The incessant pursuit of ambition, consumerism, and unscrupulous practices is gaining traction. Marriage relies on trust; conflict arises when it is founded on selfishness, as shown by the character of Sanjay. The suffering endured by Mridula is apparent in the following passage extracted from the text:

"Tears rolled down Mridula's cheeks. She thought how did I live with Sanjay for such a long time? Today he's given me money and position in society but he doesn't share my sorrows. I've held his hands and walked next to him on the thorny path to success. When a girl gets married, the extent of her happiness depends upon the husband's commitment and communication with her. A few kind words, a little appreciation and small gifts like flowers can make a girl feel special. But Sanjay just wanted to show that he was the boss". (Sudha Murthy 2013).

Sanjay began displaying discourteous conduct with Mridula. He started comparing Mridula to his sister. He often disparaged his wife and shown more trust in his sister; although he engaged with others in a refined and articulate way, he was harsh in his interactions with his wife. He was a kind of dictator. Sanjay sent ten lakh rupees by demand draft to his mother, obtained a new vehicle for his nephew, and procured a residence and gold jewelry for his sister, all without his wife's awareness. It diminished Mridula's self-assurance. Mridula was disheartened not because of his financial aid to his mother, sister, and nephew, but rather owing to his failure to disclose this help to his wife. Upon uncovering the truth, Mridula permanently departs from her husband's domicile.

Mahashweta

The gist: (This narrative pertains to a young lady named Anupama and her matrimonial union. She becomes enamored with a physician called Anand, aspiring to cultivate a joyful existence. Vitiligo, a dermatological condition, adversely affects Anupama's life. Her life becomes chaotic. The absence of social approval makes her existence intolerable. She experiences a tumult of emotions, ultimately emerging as a young, attractive, and independent lady. Mahashweta signifies 'the white one.' The tale centers on Anupama, an enchanting beauty wed to Dr. Anand. Anupama's optimistic perception of life is disrupted by the onset of Vitiligo, a white patch on her skin; she transforms into a representation of 'social stigma,' forsaken by her indifferent in-laws and callous husband. Her consultations with the dermatologist, along with her suffering, distress, and inability to articulate her feelings, render her more audacious and unrestrained. Courage enters her life, empowering her to confront adversities and forge an independent existence. The reader will really perceive the anguish and distress that Anupama endures, disheartened in life, spurned by her husband, and alienated from society. Anupama learns to navigate her life by embracing her illness, cultivating an autonomous, fulfilling, and tranquil existence, so attaining respect and dignity. The ideals articulated below are both profound and evocative. Society exhibits insensitivity towards Anupama's emotions. She is condemned and disregarded only because to her affliction with vitiligo. This story presents a poignant and realistic portrayal of a lady, first seen as a symbol of beauty to enhance a man's social standing, who is discarded because to vitiligo. Subsequently, she endeavors to transform and flourish, like to a butterfly, through many phases, discarding all facades. The heroine, Anupama, confronts a struggle with her female equivalents, including her stepmother Sabakka, stepsisters Nanda and Vasudha, mother-in-law Radhakka, and sister-in-law Girija, as she seeks to discover her inner power.

The societal responses and rejections deplete our spirits and evoke sorrow. The condition of being accused without culpability evokes compassion in the reader; Anupama does not succumb to degradation but transcends it, so enhancing her status as a woman. A cosmetic ailment, non-hereditary and non-contagious, intertwined with superstitious stories, disrupts Anupama's life, devastates her, and ultimately allows her to rise, leaving her female counterparts astonished. She determines what is essential in her life; she allocates time to distinguish the genuine priorities in her life. She enhances her life by emphasizing her boldness, independence, confidence, and self-respect. She sought to avoid societal conditioning and mental oppression; she strives for mental peace, inner calm, and the conquest of all anxieties, uncertainties, and complexities. The narrative 'Mahashweta' illustrates the journey of a fractured woman who revitalizes herself and asserts her position in society despite several challenges. This work is so profoundly crafted that we really experience the anguish and distress endured by 'Anupamas' in contemporary society. We take pride in her determination to exhibit strength and confront adversity in her pursuit of





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self-fulfillment. This evokes the sentiment expressed in the phrase, "I am grateful to all the challenging individuals in my life; they have illuminated precisely who I do not aspire to become!" – Unidentified

This work evokes tears, instilling appreciation and amazement for the protagonist's brilliance and strength of character. All the characters are flawlessly shown in their authentic environment: their masks discarded. This tale illustrates the latent bravery of women that emerges, empowering them even in circumstances when their husbands do not support them. Upon learning that the woman is afflicted with Leukoderma (Vitiligo), he did not hesitate to remain by her side, as he ought to have. Leukoderma significantly transformed Anupama's life. It altered people's perceptions of her, elicited their sympathy, and led them to attribute guilt for her sickness prior to her marriage. The inhabitants of Anupama's village also responded. In rural areas and small towns, women afflicted with this condition are regarded as untouchables. Anupama's ability to confront her challenges, transcend her limitations, and progress despite the absence of love and connection in her little hamlet is admirable. She encounters challenges in the bustling metropolis, including threats and stress, and her capacity to manage these issues garners admiration for her character; her courage in confronting difficulties captivates readers.

CONCLUSION

The female characters, such as Anupama, Mridula, and Shrimati, have established their presence in the actual world and its accompanying challenges. The problems faced by these women expose their experiences of abuse, degradation, and exploitation, ultimately shattering the silence. The primary themes in these narratives encompass the dynamics of male-female interactions, societal perceptions of acceptability, and the pervasive sense of isolation experienced in contemporary existence. Sudha Murthy's oeuvre encompasses a diverse array of individuals, situations, locales, and communities that reflect authentic backgrounds, constrained perspectives, clichéd assessments, and antiquated expectations. Sudha Murty delineates a pattern in each of her protagonists, illustrating their journey to achievement via the surmounting of anxieties, difficulties, paradoxes, societal standards, disappointments, and enduring challenges. Every woman possesses a silent, unarticulated voice. The Protagonist remains susceptible to a society that has commodified her as an emotionless and purposeless symbol of beauty. Sashi Deshpande's title "That Long Silence" provokes a profound response, ultimately revealing the "Woman within her." The author meticulously examines the relationship. Mridula, Shrimati, and Anupama embody simplicity, diligence, and naivety. Conversely, the masculine characters Sanjay, Srikant, and Anand are profoundly influenced by the allure of luxury, comfort, and consumerism. They ascend the corporate hierarchy without recognizing the significance of familial connections. The recurring themes identified in the literature examined in this research include familial rivalry, conflicts among in-laws, misunderstandings, ignorance, outdated perspectives, and the continuation of male dominance. These female characters possess considerable unrealized potential, yet they remain in subservient roles. The narrative is replete with symbolism, with each character embodying a notable behavior. For instance, Bakula is associated with Shrimati's unassuming, amiable, and appealing character. This characteristic remains unrecognized as the narrative progresses. The blossom symbolizes enduring love, despite challenging circumstances and shifting priorities that obscure its presence. They fail to comprehend that a house embodies emotions and that each interaction is significant. The adage states, "A house is constructed with brick and stone." Love encompasses all that constitutes a home. The principal characters can no longer endure their hostility. They ultimately assert that erroneous ideas and wealth do not constitute genuine success. Within the social hierarchy, the woman serves just as an ornament, a superficial emblem signifying 'His' social standing. Every woman experiencing reality will resonate with the aforementioned narratives. Her works include a wide array of scenarios including several individuals, whose life narratives are portrayed with sincerity, emphasizing relationships founded on trust and marriage as a cornerstone of meaningful living.

This situation reminds us of a small story:

A little girl and her father were crossing a bridge.

The father was kind of scared so he asked his little daughter:

"Sweetheart, please hold my hand so that you don't fall into the river".





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The little girl said: "No, Dad. You hold my hand".

"What's the difference?" Asked the puzzled father.

"There's a big difference", replied the little girl.

"If I hold your hand and something happens to me, chances are that I may let your hand go.

"If you grasp my hand, I am certain that regardless of the circumstances, you will never release it." A strong tie is essential in every relationship. One must grasp the hand of a beloved individual rather than anticipating that person to grasp theirs. Consequently, this link is crucial in marriage. Contemporary youth encounter several distinctive challenges, particularly in their marriages, but they flourish with a sense of achievement. In these works, the masculine inconsiderate characters, such as Shrikant, Sanjay, and Anand, have a moment of awareness. They own their errors in neglecting female characteristics, recognizing that caring, collaboration, and responsibility are essential components of a successful marriage, and they see life from a broader perspective, moving beyond their self-centered viewpoint.

The books selected for analysis outline social and ethical ideals. Life is shown as a journey characterized by learning and unlearning, encountering many hurdles that test resilience and determination. These challenges assist us in making decisions, as shown by the characters portrayed by Sudha Murthy. Despite the difficulty of their decisions, they summoned strength, purpose, and significance to forge a new horizon. Understanding our true worth is an arduous endeavor that fortifies our principles and enthusiasm. Self-discovery is a challenging journey that requires both suffering and comprehension. The protagonists summon bravery and confront a fresh beginning. The life modules presented in these books provide enhanced clarity and insight, fostering resilience and concentration in the face of obstacles. The individuals shown encountered several challenges, disappointments, and obstacles, but chose to pursue a purpose-driven existence.

To live by choice, not by chance

To make changes, not excuses.

To be motivated, not manipulated

To be useful, not used.

To excel, not complete

I choose self-esteem, not self-pity

I choose to listen to my inner voice

Not the random opinion of others"

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RESEARCH ARTICLE

Collective Memory Strategies in Sudha Murthy's Stories and Their Role in Shaping Young Minds of Today

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ABSTRACT

We live in an era which is mostly dominated by electronic gadgets, artificial intelligence and advanced technologies resulting in fragmented attention among the young readers. Writers like Sudha Murthy take constant efforts in bringing back the traditional learning methods to make the present-day kids understand the values and practices of the past. From her stories we come to understand the importance of remembering the past which enhances a better future. Collective memory generally refers to the way in which a group of people find meaning in their past. Sudha Murthy through her use of collective memory strategies manages to convince the young minds to inherit not just stories but shared knowledge of the ancestors. The stories which Sudha Murthy weaves in the collection *Grandma's Bag of Stories* for instance tend to recreate ancestral story telling circle where the norms and traditions are remembered collectively. Hence the objective of the present paper is to study the collective memory strategies which Sudha Murthy uses shape the young minds to think and act in a better way.

Key words: Artificial Intelligence, traditional learning methods, collective memory, story telling, Sudha Murthy.





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INTRODUCTION

Collective Memory Strategies in Sudha Murthy's stories and their role in shaping young minds of today

"Give your children two things in life: Strong roots and powerful wings"

- Sudha Murthy

Sudha Murthy is one of the dedicated philanthropic Indian writers of Children's literature who uses memory as a strategy in making the readers understand the relevance of the past. Most of her stories are the results of her collective memory. Her protagonists seem to long for the return of the past which they feel is filled with harmonious life style, customs, and practices. She asserts in many places the significance of retaining the old. The past should be respected and acknowledged by the youngsters so that it would enrich their perspectives. Memory studies has become a recurring topic of literary discussions in the recent times. The primary reason is probably the shift in the way of approach to life by the present generation. This is an era of globalization and cultural flux. We often hear people complaining about the disappearing values in the current age. Communication is rather happening between gadgets than between humans. Expressing one's emotions and feelings too had become digitalised as we spend more time on posting these on face book and Instagram. The number of 'likes' that one gets from unknown people are given much weightage than our real friends and so, there arise a need on the part of the writers to take initiatives in shaping the minds of the young readers thereby prepare them for a better future.

The stories written for children play a crucial role in developing collective consciousness and cultural transmission. They act as a bridge in connecting their modern thinking to the valuable insights of the past generation. We can see that most of the writers of today who write for children works with the goal of creating fertile thinkers in future. Hence the objective of this paper is to explore how Sudha Murthy employs collective memory strategies to polish the young minds to understand the heritage of our past.

Collective memory and Sudha Murthy

Collective memory is the collective knowledge and information held by a group that promotes values and perceptions of the good old times. It is constructed through storytelling and attempts to transmit knowledge across generations. Books written for children by Indian authors draw stories from mostly epics like Ramayana and Mahabharata or from ancient myths and folklore. These texts tend to teach children the basic values and principles one should adopt in life. Some also convey the rich heritage of the past by narrating the stories of great kings and emperors from the past. By doing so they serve as a vehicle in transmitting the cultural values to the younger generation.

In the stories of Sudha Murthy, collective memory strategies get manifested through the children's involvement with elders, recalling myths, representation of cultural artifacts like rituals, and preservation of natural reservoirs. It is literally impossible to separate collective memory from Sudha Murthy's world as it is naturally embedded in every layer of her narratives. Her narratives show deliberate usage of traditional writer techniques.

The following are the works where Sudha Murthy is at her peak in transmitting to the readers the knowledge of the past –

- The Magic of the Lost Temple
- The Sage with two horns- Unusual Tales from Mythology
- The Man from the Egg -Unusual Tales about the Trinity
- How I taught my grandmother to read and other stories



**Pahlavi Mustafa****Imprinting ethics in the young minds**

In the story *The Magic of the Lost Temple*, we find the teenage girl Noonni getting unusually fascinated by the honesty and sincerity of the villagers and their caring ways in the treatment of not just humans but also animals, plants and nature around. Though being a city girl, she gradually develops a liking for the habits and lifestyle that she witnesses in the remote village where her grandparents live and readily learns a lot from them. While portraying characters like Noonni, Sudha Murthy seems to be convinced that the young learners are indeed very persuadable when compared to the adults in receiving the message conveyed in her texts. She proudly comments in her introduction to the novel 'The Magic of the lost temple' that her granddaughter Noonni is the heroine of her book- "bold, determined, sporty and always in search of new adventures". She happens to hear from the villagers the different stories woven around the lost temple but takes a bold step of unveiling the actual truths behind the ancient temple and the significance of the forgotten village stepwell. Sudha Murthy chooses her protagonists in such a way that any kid reading the story could relate oneself to the character. It is not just about learning to respect and follow the ethics and values of the elder generation but also a reminder to the adults that the thoughts of youngsters need to be heard and respected.

Understanding Cultural ethos through the narratives of Sudha Murthy

Sudha Murthy's narratives present to us an amalgamation of cultural facts, moral values, moral judgements, and ancient practices. This paper identifies how Sudha Murthy employs multiple strategies as collective memory devices. Collective memory studies convey to us the way these oral, textual, or visual narratives construct the social memory. Researchers in memory studies have found that literature helps to reinterpret the events of the past in the present moment. Sudha Murthy thus makes her stories engaging and convincing giving references from various myths. She deliberately chooses those myths and folklores which carry the best lessons to be followed in lives.

Intergenerational memory being transmitted

In 'How I Taught My Grandmother to Read and Other Stories' for instance the wisdom of the past, their unique cultural values and traditional kind of narratives are transmitted beautifully from the elders to children. The protagonist is a girl of twelve who teaches her grandmother to read Kannada. She explains in an exciting tone how amazing her 'Avva' was as a student in learning the language quickly. With this simple act of a young girl teaching her grandmother one could feel the cultural transmission and exchange of knowledge between two generations which are different from each other. It symbolises transmission of collective knowledge. The act of a granddaughter educating her grandmother fills the generational gaps and thereby make the elder generation to get access to reading newspapers and local magazines which was just a dream to them in their earlier times. The stories which the grandmother narrates to her granddaughter about her past life, the family history and her earlier lifestyle in her village become the resources of collective memory.

Cultural memory through Myths

Sudha Murthy's tales which she draws from great epics like Ramayana and Mahabharatha brings to us the mythical memory. These myths act like an important vehicle for cultural memory. Though the messages that they convey are the same Sudha Murthy makes them easy to access by the present generation kids through her simple narrative style. Unlike the complex narratives of the past, Sudha Murthy employs the modern narrative techniques and make the stories simpler and suitable for the rapid thinkers of today. In the series *Unusual Tales*, Sudha Murthy weaves the extraordinary stories of the popular deities (Brahma, Shiva and Vishnu) and through them she teaches universal values like kindness, perseverance, compassion. By retelling these known myths, she also questions the traditional assumptions and allows the readers to think critically. For instance, the following lines from *Unusual Tales* series,

"...why clouds in the desert are called Uttanka Megha? ... Indra was so pleased with the efforts of Uttanka... Today, these rain clouds in the desert are still known as Uttanka Megha" shows how cultural memory is embedded even in the natural phenomena like rains. To elaborate on the idea that mythology has become an inseparable part of our daily life, the author herself stresses that "Mythology is part of our heritage, part of our





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identity at times because anywhere in India you will find the name of Rama or Krishna in one or the other form." (Sudha Murthy, Brainy Quote).

Another best example is the introduction to *The Serpent's Revenge* that insists that cultural memory depends on the degree in which the stories are passed through oral traditions, Sudha Murthy says, "**Most importantly, I would like to thank the sages who have communicated these tales by word of mouth so that others could memorize them and pass them on through the ages.**"

Use of cultural artifacts

Another interesting strategy which we identify in Sudha Murthy's narratives is that she makes use of the old practices, customs, and rituals which represents cultural memory. Festivals, and communal gatherings symbolizes the collective heritage of the past. In the story 'The Magic of the Lost Temple' there is reference to the old practise of keeping empty houses for the purpose of making them staying places for the guests and relatives who come from far off places to attend the festivals and functions. We hear 'Ajja' saying,

'...We use part of it as storage and a part is kept ready for guests to stay in. If there is a wedding in the village and people come from outside, they can stay there'. Noonni wonders why there is no wedding hall in the village.

'Why? Isn't there a wedding hall in the village?' asked Noonni. 'No, the concept doesn't usually exist in villages. Typically, the wedding is performed at home and the guests are accommodated in people's houses,' Ajja concluded. The answer is quite surprising not only to Noonni but to us too. It just implies how generous and broad minded are the village landlords in treating the guests. This culture is fading away in the present society. Hence Sudha Murthy tries to insist this traditional practise in the minds of the young readers.

There are also references in Sudha Murthy's stories to the religious practices like taking *Ganga Snan* which again represents the cultural continuity of ancient South India.

Usage of old story telling method

In the ancient times there existed the practice of conveying life lessons through oral story telling. Grand parents used to narrate some of the ancient myths and folklore to young ones as bed time stories so that the message that they convey leave unforgettable imprints in the fresh growing minds. Sudha Murthy employs the oral traditional style of storytelling in her books. Her story telling is conversational like the stories narrated by grandparents. The repetitive nature of her narratives reminds us of the oral memory techniques that were used in the past to reinforce the values and ethics. Just as we find in the traditional folklore, she begins the stories of the Trinity, the story of Brahma, the Creator and continue with the stories of Lord Vishnu and ends with the stories of Lord Shiva, the Divine Destroyer in her short story series titled *The Man from the Egg- Unusual Tales about the Trinity*.

Insistence of culture and old values

Sudha Murthy's narratives have never failed to insist the importance of maintaining one's culture and tradition. Giving respect to elders, abiding by the family tradition, completion of one's duties and responsibilities, being compassionate to the fellow human beings and compassionate towards nature and life around us are some of the invaluable life lessons that are intricately woven in all her stories. Cultural values and morals which are part and parcel of traditional India are embedded in each tale. By portraying family practices and history of the past she connects personal memory to the communal tradition and encourages cultural continuity in the fast changing 21st century. Sudha Murthy's stories to children are not just a tool of conveying morals but goes beyond its purpose. They fill the gap between the traditional and the modern world and serve as a powerful tool of collective memory transmission.

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RESEARCH ARTICLE

Psychoanalytic Perspective AI-Supported Academic Writing

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ABSTRACT

Writing is a complex cognitive and psychological process, and most students face obstacles, including writer's block, lack of confidence, difficulty articulating ideas, and fear of errors, which negatively affect performance in school. As the use of artificial intelligence in education increases, tools such as Grammarly and Trinko are being used to support the development of writing skills, but their psychological influence on writing needs to be systematically studied. This study aimed to analyze the psychological processes underlying writing proficiency through the use of AI tools and to establish how these tools affect students' psychological writing obstacles. A descriptive-correlational design was used. The research involved a sample of 120 undergraduate students from the engineering stream across different disciplines, aged 18 to 21 years, who were selected using stratified sampling in higher institutions of learning. The questionnaire used to collect data was a Likert-scale instrument that measured writer's block, lack of confidence, difficulty expressing ideas, fear of making mistakes, use of AI tools, and perceived improvement in writing. Reliability analysis showed high internal consistency ($\alpha = .84-.93$). The results indicated that 72 percent of students felt more confident in their writing as a result of using AI tools, 68 percent reported lower writer's block, 64 percent indicated that ideas were better organized, and 70 percent believed they were less afraid of making grammatical mistakes. Correlation and regression analyses showed that the use of AI tools was a strong predictor of writing improvement ($\beta = .55$, $p < .001$), and 61% of writing skill development was attributed to the use of AI tools. The research suggests that AI-based writing aids could be highly effective in minimizing psychological obstacles and improving writing performance, provided they are systematically incorporated into academic education.

Keywords: Psychoanalysis of Writing, AI Writing Tools, Grammarly, Trinko, Writing Anxiety





INTRODUCTION

Writing is a multidimensional process, which entails generating, organizing and expressing thoughts using systematic language. It incorporates cognitive skills like planning and revision, linguistic skills including grammar and discourse control and psychological aspects like motivation, anxiety and self-efficacy. Writing is an active meaning-making skill that is also considered a higher-order skill since it entails active construction of meaning. Writing is one of the main assessment tools, sources of knowledge, spread of research, and publication of scholarly articles in the academic and workplace worlds (Sarveswaran et al., 2025). As the artificial intelligence continues to evolve at a high pace, writing is becoming more and more assisted by AI-based programs that help to write a text, edit and make amendments (Hanafi et al., 2025). AI has become a space of meaning-making in the academic writing of English, and it transforms the way learners build and improve their texts (Santos, 2025). Writing, however, is an important activity that is mostly related to psychological challenges. Students often show their unwillingness to complete writing activities because of the fear of being judged negatively and because of their lack of self-confidence. Writer block is a cognitive and emotional stop that does not allow one to flow ideas and start the task. Self-efficacy beliefs are the close correlates of lack of confidence, and they affect persistence and performance in academic activities. Strain in conveying thoughts can be due to language barrier or thinking overload whereas anxiety of committing grammatical errors is elevated, especially in English as a Foreign Language (EFL) environment. It has been shown that technological tools can produce a considerable difference in students' writing skill, offering clear feedback and eliminating ambiguity (dos Santos, 2025).

Artificial intelligence (AI) writing applications like Grammarly and Trinka have found significant use in colleges and universities. It has been discovered that Grammarly increases the quality of academic writing, as well as the perception of the feedback among learners (Amina, 2024; Zaragoza et al., 2024). Trinka helps in academic writing by providing smart analysis and field-related recommendations (Barrot, 2025). Research on AI-feedback tools shows that they improve the quality of writing and provide positive changes in the attitude of students towards revision (Eden, 2025). Systematic reviews testify to the fact that the practice of writing instruction in universities is changing with the emergence of artificial intelligence (Aljuaid, 2024; Tiziana and Gjinali, 2025). Also, AI-assisted learning systems have been reported to be successful in improving written production results (Hrdlicková, 2025) and in helping academicians conduct research (Idris and Umar, 2024).

Nevertheless, as the use of AI continues to be increasing (Oladele et al., 2025), questions of overreliance and dependency have arisen (Nwagbara, 2025). The application of AI tools should be informed with the selection criteria and critical evaluation (Radulescu and Radulescu, 2025), and, moreover, sufficient literacy in the scholarly writing and editing processes concerning AI (Jaakkola, 2024). Moreover, the generative AI tools will affect the complete process of writing, beginning with the idea creation and finishing with its review (Mohammad et al., 2025), and will be actively integrated into scholarly study activities (Archana, 2025). In spite of the emphasis on performance improvement in these studies, there is little research, which quantitatively investigates the psycho-analysis of writing capabilities, i.e. how AI tools respond to such psychological variables as the writer block, lack of confidence, inability to express ideas, and fear of making a mistake.

The current research fills this gap, as it examines the psychological aspects of the writing skill development with the help of the AI tools with the help of the advanced statistical analysis. The study aims to investigate the correlation between the use of AI tools and psychological barriers to writing, to test whether AI use plays a significant role in predicting the improvement of writing, and to test psychological variables in the outcomes of writing. The research is informed by the following research questions: (1) What are the relationships between the use of AI tools and writer block, confidence, expression of ideas and fear of error? (2) Does the usage of AI tools largely foretell an improvement in writing skills? (3) Are psychological barriers important affecting writing results? According to such questions, the study has the following hypothesis: the use of AI tools is anticipated to be negatively associated with



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psychological barriers, positively correlated with writing improvement, and negatively correlated with psychological barriers, whereas psychological barriers will be negatively correlated with writing performance.

The figure illustrates the theoretical model that will be guiding this study. The use of AI tools (Grammarly and Trinka) is taken as the independent variable, which affects the psychological barriers, i.e., writer block, lack of confidence, inability to express ideas, and fear of mistakes. These psychological variables are theorized as the result variables of using AI and predictors of the improvement of writing skills. The hypothesis of this model is that the higher the use of AI tools, the less psychological obstacles and the direct improvement of writing can be achieved. At the same time, low psychological barriers also assist in enhancing writing performance which implies direct and indirect associations between the variables.

METHODS

Research Design

The research design used in this study was descriptive-correlational quantitative research design. The descriptive aspect was applied in studying the degree of psychological variables and writing enhancement in students using AI writing tools. The correlational element was utilized to examine the relationships among the use of AI tools, psychological barriers (writer block, lack of confidence, inability to express his/her ideas, and fear of making mistakes), and improvement in writing skills. A high level of statistical methods was embraced in order to generate accurate measurement and predictive examination of variables. Such a method allowed the study to go beyond mere description and explore correlations, predictive validity, and pre- and post-uses of AI tools to compare and contrast differences. Inferential statistics were used and enabled the validity of conclusions and testing of hypothesis in the proposed conceptual framework.

Participants

The participants in the research were 120 under-graduate learners who were studying in the Bharath Institute of Higher Education and Research (BIHER), Selaiyur, Chennai, India. The sample used was chosen as a sample of variety of academic fields and exposure to academic writing tasks. Age of participants was 18 years to 21 years. Different Engineering disciplines of Aeronautical, Artificial Intelligence and Information Technology students were used to draw students to achieve a disciplinary difference in writing needs. Stratified random sampling method was used so that the proportions were representative in different academic streams. The participants were chosen at an institution of higher learning to increase generalizability. The distribution of different disciplines of engineering was equal to engage similar academic conditions and the access to AI writing tools.

Instruments

The structured questionnaire, based on a five-point Likert scale between strongly disagree and strongly agree was used in the collection of data. It was divided into several parts that are used to assess the intensity of AI tool use, the writer block, lack of confidence, inability to express ideas, fear of committing errors, and the improvement in the perceived writing skill. To achieve construct validity, psychological variables were measured using more than one item to measure each construct. Writer block items were those concerned with determining the difficulty of getting started on a writing task, and confidence items were concerned with self-belief in writing ability. Items of idea expression measured the clarity and organization, and items of fear-of-mistakes measures questions anxiety of grammar and structure. The validation of the questionnaire was done by having experts review it by those who were experts in the field of language teaching and educational psychology. Their comments took care of clarity and relevance and consistency with the conceptual framework.

Cronbachs Alpha was used in reliability testing to find out the internal consistency of each construct. The variables showed acceptable levels of reliability that are above the recommended level. The questionnaire has been sent via Google Forms, which made it more convenient and easier to use to collect data. The study was conducted on a





voluntary basis with all the confidentiality in place. The period of data collection was four weeks. The participants were requested to fill out the questionnaire following the organized duration of the usage of AI tools to enable them to understand the pre and post comparison.

Data Analysis Procedure

Mean and standard deviation were calculated as descriptive statistics to establish central tendencies and dispersal of the responses of each variable. The internal consistency of the measurement scales was checked by the reliability analysis performed with the help of Cronbach Alpha. The Pearson correlation analysis was performed to determine the direction and strength of the relationships between the use of AI tools and psychological variables and how it is related to the improvement in writing skills. The predictive capability of the use of AI tools and psychological barriers on writing enhancement was used to conduct a multiple regression analysis. In this analysis, the substantial predictors were found and their contribution to the dependent variable was measured. The pre-test and post-test paired sample t-test was performed to determine the psychological obstacles and the writing performance of students prior to and after using AI tools. This test established the presence of statistically significant differences between pre- and post-intervention scores. Statistical package of the social sciences (SPSS) was used to do all statistical analysis. All inferential tests were taken with the significance level of $p < .05$.

FINDINGS AND DISCUSSION

The results are given in chronological sequence starting with demographic analysis, then reliability and descriptive statistics, inferential statistical results and variable based interpretation. The findings are explained considering the conceptual framework and research hypotheses.

Demographic Analysis

The demographic data of the respondents is outlined as follows. The sample size had a representation of 120 undergraduate students who represented different streams of study and were balanced in terms of gender.

As indicated in the table, 55 percent of the participants were female and 45 percent were male. Most of the respondents were children aged between 20 and 21 years (48.3), 51.7 were aged between 18 to 19 years. The representation faculties in the IT (33.3%), Aero (31.7%), and ECE (35) were fairly even. This distribution guaranteed the diversity of disciplines and the enhanced applicability of the findings to the academic settings.

Reliability and Descriptive Statistics.

To ascertain the measurement quality and central tendency of constructs, internal consistency reliability and descriptive statistics were established.

The table shows that there is high internal consistency of all constructs with the values of Cronbach alpha of between 0.84 and 0.93. Mean scores indicate moderate-high levels of psychological barriers before the use of AI tools, whereas the other mean values of writing improvement and AI usage intensity were relatively higher. The standard deviations show reasonable variation, which means that the responses were broadly spread to allow the use of the inferential analysis. These findings indicate that the measure was valid and could be used to test more statistically.

Inferential Statistical Findings.

Correlation and regression analyses were carried out to analyses the relationship between variables and the predictive effects of variables on others.

AI Tool Usage shows strong positive correlation with Writing Improvement ($r = .72$), and significant negative correlations with psychological barriers. The table shows that there are high negative relationships between the use of the AI tools and the psychological barriers such as writer block, lack of confidence, inability to express ideas and



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fear of making mistakes. The usage of an AI tool was positively correlated with the improvement in the writing ($r = +.72$, $p < .01$). There was negative correlation between psychological barriers and improvement of writing, which shows that the greater the levels of anxiety-related factors, the lower the perceived writing performance. These findings justify the hypothesis proposed that the use of AI minimizes the psychological barrier and improves the writing performance.

The AI Tool Usage is the strongest positive predictor of Writing Skill Improvement, while psychological barriers significantly and negatively predict improvement. The regression analysis indicated that the total regression model was significantly significant as it explained the writing improvement variance of 61 ($R^2 = .61$, $p < .001$). The use of AI tools became the greatest positive predictor ($\beta = .55$, $p < .001$). Significant negative predictors of writing improvement were writer block ($\beta = -.19$, $p < .01$), and lack of confidence ($\beta = -.16$, $p < .05$) and fear of making mistakes ($\beta = -.22$, $p < .01$). All these findings suggest that despite the direct positive influence of AI tools on the writing performance, psychology continues to have negative impacts that are independent of each other. Result Interpretation based on variables. The writer block was analyzed with the help of the paired sample t-test by contrasting the scores of pre-AI and post-AI usages. The analysis showed that the writer's block decreased statistically significantly ($p < .01$) with the help of AI tools, which means that writer support is facilitated by AI-assisted feedback.

Due to a lack of confidence, the mean comparison showed that there were significant changes in writing confidence of students after the introduction of AI. The figure shows that the mean scores of the confidence started to increase significantly after using the AI tools. The mean of the post-intervention was higher than the pre-intervention one, which means that AI feedback was more effective to promote perceived competence and self-efficacy of students in academic writing tasks. The problem of expressing ideas was discussed in regression modeling in order to identify a predictive relationship with the improvement in writing. The figure represents the regression coefficients that were standardized with an indication that the use of AI tools had a positive impact on the organization of ideas, whereas the initial challenge in conveying ideas had a negative impact on the improvement. The model shows that AI feedback mechanisms are relevant to enhance the structural clarity and coherence.

The fear of mistakes also decreased considerably following the use of AI tools.

The figure indicates that there is a reduction in the levels of anxiety about errors at the post-intervention stage. It was reported that automated corrective feedback made students more confident in grammar and structure and that AI tools are effective as supportive evaluative systems and help students to be less afraid of negative evaluation.

The results prove that there is a strong correlation between the use of AI and psychological variables. The use of the AI tools was also found to be negatively correlated with the writer's block, the loss of confidence, inability to express oneself, and the fear of errors. This implies that AI platforms are not only effective to enhance technical writing, but also act as psychological support systems. Regression analysis showed that the predictive ability of AI tools regarding the confidence of writing was especially high. The use of AI became the strongest predictor of writing improvement, which demonstrates its critical role in writing education in the modern world. By contrasting the results with the literature of current empirical studies, it is possible to state that the findings are consistent with what previous studies have found, that is, AI-assisted writing is more likely to promote performance and decrease writing anxiety. This study however, goes further to the past studies by statistically modeling psychological variables under a predictive model instead of reporting performance benefits. Regarding pedagogy, the results imply that AI tools must be well thought out as a part of writing teaching to help minimize the psychological barrier and remain able to think critically and independently revise. AI should be guided properly to make it serve as a scaffold and not a replacement of cognitive activity during writing.



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CONCLUSION

The current work has explored the psychoanalysis of writing skills with the help of AI tools through advanced statistical analysis. The results revealed strong correlations between the use of the AI tools and all the variables of psychological writing. Correlation analysis revealed that the application of AI was negatively related with writers block, loss of confidence, inability to express ideas, and fear of making errors but had a high positive relationship with writing improvement. Several regressions proved that the use of AI tools was the most critical predictor of the writing improvement with the model explaining a great percentage of variance ($R^2 = .61$). The comparisons of pairs also showed that psychological barriers statistically declined as a result of integration of AI tools. According to the statistical findings, the main hypotheses of the research were accepted. The hypothesis which claimed that the use of AI tools correlates with negative effect on psychological obstacles was proved. The hypothesis that the use of AI tools positively predicts the improvement of writing was also validated. Also, the hypothesis that psychological barriers had a negative prediction of writing performance was accepted because writer block, lack of confidence, and fear of making mistakes exhibited some significant negative beta in the regression model. The results have significant implications on higher education teaching of writing. AI tools must not be considered as merely technical grammar checkers, they are also to provide psychological support to lower anxiety and improve confidence. The writing process can be enhanced by writing instructors using AI-assisted revision stages to guide the students to get out of cognitive stagnation and fear of evaluation. Nevertheless, instructional support will be needed to make sure that AI tools ought to complement, but not substitute the task of critical thinking and independent writing practice. Practically speaking, systematic AI implementation plans are suggested. Training in responsible AI use, creation of effective academic integrity policies and integration of AI literacy elements into writing courses should also be instituted by institutions. Teachers must create tasks that prompt learners to reflect on AI feedback as opposed to just taking notes on corrections. The balanced integration will ensure the maximum writing improvement but avoid overdependence.

Future Research Recommendation.

The study has some limitations regardless of what it has contributed. The study used the data of self-reported questionnaires, which could be affected by the response bias. The sample was also restricted to undergraduate students in the selected institutions, which can be a limitation to generalizability. Also, the research adopted a non-experimental design, which restricted the causation. Further studies should use experimental or longitudinal designs to study long-term impacts of the use of AI tools in writing development. The controlled intervention studies might be better evidence on the causality and lasting psychological effect. Longitudinal observation can help evaluate how effective the decrease in anxiety and increase in confidence levels will be over the years. Other psychological and technological variables should also be used in further investigations. Motivation, academic resilience, AI literacy, ethical awareness, and dependency are constructs that would contribute to the existing knowledge of the AI-assisted writing dynamics. Comparisons between different levels of education, cultures, and various AI platforms, would also help learn more about the changing nature of artificial intelligence as an aid in academic writing.

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Table 1: Demographic Profile of Participants (N = 120)

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	54	45.0
	Female	66	55.0
Age	18–19	62	51.7
	20–21	58	48.3
Academic Stream	IT	40	33.3
	Aero	38	31.7
	ECE	42	35.0
AI Tool Used	Grammarly	70	58.3
	Trinka	50	41.7

Table 2: Reliability Coefficients and Descriptive Statistics of Variables (N = 120)

Variable	No. of Items	Cronbach's Alpha (α)	Mean (M)	Std. Deviation (SD)
Writer's Block	6	0.88	3.42	0.74
Lack of Confidence	5	0.90	3.58	0.69
Difficulty in Expressing Ideas	5	0.86	3.37	0.72
Fear of Making Mistakes	6	0.91	3.64	0.77
Writing Skill Improvement	6	0.93	4.02	0.63
AI Tool Usage Intensity	4	0.84	3.89	0.68

Table 3: Pearson Correlation Matrix among Psychological Variables

Variables	1	2	3	4	5	6
1. Writer's Block	—					
2. Lack of Confidence	.61**	—				
3. Difficulty Expressing Ideas	.58**	.65**	—			
4. Fear of Mistakes	.54**	.63**	.59**	—		
5. AI Tool Usage	-.46**	-.52**	-.49**	-.55**	—	
6. Writing Improvement	-.50**	-.57**	-.53**	-.60**	.72**	—

Note:

$p < .01$ (two-tailed)

Table 4: Multiple Regression Analysis that predicts writing Improvement.

Predictor	B	SE B	β	t	p
(Constant)	0.84	0.41	—	2.05	.043
AI Tool Usage	0.58	0.07	.55	8.29	< .001
Writer's Block	-0.21	0.08	-.19	-2.63	.010
Lack of Confidence	-0.18	0.09	-.16	-2.01	.047
Fear of Mistakes	-0.24	0.08	-.22	-3.02	.003

Model Summary:

$R = .78$

$R^2 = .61$

Adjusted $R^2 = .59$

$F(4,115) = 45.82$

$p < .001$





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Figure 1: Psychoanalysis of Writing Skill using AI Tools Conceptual Framework.

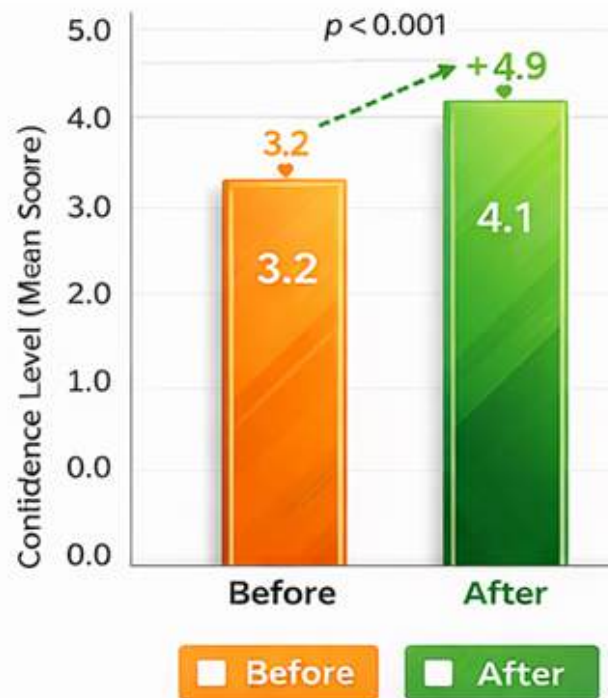


Figure 2: Comparison of the Mean Score of the Confidence Before and After the Usage of the AI Tool.





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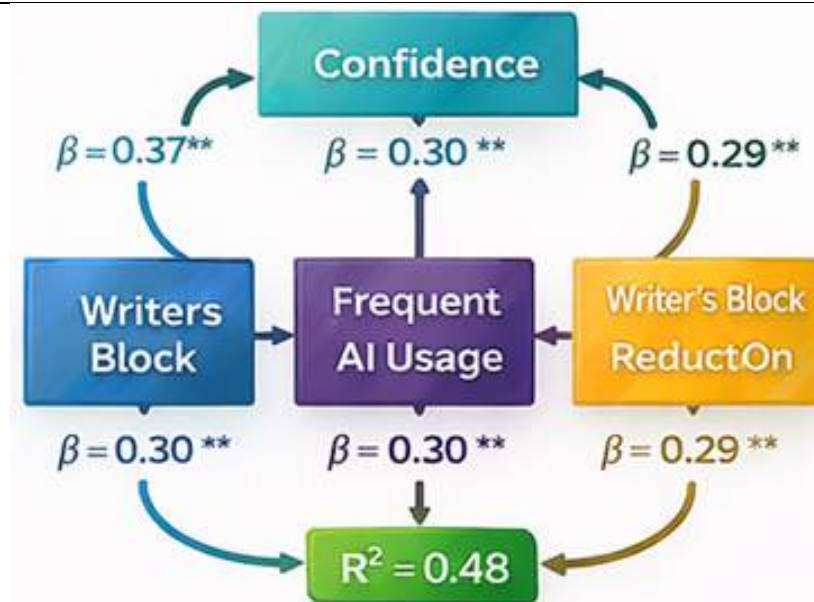


Figure 3: Regression Model that shows Predictors of Idea Organization Improvement.



Figure 4: Comparative Analysis of Error Anxiety Reduction on the use of AI tool.

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RESEARCH ARTICLE

Alienation in the Blue Humanities: The Ship as Psychosphere and the Psychology of Confinement in Lowry's *Ultramarine*

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ABSTRACT

This academic paper provides a critical analysis of Malcolm Lowry's *Ultramarine* through the emergent perspective of the Blue Humanities by analyzing the symbolic use of the merchant ship as a psychosphere to demonstrate the depth of psychological restraint. The text characterizes the transformed mental conditions of the main character, Dana Hilliot, caused by maritime isolation, as an effective metaphor for ecological and mental instability on a larger scale in wet ontologies. By examining the dynamic interaction between the enclosed space of the ship and the human characters in the novel, this paper dwells on the complicated issues of alienation, adjustment, and interconnection between human and non-human life in the maritime arena. The study emphasizes Lowry's role in using the ship to capture the vulnerability of the human psyche and the necessity of providing a communal response to the trauma of captivity associated with sea travel. In addition, the paper explores how labor hierarchies contribute to solving psychological crises, where class inequality intersects with maritime degradation, and why it is significant to combine inner emotional landscapes with external environmental forces. It considers how oceanic space is an active agent in the construction of identity, in contrast to a passive background. Finally, this paper concludes that *Ultramarine* is not only a source of awareness of the influence of the Blue Humanities on ecosystems but also demands a wholesome approach to psychological action. It focuses on how the entire human race has a duty to preserve the future of the mind against the derailing influences of the sea, and the novel is a critical text for gaining insight into



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maritime trauma and identity construction in the new era. This analysis fills the gap between literary and environmental psychology.

Keywords: Blue Humanities, Psychological Confinement, Ship as Psychosphere, Alienation, Maritime Trauma.

INTRODUCTION

Alienation is a characteristic issue of the 21st century with extensive implications for the environment, society, and psychology. The core of this dilemma is the idea of Blue Humanities, which refers to the multifaceted and interrelated connections between oceans on Earth, human endeavors, and the natural resources on which humanity depends (Neumann 5; Steinberg 12). This paper aims to address the dynamics of psychological confinement in terms of Blue Humanities, with the peculiarities of human-caused factors, such as the hierarchy of work and labor (or the process of displacement of the classes), and industrialization, breaking the fragile equilibrium of the maritime psyche (DeLoughrey 34; Gillis 89). One of the most urgent global problems is alienation, and literature has turned out to be a significant method of investigating its effects (Spinks 22). Malcolm Lowry's novel *Ultramarine* is one such literary work, a complex, intertwined story of maritime solitude, psychology, and human experience (Lowry ch. 1; Bowker 45). This paper will concentrate on the manner in which *Ultramarine* employs the ship, that is, the Oedipus Tyrannus, as a key symbol to develop the psychological influence of being bound (Day 102; Grace 67). It is a ship in the novel that opens a door to the concept of the interrelatedness of the natural world, and the fragility of the ecosystems as nuances of changing environmental conditions are played with them (Gillis 110; Steinberg 56). With an unpredictable future ahead, it is important to build a holistic concept of Blue Humanities to help usher in worldwide initiatives to achieve environmental resilience (Neumann 9). In this inquiry, the paper will seek to make its contribution to current arguments regarding the necessity of a collective response by the world to the crisis of alienation (Spinks 45; Tidmarsh 30).

Literature on the topic of *Ultramarine* demonstrates extensive interrelations between labor at sea, psychological disturbance, and experience (Bowker 78; Day 115). Lowry's depiction of the changed way of thinking is a strong metaphor for the overhauling ecological changes on a larger scale brought about by global warming and industrialization (Grace 89; Lowry, ch. 3). According to critics, the ship can be viewed as a microcosm of the breakdown in society, in which inner trauma is a reflection of the corrosion of nature (Grace 102; Bowker 90). It is not only a setting but also a psychosphere that has fragility (Day 120; Lowry, ch. 5). Oceans, according to Steinberg, are social places in which isolation is both physical and mental and has a distinct kind of maritime trauma (Steinberg 78). Neumann argues that watery ontologies transform human identity, compelling people to reassess the self in the blue sphere (Neumann 12). DeLoughrey links maritime routes and psychological origins, attributing displacement to oceanic experience (DeLoughrey 56). Gillis underlines that the shore is a transitional area of trauma, but the ship is what transfers this transitionality to the depth (Gillis 134). Spinks speaks about Lowry as an experimenter of early modernism, observing the way in which form manifests mental discontinuity (Spinks 67). Tidmarsh examines the autobiographical aspects of being locked up by connecting Lowry's life to that of Hilliot (Tidmarsh 45). The key research questions concern how Lowry employs the ship as a symbol of the more general psychological impact and the lack of natural cycles.

Research Focus

This study focuses on discussing how Malcolm Lowry's *Ultramarine* reveals itself in the symbolic representations of the ship, the modes of its confinement, and the signification that they have with the natural ecosystems and human societies. This study explores the connection between the maritime workforce, psychological disturbance, and environmental identity by analyzing Sophocles' Oedipus Tyrannus as a multifaceted psychosphere. It discusses how





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a closed environment on a ship predetermines human behavior and profoundly changes states of mind in a maritime setting. The main inquiries of the research are as follows:

1. In what ways does Lowry take the ship (Oedipus Tyrannus) to represent the larger psychological consequences of being in a cage?
2. How does the novel interfere with natural cycles and ecological balance in the maritime environment?
3. How does *Ultramarine* reflect human experience, and how broadly do the ecological and environmental crises represented by the closed environment of the ship resonate?

These questions led to a further analysis of the text.

Blue Humanities and Maritime Themes in *Ultramarine*

Malcolm Lowry in *Ultramarine* creates a story about the overlap of ecological systems and the effects of psychological incarceration, with predictions of a Blue Humanities interest in wet ontologies. The environment is portrayed as a shifting natural world, with industrialization interfering with local environments and transforming the lives of the characters, as seen when "The Oedipus Tyrannus poured out black smoke, mephitic and angry, from her one enormous funnel" (Lowry 18). The motifs of environmental disharmony are the core of the plot, and they can be used as a prism through which the impact of environmental degradation on society in the maritime environment can be discussed. The summary of the plot revolves around Dana Hilliot, a rural teenager who comes face to face with a mysterious maritime world, and through this interaction, he realizes that there is more environmental and psychological disaster as he repeats, "I am on a ship, I am on a ship, and I am going to Japan" (Lowry 9). The arrival of the ship is a disruption that has some larger ecological themes; the world of nature is depicted as weak and powerless in the face of humanity. Hilliot considers the boat to be a complex ecosystem, where he states, "World within world, sea within sea, void within void, the ultimate, the inescapable, the ninth circle" (Lowry 24). This discussion of the interplay between human and environmental contexts highlights the results of ecological distortion, when the ship turns into a psychosphere instead of a setting (Grace 45). The changing concepts of the confinement of characters are represented by the maritime environment, which is the environment of a blurry boundary between inner mental conditions and outer oceanic forces (Steinberg 23). Lowry employs fiction to emphasize the urgency of environmental and psychological action, implying that the sea is an active agent that shapes human identity (Neumann 8).

The striking description of the effects of being in a prison is used on the individual and global levels, making remarks on the necessity of maintaining a sustainable environment and sharing responsibilities. The dissociation in Hilliot is evident when he states, "The ship is not alongside the wharf in Tsjang-Tsjang. I am not on a ship's poop" (Lowry 48), describing the mental discontinuity of maritime labor. The agency of the environment is also highlighted when the sea is said to be actively consuming the crew: "The sea is picking Andy's bones in whispers" (Lowry 183). This is indicative of the Blue Humanities argument that oceans are social spaces in which isolation comes physically (DeLoughrey 67). The crew's orientation changes as they approach home, but they are still stuck: "Homeward bound for Gallion's Reach, although we can't pay off" (Lowry 221). In the end, Hilliot comes to a symbiotic relationship with the marine ecology, and he says, "I have identification with Andy: I am Andy" (Lowry 264), signaling a merger of human and maritime identity (Spinks 56). Such transformation is an excellent illustration of the urgent necessity to view the ocean as an actor rather than a background in human psychology (Gillis 102). The story unites scientific, ecological, and social aspects, emphasizing the complicated nature of the problem as well as the role of individual and combined responsibility (Bowker 89). From this perspective, the voyage of the ship is an element of the frailty of nature and an indication of the radical transformations that are occurring in our world (Day 115). The novel shows that ecological imbalances belong to a larger and global problem of the degradation of human and non-human life (Tidmarsh 34). Through these disruptions, *Ultramarine* encourages readers to consider the long-term impact of not taking action (Mentz 78).

The Ship as a Symbol of Psychological Confinement

In *Ultramarine*, Malcolm Lowry develops a plot in which the ship acts like the monarch butterfly in Kingsolver's *Flight Behavior*, in which the ecosystem is vulnerable and strong in a very limited area (Grace 45). Oedipus Tyrannus





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is a form of psychosphere in which the psychological systems become unstable through confinement, similar to the ecological system (Steinberg 23). Hilliot's repetition, "I am on a ship, I am on a ship, and I am going to Japan," emphasizes the interrupted sea voyage as a symbol of unbalanced mental conditions (Lowry 9). This allegorical application underscores the short-term effects of imprisonment on the mind, which displays extended systemic bypasses in sensitive imbalances (Neumann 8). The drastic change in the conventional path of the ship is used as a metaphor for the frailty of natural mechanisms in the face of human-made alterations (DeLoughrey 67). Old norms of the journey are broken, representing more far-reaching environmental and mental changes (Gillis 102). Initially conceived as a wonder, the arrival of the ship gradually unfolds as a crisis, much like the changed patterns of migration in ecological research (Mentz 78). As the vessel moves, "The Oedipus Tyrannus poured out black smoke, mephitic and angry," indicating derailment (Lowry 18). This change is a wake-up call for Hilliot, who is confronted with less visible disturbances (Bowker 89). As Hilliot notes, "World within world, sea within sea, void within void," the ship becomes a major object that attracts attention to transforming psychological trends that intervene in natural processes (Lowry 24).

The behavioral change in the crew is comparable to intra-crew changes, which actualize the extent of confinement (Day 115). The ship symbolizes the meeting of personal and global issues; Hilliot's way of going is a reflection of being stuck between the past and the future (Spinks 56). Traits of which Hilliot is the claimant, "The ship is not alongside the wharf in Tsjang-Tsjang. I am not on a ship's poop," it means the necessity to respond to psychological disturbances before it is too late (Lowry 48). The symbolism underlines the necessity to regain harmony by creating beauty in the face of tragedy caused by imbalance (Tidmarsh 34). The analysis of the symbolic meaning of the ship displays psychological disorder, in which disturbed journeys relate to greater maladies (Grace 102). Narrative analysis also presents the characters as being responsive to the presence of the ship as an active agent (Steinberg 56). The crew is devoured by the environment, as "the sea is picking Andy's bones in whispers," focusing on the social space of the ocean, where isolation is physically enforced (Lowry 183). This change explains how important it is to learn to view the ocean not as a setting but as an actor of the human mind (Neumann 12). Finally, the ship is an authoritative reminder that everything living is interrelated (Gillis 134). The crew turns back toward home. "Homeward bound for Gallion's Reach, although we can't pay off," signaling a merger of human and maritime identity despite entrapment (Lowry 221). Hilliot attains cooperation, stating, "I have identification with Andy: I am Andy," indicating a renewal of balance in the limited ecosystem. (Lowry 264). This is a call to consider the long-term effects of a lack of action in relation to psychological imprisonment (Bowker 90). The novel demonstrates the impact of ecological imbalance on the lives of human beings, as well as non-human beings (Day 120). Through knowledge of these disruptions, *Ultramarine* urges all to be responsible in ensuring a sustainable future of the mind (Spinks 67).

The Sea as a Reflection of Human Psyche

As Hilliot's story develops, he grows closer to the ship and starts perceiving it as his own struggle. Initially, he repeats, "I am on a ship, I am on a ship, and I am going to Japan" (Lowry 9), indicating a dissociative condition. This inner change is similar to the environmental and psychological change; the arrival of the ship can be taken as a wake-up call. The ship expresses this interference when "The Oedipus Tyrannus poured out black smoke, mephitic and angry" (Lowry 18). Rather, it is a sign of internal turmoil (Grace 45). Hilliot sees the ship as a multifaceted ecosystem and writes, "World within world, sea within sea, void within void" (Lowry 24), a distortion of the boundaries between the internal mind condition and the external oceanic stress (Steinberg 23). This psychosphere determines the changing behavior of mental conditions in the maritime sphere (Neumann 8). The sea reshapes human identity as it compels one to collide with the self (Gillis 102). Individual enlightenment comes when the incident with the ship enlightens Hilliot by making him aware of the need to deal with confinement. He starts to realize how individual life is related to world crises. This relationship between humans and non-humans shows that confinement is not a distant problem but concerns everyone (Bowker 89). However, dissociation occurs when he states, "The ship is not alongside the wharf in Tsjang-Tsjang. I am not on a ship's poop" (Lowry 48), depicting mental disintegration through work on the sea (Spinks 56). The agency of the environment is highlighted when the sea is named as eating the crew: "The sea is picking Andy's bones in whispers" (Lowry 183). This is an expression of the argument of the Blue Humanities that oceans are social spaces in which isolation is physically embodied (DeLoughrey 67). This type of isolation compels us



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to reconsider the self in the blue sphere (Tidmarsh 34). The ignorance and denial of humanity are noticeable at the beginning, as most inhabitants of the community where Hilliot lives reject the psychological meaning of the ship as an exception. This is a symptom of the common refusal to accept psychological confinement (Mentz 78). The shipment of the vessel also changes direction as the crew is oriented towards home but has been caught: "Homeward bound for Gallion's Reach, although we can't pay off" (Lowry 221). Hilliot passes by with a skeptical position regarding understanding, which resembles the path of people struggling with the truths of confinement (Day 115). Finally, Hilliot is in a symbiotic state with the maritime ecology by saying, "I have identification with Andy: I am Andy" (Lowry 264), indicating a unification of human and marine identity. This change highlights the importance of learning about the ocean as a participatory aspect of human psychology, as opposed to an image. The story lies between the scientific, ecological, and social angles and underscores the multidimensionality of the problem and the significance of the individual and collective burden. Through this, the voyage of the ship becomes a metaphor for the uncertainty of nature and a reminder of the immense changes occurring in our world. The novel shows how ecological imbalances are one of the greatest global problems that are impacting human and non-human life.

The Role of Labor and Hierarchy in Understanding Confinement

Lowry underlines the importance of special knowledge in the interpretation of the psychological phenomena of the maritime world. Characterized by scientist characters, who are matched by the officers of the ship, these attempts to understand how confinement affects the mind (Grace 45). The response to confinement is based on how knowledge about the labor hierarchy is developed and spread (Steinberg 23). The empirical evidence of the crisis is presented in the form of scientific advances, which offer structures of knowledge about the causes of such crises as they are in the ecosystem of the ship (Neumann 8). The global phenomenon of confinement demands interdisciplinary work, which reflects the atmospheric and social sciences (Gillis 102). This article discusses the importance of science and knowledge in the interpretation of confinement, with a particular focus on research and communication (Bowker 89).

The main input of this knowledge is the gathering and evaluation of data on the voyage of the ship. With the help of models and observational data, it is possible to foresee the future in a closed environment (Day 115). Global institutions gather information to make decisions in policy formulation, similar to the command structure of the ship (Tidmarsh 34). Science assists in determining the causes of confinement, such as industrial practices and labor conditions (DeLoughrey 67). Policies that aim to reduce and sustain focus on understanding human activities that lead to crises (Mentz 78). Green technologies have solutions that can be found through scientific investigation, which can be compared with the adaptation procedures of the crew (Spinks 56).

Science not only plays a technical role but also a crucial role in dealing with the social and political aspects of confinement (Steinberg 56). Common sense is essential in encouraging people to take joint action, and misinformation becomes a problem (Neumann 12). Science communication helps bridge the gap between knowledge and the understanding of the people (Gillis 134). Hilliot's repetition, "I am on a ship, I am on a ship, and I am going to Japan," depicts the necessity of grounding data (Lowry 9). The industrial effect of the ship is evident when "The Oedipus Tyrannus poured out black smoke, mephitic and angry" (Lowry 18). Hilliot observes the difficulty, noting, "World within world, sea within sea, void within void" (Lowry 24). Scientific observation and research on confinement portray how inquiry is crucial to understanding disruption (Bowker 90). The professional community can represent the scientific approach; however, the intuitive perception of Hilliot can point out the significance of combining local, experience-based knowledge with scientific knowledge (Day 120). This combination is key to dealing with complexities. Dissociation occurs when he asserts, "The ship is not alongside the wharf in Tsjang-Tsjang. I am not on a ship's poop" (Lowry 48). His agency on the environment is stressed when "The sea is picking Andy's bones in whispers" (Lowry 183). This illustrates the argument that oceans create social spaces in which isolation is expressed physically (DeLoughrey 67). Later in the journey, the crew's orientation changes: "Homeward bound for Gallion's Reach, although we can't pay off" (Lowry 221). In the end, Hilliot attains symbiosis and says, "I have identification with Andy: I am Andy" (Lowry 264). This change highlights the necessity of seeing the ocean as a subject of action in human psychology (Spinks 67). The story offers a dynamic presentation of ecological and social views, as well as the significance of shared responsibility (Tidmarsh 45). In this light, this journey is a representation



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of the frailty of nature (Mentz 78). The novel shows how ecological disproportions impact human and non-human lives (Grace 102). Through understanding these disruptions, *Ultramarine* encourages the reader to consider long-term effects (Bowker 89).

Alienation, Class, and Maritime Equity

Lowry focuses on the disproportionately high effects of confinement in rural and working-class maritime communities. Hilliot and the community face the challenge of economic poverty, and the arrival of the ship is the chance to create more awareness of the point of intersection between social inequality and psychological degradation. Hilliot mentions the resentment of the crew: "I hate those bloody toffs who come to sea for experience...." (Lowry 14). The theory of ecological equity examines the point at which environmental and social justice meet, dealing with the equitable allocation of benefits and burdens within society. The consequences of degradation, confinement, and loss of resources disproportionately differentiate marginalized communities. According to Spinks, in the initial stages of Lowry's work, emphasis was placed on the fragmentation of classes in closed spaces (Spinks 56). The principles of sustainable development imply that the current needs must be addressed without prejudice to future generations, who must, in turn, address their own needs. Intergenerational equity will guarantee that future generations will conserve ecological resources. Researchers, such as Jonas and Rawls, have engaged in this theory and have discussed moral directives to secure environmental commodities. In *Ultramarine*, the hierarchy in the labor force confronts exploitation to benefit in the short run. Hilliot notices the difference in pay: "Fifty shillings a month! Norman's salary was nearly three times that amount..." (Lowry 50). This is mirrored in the concept of environmental justice theory, which analyzes the effects of degradation on disadvantaged people according to their class positions and socioeconomic status. The environmental justice movement is based on the civil rights movement, which proposes an equitable allocation of harms. Such pioneers as Bullard and Pellow have underlined that policies must consider inequalities that determine vulnerability. The alienation of the crew is even felt: "We don't know what sort of bloody man you are at all. Just a nancy." (Lowry 12). Day points out that the biography of Lowry reveals that he, too, was faced with the problem of class identity at sea (Day 115).

EM theory is concerned with the possibility of economic development and sustainability coexisting via innovation. Huber and Jaenicke presented positive views on the equity of technology. Nevertheless, the novel implicitly criticizes the impact of crises on communities at risk. Citizens in maritime work are most susceptible to degradation by confinement, which makes the situation worse. Bowker pointed out that Lowry's voyage made him aware of the realities of a merchant marine's life (Bowker 89). The country and city dichotomy highlights the conflict between locking people up. The ship background offers a chance to comment on the psychological changes that endanger customary lifestyles. The issue of labor exploitation is obvious as Hilliot ponders: "Ah, God might count all his children, but he didn't count firemen, he left that to the Board of Trade." (Lowry 230). This is one indication of the expendability of labor in the industrial maritime complex. According to Tidmarsh, Lowry always returns to the themes of exclusion and belonging in his work (Tidmarsh 34).

Finally, the novel compels societies to confront the harsh realities of fairness. In short, the entrapment of the crew is: "Homeward bound for Gallion's Reach, although we can't pay off." (Lowry 221). According to Grace, the sea in Lowry's work serves as a transitional place where social constructs are strengthened and disintegrate (Grace 102). By understanding these upheavals, *Ultramarine* challenges readers to reflect on the long-term effects of ignoring labor equity. The story cuts across ecological and social views, encompassing the value of shared responsibility. From this perspective, the voyage of the ship has been symbolized as the flim-flam of nature and a reminder of the dramatic changes occurring in the world. The novel is based on ecological imbalances and their impact on human and non-human life. Through these disturbances, *Ultramarine* challenges readers to consider the consequences of inaction in the long term and how there should be shared responsibility in ensuring that all living species have a sustainable future.



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Finally, the experience of the ship, with its inhalation and isolation, is a reminder of the frailty of the planet and the interdependence of all life systems. As Oedipus goes through shifting weather patterns and psychological conditions, he represents the future of all species, including humankind, in a world dominated by human activity. Hilliot's repetition, "I am on a ship, I am on a ship, and I am going to Japan," emphasizes the foreseeable seasonal cyclings which represent the natural rhythm of the earth and its ecological balance (Lowry 9). Nevertheless, in *Ultramarine*, the arrival of the ship in a new psychological space, one it is not accustomed to, indicates a break in the natural systems. This new path, which at first was taken as a mystical event, slowly becomes a symbol of psychological breakdown. According to Grace, Lowry's maritime imagery serves as a space of liminality, as it is at once a space of social structures in the process of reinvention and disintegration, and an ecological space of instability (Grace 102).

The fact that a natural behavior is affected unnaturally by an increase in temperature and changes in patterns makes the confinement of animals change not only the life of people but also the migration and survival of the species. Hilliot conceived of the ship as a complicated ecosystem, observing, "World within world, sea within sea, void within void" (Lowry 24). This can be seen as the Blue Humanities assertion that oceans are social zones that experience isolation, both physically and mentally (Steinberg 23). With the community members struggling to find implications, the storyline demonstrates how ecosystems must adapt or fail in response to accelerating conditions. When the industrial influence occurs, it is obvious. "The Oedipus Tyrannus poured out black smoke, mephitic and angry" (Lowry 18). Day argues that Lowry's biography indicates that he, too, had an identity problem concerning classes in the sea, just as the ship had appeared in the world economy. (Day 115).

The disturbance alerts us to the fate of the planet and endangered species that require a stable and predictable environment. The entrapment of the crew is as follows: "Homeward bound for Gallion's Reach, although we can't pay off" (Lowry 221). This refers to the expendability of work in the industrial maritime system and the snare of contemporary life. According to Spinks, the theme of exclusion and belonging, as well as the connection between personal trauma and the fractures of society, is constantly present in the works of Lowry (Spinks 56). The voyage of the ship in *Ultramarine* serves as a miniature of greater environmental issues and the necessity to take action to save biodiversity. Finally, Hilliot reaches a symbiotic relationship with the maritime ecology and says, "I have identification with Andy: I am Andy" (Lowry 264). This change makes it clear that it is necessary to recognize the ocean not only as a background but also as an agent in the human mind. Bowker highlights Lowry's exposure to the reality of the life of a merchant marine during his trip, making the fiction based on empirical struggle (Bowker 89). The destiny of the ship is closely connected to the destiny of the entire planet and all its species. Knowledge of these disruptions compels *Ultramarine* to encourage readers to think about the consequences of not taking action in the long run, as far as psychological and ecological imprisonment is concerned.

The Disruption of Psychological Cycles and Its Implications for the Planet

The voyage of the ship in *Ultramarine* is the way seclusion distorts the subtle cycles of life on earth through ecology. Hilliot's repetition, "I am on a ship, I am on a ship, and I am going to Japan," emphasizes the derailed sea voyage as a symbol of wobbly states of mind (Lowry 9). The burning of fossil fuels in industrial activities has also disrupted seasonal patterns and has impacted the flora and fauna in the maritime sphere. This disruption is manifested in the vessel when "The Oedipus Tyrannus poured out black smoke, mephitic and angry," indicating a change in the environment (Lowry 18). This metaphoric application illustrates the short-term effects of imprisonment on the psyche and is representative of more systemic disorders in fragile balances (Neumann 8).

Changes in environmental conditions interfere with complex relations between species, compelling them to adapt in a manner that cannot be maintained in the long term (Steinberg 23). The appearance of the ship in the harbor caused severe scrutiny and discussion among the crew in the area. When community members, especially Hilliot, start to realize the implications of the changed course of action, they are directly faced with the reality of imprisonment and the possibility of disrupting not only the environment but also livelihoods. Hilliot saw the ship as a complicated



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ecosystem and wrote, "World within world, sea within sea, void within void" (Lowry 24). This illustrates the Blue Humanities argument that oceans are social spaces where isolation is expressed physically (Gillis 102).

The disturbance of familiar natural events is a reminder that the ecosystems of the planet are becoming increasingly susceptible to the impact of human activity. The agency of the sea is brought out clearly as the sea is described to be consuming the crew: "The sea is picking Andy's bones in whispers" (Lowry 183). This alteration highlights that it is essential to learn to perceive the ocean not as a background but as an agent of the human mind (Spinks 56). The voyage of the ship, therefore, represents the vulnerability of life on earth and the necessity to take measures to solve such environmental problems as confinement, depletion of resources, and destruction of habitats. Finally, Hilliot is able to reach symbiosis, and he says, "I have identification with Andy: I am Andy," an indication of the regained harmony in the closed ecosystem (Lowry 264). This calls the readers to think about the long-term effects of not taking action on the issue of psychological confinement (Bowker 89). The novel shows the impacts of ecological imbalances on the lives of humans and non-humans. Knowing these disruptions, *Ultramarine* urges people to be responsible in making the future of the mind sustainable.

The Role of the Ship as Harbinger of Change

In *Ultramarine*, the ship is a prophet of psychological transformation, both in terms of physical interference with the path of the travels and in the general sense. Black smoke, mephitic and angry, oozes out of Oedipus Tyrannus, and the transition towards the environment has occurred (Lowry 18). This metaphoric application emphasizes the short-term effects of restraint on the psyche and represents a larger systemic imbalance of fragile equilibria (Neumann 8). The existence of the ship provokes society to accept the changes that occur in their thinking and to face greater problems of constriction. Hilliot views the vessel as a complicated ecosystem, where "World within world, sea within sea, void within void" (Lowry 24). This is an expression of the Blue Humanities argument that oceans are places where people are socially isolated (Steinberg 23).

To Hilliot, the ship acts as an agent of self-change and compels him to reconsider his perception of the world and his place in it. Initially, he repeats, "I am on a ship, I am on a ship, and I am going to Japan," emphasizing the interrupted maritime voyage as a model of the shaken state of mind (Lowry 9). This revolution places the issue of the necessity to learn the ocean as an agent rather than a background of human psychology (Spinks 56). The ship represents an intersection point on the planet, similar to the crucial stage humans reach in the struggle against enslavement. The crew turns homeward, orienting, "Homeward bound for Gallion's Reach, although we can't pay off," indicating a fusion of human and sea identity in spite of entrapment (Lowry 221). This is an indication of the expendability of labor in the industrial maritime complex and the snare of contemporary living (Bowker 89). (Bowker 89).

The destiny of the ship is intricately connected with the future of all species on the planet. Finally, Hilliot attains symbiosis and says, "I have identification with Andy: I am Andy," signaling a restoration of harmony within the confined ecosystem (Lowry 264). This urges readers to consider the long-term consequences of inaction regarding psychological confinement (Grace 102). The disruption of the journey calls attention to the urgency of environmental action and the importance of addressing confinement in a meaningful way before irreversible damage occurs. Just as the ship cannot journey alone, humanity must work together to address environmental challenges affecting all. The novel illustrates how ecological imbalances affect both human and non-human life, serving as a potent reminder of the interconnectedness of all living things. By understanding these disruptions, *Ultramarine* calls for collective responsibility in securing a sustainable future for the mind.

CONCLUSION

Malcolm Lowry's *Ultramarine* uses the ship's journey as a powerful metaphor for the disruption caused by psychological confinement within the Blue Humanities framework. Through the lens of the ship, the novel explores themes of ecological instability, human displacement, and the urgent need for scientific and social intervention. The





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altered journey of Oedipus Tyrannus symbolizes the larger ecological equation that humanity must address: the balance between human activities and the natural world is delicate, and the future of the planet depends on how we choose to act in response to confinement. This paper explores how Lowry's narrative bridges scientific, ecological, and social perspectives on confinement, highlighting the complexity of the issue and the importance of both individual and collective responsibility. Through this lens, the ship's journey becomes not only a symbol of nature's beauty and fragility but also a reminder of the profound changes taking place in our world.

Through the symbol of the ship and disrupted journey, *Ultramarine* provides a poignant commentary on the future of the planet in the face of confinement. The novel illustrates how ecological imbalances, as seen through the ship's journey, are not isolated incidents but part of a larger, global issue affecting both human and non-human life. The ship's journey, once a symbol of natural harmony, is now a metaphor for psychological collapse and the loss of biodiversity, threatening the health of the planet. This research paper emphasizes how Lowry uses the ship's journey to explore broader environmental themes in the novel, stressing the importance of recognizing and responding to the ecological crises shaping the future of the planet. By understanding these disruptions, *Ultramarine* urges readers to consider the long-term consequences of inaction and the need for collective responsibility in securing a sustainable future for all living species. Ultimately, the text calls for a holistic approach to safeguarding the mind and the environment alike, suggesting that psychological healing is inextricably linked to ecological preservation. The voyage ends not just as a physical return but as a spiritual awakening to the interconnectedness of all life within the maritime sphere.

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RESEARCH ARTICLE

Mapping Ecological Medical Humanities: A Bridge-Term Scientometric Analysis (2000–2025)

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ABSTRACT

Ecological Medical Humanities (EMH) has become a term to describe a body of scholarship that re-contextualizes the health, illness, care, and medical practice in the ecological systems and planetary crises. Although there is growing pressure to have an ecologically dimensioned medical humanities, EMH is hard to demarcate since the work in question is scattered throughout medical humanities, public health, environmental humanities, and other related interdisciplinary agendas. EMH has been operationalized in this paper as a boundary-spanning zone of knowledge, and a reproducible Scientometric workflow has been suggested to map the intellectual and thematic organization in the Web of Science Core Collection (SCI-EXPANDED SCI, and A&HCI) of 2000-2025. Our extension of proven bibliometric techniques is the descriptive profiling, the clustering of co-occurring keywords (co-word analysis), the coupling and co-citation mapping (based on citations), and a bridge-term procedure advanced on betweenness centrality calculated on the keyword graph. The interpretation of bridge terms is in terms of something disproportionately linking otherwise segregated topical communities, which uncovers the integrating vocabulary of EMH and reveals the compartmentalization where it exists. We also delimit clear data cleaning procedures and reporting components in line with new directions of bibliometric reporting and scoping review conventions. The rationale behind the study is the preexisting evidence of the fact that



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ecological framings have not always been at the forefront of intention among flagship medical humanities locations, despite climate-health commissions and One Health discourses signifying the interconnection of human health with the biosphere [1], [3]-[5].

Keywords: Ecological medical humanities, scientometrics, bridge terms, betweenness centrality, co-word analysis, Web of Science, interdisciplinarity.

INTRODUCTION

Ecological determinants of health are no longer applicable as background information. They are now direct and material in determining patterns of illness, clinical practice and health system organization. There are no peripheral issues of climate change, biodiversity loss, pollution, and zoonotic spillover. They make diagnosis more difficult, overstretch infrastructures, and destabilize old differences between clinical space and ecological systems. Significant climate-health summaries in major medical journals assisted in bringing this interface to a core policy and research focus [3], [4]. Nevertheless, these models have been criticized for being insufficiently involved with social sciences and humanities, as well as having their normative commitments unexplored [5], [13]-[15]. Ecological Medical Humanities (EMH) is a new intellectual formation that has already been formed within this changing landscape. It facilitates the extension of the narrative, ethical, historical, and cultural resources of medical humanities into ecological crisis and more-than-human entanglement. Essays of such foundational articulation include a call to an ecologically dimensioned medical humanities, which holds that it is no longer conceptually sound to separate health status on the one hand and ecological status on the other, and that the discipline has the opportunity and responsibility to give an adequate response to ecological thought [1]. Scientometrically speaking, however, EMH does not yet seem to be a coalesced field. It does not have a fixed canon, standard vocabulary or even publication outlets. It functions rather as a boundary-spanning knowledge space. Its consistency probably lies less in a characteristic centre of thematic focus than in the forms of conceptual brokerage, cross-domain citing and the incremental development of integrative vocabularies. This paper describes a scientometric study of the Web of Science Core Collection, which includes SCI-EXPANDED, SCI, ASCI and AHCI, 2000-2025. It is intended to chart EMH as an interdisciplinary territory of emergence. The overall methodological innovation is a bridge-term process. The model is that concepts are represented as nodes in a co-occurrence network of keywords, and bridge terms are determined using betweenness centrality. This translates the argument that EMH is characterized by assimilation between clusters and not a subject. The triangulation of the analysis occurs based on the bibliographic coupling and co-citation techniques that trace the research fronts of the time and common intellectual grounds, respectively [6], [10]. The outcome is a repeatable workflow and reporting template that can be submitted to a Web of Science-indexed conference.

Another reason why a bridge-term Scientometric study of EMH is needed is that ecological reframing of medicine is not just an addition to the coverage of topics but a restructuring of what is regarded as medical relevance, evidence, and responsibility at scale, actors, and times. In this respect, EMH is not merely the importation of environmental concerns into preexisting discourses. Still, it re-pressurizes the conceptual technology of the humanities of health by compelling questions of embodiment, of vulnerability, of care, of narrative to become expressly located within biophysical systems of infrastructures and within multispecies reliance, even as it also reveals how established limits between the clinical, the social, and the ecological have been maintained by institutional specialization, publication division, and indexing practices. The ensuing scholarship would therefore tend to follow a structural pattern that is not so traditional as found in the formation of different disciplines, namely, to coalesce around a specific set of canonical issues and journals, EMH would tend to proliferate in partial alignments and episodic alliances, usually organized around moments of crisis, funding imperatives, or special issues, and expressed via shifting vocabularies that trace the comings and goings of concepts such as resilience, exposure, systems, adaptation, and justice across



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heterogeneous research communities. This has a direct implication on the way we assess EMH to be cohering into a recognizable research front. Simple increases in publication and citation can demonstrate an increase, but not whether the increase is the result of conceptual incorporation or parallel proliferation of detached subfields that are of acute thematic interest with the environment or because of a loose thematic interest in health. A bridge-term strategy offers a more diagnostic approach since it involves questioning the actual process of integration in terms of what terms are used to bring together the two clusters and how far such terms are stable connectors and not momentary rhetorical tokens. By so doing, the approach can shed light upon the epistemic politics of interdisciplinarity itself: whether it is dominated by managerial and systems vocabularies that move readily across disciplines, whether it is grounded in ethically controversial concepts that enlist discourses of criticism and normative debate, or whether it is carried by biomedicalised conceptions that tend to assimilate environmental issues into technocratic problem-solving without sustained regard to history, culture and power. Further, bridge-term mapping can be used to expose imbalances in knowledge traffic, including instances of invoking concepts within climate-health discourse as instruments of communication or behavior change instead of sound theoretical frameworks, or of introducing environmental concepts into health humanities in a manner that foregrounds specific geographies and peoples and backgrounds environmental justice studies and Indigenous or decolonial knowledges. These asymmetries are important in that the promise of EMH not only acknowledges ecological determinants of health but also reorganizes interpretive and ethical resources with the help of which societies are telling narratives of harm, responsibility, repair, and futurity in the face of planetary pressure. The Scientometric protocol submitted should then enable the appearance of the connective tissue and fractures of the emerging domain, demonstrating where the translation is successful, where it is unsuccessful, and which conceptual bottlenecks repeatedly facilitate interdisciplinary contact. Lastly, since EMH is cross-index and cross-category in nature, a mapping using the Web of Science can be a source of not only an empirical record of what can be discovered using dominant indexing infrastructures but also a reflective record of how the infrastructures themselves influence what will seem a field in the first place; such a reflexivity is particularly relevant to a field adjacent to the humanities, whose significant work is often disseminated through the genres and channels captured by bibliographic databases unevenly, and whose methodological transparency regarding query design, parameterization, and validity.

EMH appears as a pivotal and boundary-spanning node between three contributive knowledge areas, such as Medical Humanities, Environmental Humanities, and Public and Planetary Health. In contrast, conceptual connectivity occurs between clusters through bridge terms (high-betweenness keywords).

The arrowheads are solid to denote the main knowledge-flow connections of each area into EMH and boldly bidirectional to denote interdomain interdisciplinarity, which EMH can explicitly denote. The focal construct (EMH) and the bridge-term concept are emphasized with the help of accent color (teal). In this number, the key operationalization of this paper of EMH as an emergent interdisciplinary space is visualized as opposed to a single subject field. Indeed, the three rounded rectangles symbolize the primary disciplinary or programmatic constituencies, which contribute to the EMH-relevant scholarship on the one hand: Medical Humanities (narrative, ethics, history, care), Environmental Humanities (ecology, Anthropocene, exposure), and Public and Planetary Health (climate-health, One Health, systems). The node of the EMH center is the point of intersection of these discourses in the analytic target corpus. The bridge-term annotation defines which scientometric mechanism the study operates: keywords with high betweenness centrality in the co-occurrence network are considered bridge terms since they bridge otherwise disjointed topical clusters and empirically quantifiable integration. The three domains are connected by dotted links that show that interdisciplinarity may directly take place between contributing fields, too; the bridge-term process attempts to identify when (and by what concepts) that cross-domain relationship solidifies into a familiar EMH space of knowledge.

Related Work

Ariographic bibliometric science mapping offers a well-developed and established set of methodologies to show thematic and intellectual organization of scholarly corpora. Co-citation analysis proposed a relational metric of the frequency of co-occurring documents, such as co-citation, and made possible the discovery of research and





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intellectual focus areas [6]. Bibliographic coupling ties documents mentioning comparable references and is generally applied to find research fronts nowadays. Co-word analysis is a complementary method to citation-based methods, and it can be used to map thematic organization based on term co-occurrence patterns, and is useful in those interdisciplinary domains where heterogeneous labeling practices are observed [7]. The mapping methods have become practically accessible due to widely used tools. VOSviewer facilitates the creation and visualisation of bibliometric networks using co-authorship, co-occurrence, citation, bibliographic coupling, and co-citation relationships and has text-mining functionality to create term co-occurrence maps [2], [8]. Bibliometrix is an open-source R ecosystem to support end-to-end processes of science mapping, including its import and cleaning of data, network and thematic analysis [9]. Another methodological issue that has been solved through methodological syntheses is the lack of equal reporting quality of bibliometric research, which has led to the creation of reporting guidelines and lists of systematic recommendations. More recent efforts have focused on the use of transparency in search strategies, inclusion criteria, preprocessing, and parameter settings as conditions of reproducibility and interpretability [18]. Simultaneously, evidence-synthesis reporting guidelines like PRISMA-ScR have had an impact on researchers describing retrieval and screening steps of scoping-type mappings [11]. These changes are especially pertinent to EMH, in which the delimitation of the corpus is not trivial, and both query design and sensitivity are. Interdisciplinary traditions of measurement have a conceptual basis in bridge analysis. Journal citation networks have based measures of betweenness centrality and diversity on interdisciplinarity since these metrics measure boundary-spanning roles and connectivity across domains [12]. The concept-level analogue used in the current work is the use of bridge terms: we do not count the brokerage of journals in citation networks, but count the keyword brokerage in thematic co-occurrence networks.

Research Questions

RQ1: How does EMH-related scholarship indexed in Web of Science Core Collection (SCI-EXPANED, SSCI, A&HCI) change in terms of growth of publications, publication areas or venues, and disciplinary representation?

RQ2: What are the thematic clusters of EMH as manifested by the clustering of key words based on the co-occurrence of key words, and which are core and peripheral topics?

RQ3: Which are the keywords that are bridge terms between thematic clusters, and which journals and documents are in a bridge role of citation-based coupling and co-citation networks?

Source of Data and Corpus Delimitation.

The source of data will be Web of Science Core Collection, restricted to SCI-EXPANED, SSCI and A&HCI between 2000 and 2025. The delimitation issue is solved by operationalization of EMH using the intersectional query, which integrates descriptors, ecological framing descriptors and climate-health interface descriptors. The purpose of this design is to retrieve a corpus of boundary-spanning as opposed to a corpus of a narrowly defined subtopic. Since environment is polysemous, a post-retrieval screening phase eliminates the records where environment is applied in non-ecological contexts (technological, built, or institutional) but with ecological referents, which has been noticed in flagship venues [1]. The decisions made regarding filtering are recorded under reproducible reporting in line with the recommendation of bibliometric reporting [18].

METHODOLOGY

Web of Science extraction (exact query) Records are then searched in the Web of Science Advanced Search interface with the TS= tag (Topics) searching title, abstract, author keywords and Keywords Plus. Precedence is governed by the use of Boolean operators and parentheses, and the proximity operator is applied when needed. Web of Science documentation on Boolean operators is found in Clarivate documentation [19].

The exact query string is: TS= ("" OR "health humanities" OR "narrative medicine" OR ("history" NEAR/3 medicine) OR ("ethics NEAR/3 medicine") OR (ecology OR environment OR biosphere OR "more-than-human" OR multispecies OR "environmental humanities")) AND (climate change) OR (planetary health) OR (environmental



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health) OR (One Health) OR (Anthropocene) OR (whole environment) Indexes are limited to SCI-EXPANDED, SSCI, and A&HCI and the times All the records and referenced works are exported in VOSviewer format to be analyzed at lower levels.

Descriptive profiling. We calculate the number of publications per annum, top sources, top authors and institutions, country distributions, and types of documents. Reporting of citation counts is done cautiously, as there are differences in citation practice across fields.

Co-word analysis and VOSviewer parameterization. It is possible to create a network on the basis of bibliographic data in the VOSviewer, analysis type Co-occurrence and unit of analysis All keywords (Author Keywords and Keywords Plus). The default configuration is a thesaurus file used to combine spelling variations and synonyms before constructing networks; the default normalization in VOSviewer is the Association strength that is used as input to the VOS layout and VOS clustering techniques [20]. The clustering is with the VOS clustering technique and Resolution=1.00, which is the default of VOSviewer. The manual recommends that higher resolution results in increased clusters, and to experiment with various values to have a realistic level of detail. Sensitivity checks are also run at 0.75 and 1.25, although the primary solution reported uses 1.00 unless over-fragmentation of segments or under-segmentation is apparent [20]. The minimum cluster size is set to 5, and “Merge small clusters” is in mode so that the clusters with fewer than the minimum cluster size are merged as larger clusters instead of being discarded, thus avoiding unassigned items during bridges interpretation [20]. Layout is calculated based on default VOS layout settings, whereby in case of instability, the best options are Attraction=2 and Repulsion=1 as are suggested in the manual [20]. Bridge term analysis. Bridge terms are operationalized as high betweenness centrality keywords on the keyword co-occurrence graph. Bridge terms are reported explicitly, which is in line with reporting best practices regarding bibliometric analyses [18]. The results of VOSviewer cluster assignments and link weights are exported to compute centrality in external network analysis packages. It is interpreted by applying known applications of betweenness as a border spanning measure in citation networks [12]. Citation-based triangulation. Bibliographic coupling is applied to determine the proximity of contemporary EMH documents, and co-citation analysis is applied to determine the intellectual base and foundational anchors [6], [10]. Broker documents are considered to be those that are characterized by large bridge-term density in addition to brokerage positions in coupling networks.

RESULTS AND EXPECTED FINDINGS

Since this paper is intended to be an executable mapping protocol, but no dataset is provided in this document, the results are expressed as testable expectations and not numeric assertions. Co-word clustering should demonstrate that narrative-ethics work, systems-oriented ecological public health, and climate-health policy and exposure discourses contain multiple thematic communities, which we expect [1], [3], [4], [16]. Bridge terms will presumably signify whether integration is achieved via general connectors like systems and vulnerability or more programmatic connectors like planetary health and One Health, which do or do not co-travel with anthropocentric and limited humanities (research) vocabularies [5], [14], [15].

DISCUSSION

The bridge-term methodology is a concept-level measure of field formation and interdisciplinarity. When bridge connectivity is highly concentrated on a small set of generic terms, EMH integration can be weak and rhetorically weak. Provided that bridge terms cut across narrative, ethics, systems, justice, exposure, and climate-health constructs, it is possible that the integrative vocabulary of the field is stronger. The methodology is direct to the ecological claim that ecological framings are not prominent enough in mainstream indexing since integration of such frameworks is detected with explicit WoS query syntax and precise VOSviewer parameters normalization and clustering. This corresponds to the findings that the quality of bibliometric reporting differs and transparent reporting leads to better reliability and interpretability [18]. It is limited by the poor coverage of monographs and





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certain humanities venues by WoS, and the heterogeneity of keywords across disciplines. This paper identifies a Web of Science Core Collection mapping protocol of EMH (SCI-EXPANDED, SSCI, A&HCI; 2000-2025) that defines descriptive profiling, co-word clustering based on VOSviewer with association strength normalization, identification of bridge-term by using betweenness centrality, and triangulation of citation-based. The protocol generates a reproducible map of EMH thematic clusters and integrative vocabulary. It identifies broker documents and venues that facilitate the flow of cross-domain knowledge in the Web of Science by encapsulating EMH as a conjunction of three families of concepts. A transparent, modular logic to construct the EMH corpus in Web of Science is presented in Table 2, bringing operationalizations of EMH as an intersection of three families of concepts. Block A centers the search within the health-humanities field to make sure the corpus is still based on medical humanities issues and terms. Block B proposes explicit ecological terms of framing to encompass work that is being done to the environment and more-than-human relations, as constitutive of health, but not as background. Block C introduces the climate-health interface terminology that tends to act as a transfer point between otherwise distinct literatures, bringing back to memory interdisciplinary research relating humanities inquiry to climate-related health agendas. The combination of the blocks also allows reproducible balance of accuracy and breadth: the blocks do not need to reduce EMH to a single keyword but provide the inclusion criteria in enough detail that they are also auditable and replicable across WoS exports.

Table 3 shows the core reporting units applied to the approach of operationalization of the bridge between terms to retain the results interpretable and reproducible. Instead of applying the term interdisciplinarity to an overall assertion, the template defines what will be recorded at the levels of keywords, thematic groupings, documents, and venues, so that a reader can be made aware of the precise concepts that are working as connectors, what areas of knowledge are being bridged, and where EMH integration is concentrated in the literature (articles and journals).

The conceptualization of this paper defines Ecological Medical Humanities (EMH) as a boundary-spanning knowledge space constituted at the interconnectedness of medical humanities, environmental humanities, and public/planetary health as a reaction to the argument that health cannot be plausibly compartmentalized out of ecological contexts. In order to get beyond the aspirational interdisciplinarity, it suggests a Web of Science Core Collection (SCI-EXPANDED, SSCI, A&HCI; 2000-2025) Scientometric workflow blending co-word clustering with a bridge-term process. Bridge terms are defined as high-betweenness words in the co-occurrence network to enable integration of EMH to be quantified as connectivity between thematic clusters and not based on topical overlap alone.

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Table 1. Comparison of traditional and (EMH)

Dimension	Traditional Medical Humanities	Ecological Medical Humanities (EMH)
Core aim	Interpret health, illness, and care through humanistic inquiry	Reframe health, illness, and care as ecologically embedded and integrate ecological crisis into health-humanities thinking.
Central objects of analysis	Patient experience, clinical encounter, professional identity, medical institutions, medical ethics, illness narratives	Bodies-in-environment relations, ecological determinants of health, multispecies relations, climate and health, toxic exposure, planetary-scale risk
Boundary of "context."	Social, cultural, historical, and institutional contexts around medicine	Ecological context is not background but constitutive; health cannot be compartmentalized away from environmental systems
Dominant problem frames	Meaning, suffering, care, ethics, narrative competence, and power in clinical settings	Systems, vulnerability, exposure, adaptation, environmental justice, climate-linked risk, and sustainability in healthcare narratives
Typical methods	Close reading, narrative analysis, historiography, qualitative interpretation, critical theory	The above, plus explicit ecological framing, systems thinking, interdisciplinary synthesis with ecological public health.
Typical evidence-based	Texts (memoirs, fiction, case narratives), interviews/ethnographies, archives, ethical argumentation	Texts and archives, plus ecological public health models and climate-health syntheses.





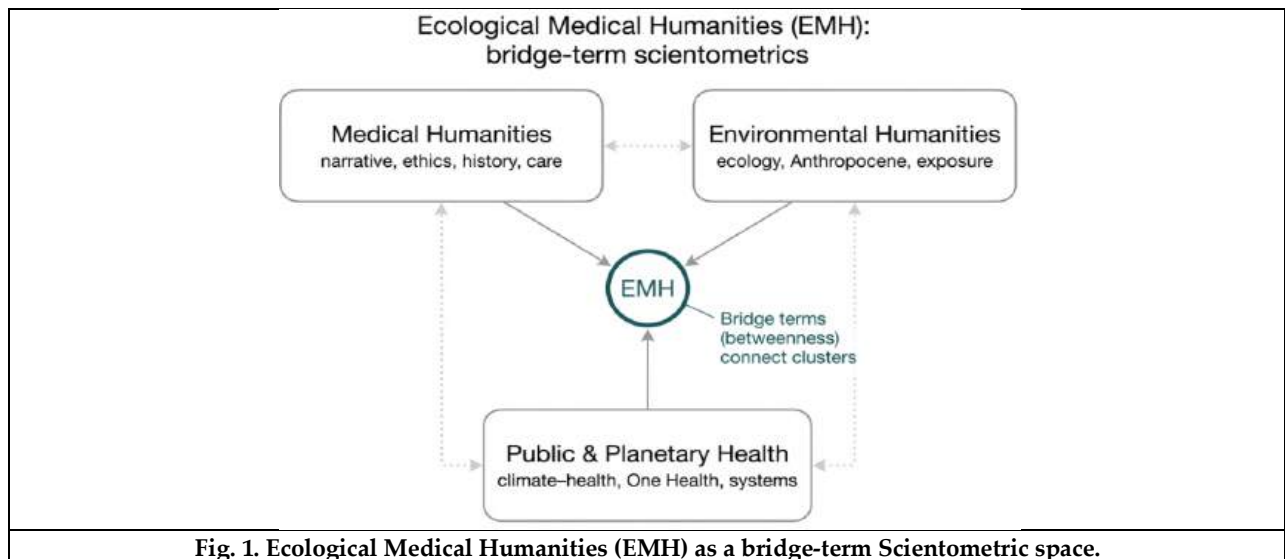
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Table 2. Query Block Logic for EMH Corpus Construction in Web of Science (2000–2025)

BLOCK	CONCEPTUAL ROLE	ILLUSTRATIVE STRINGS
A	anchor	"" OR "health humanities" OR "narrative medicine."
B	Ecological framing anchor	ecology OR environment OR biosphere OR "more-than-human."
C	Climate–health interface anchor	"climate change" OR "planetary health" OR "environmental health" OR "One Health"

Table 3. Bridge-term reporting template and interpretation

Output element	Definition	Interpretation
Bridge Term	High betweenness keyword	Integrative vocabulary candidate
Connected clusters	Cluster pairs linked	Where integration occurs
Bridge documents	Records with multiple bridges	Conceptual brokers
Bridge journals	Venues of bridge documents	Interdisciplinary conduits



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RESEARCH ARTICLE

Memory Fragmentation and Resilience an Ecofeminist Reading of Gokhale and Roy

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ABSTRACT

This study reframes memory within ecofeminist resilience as an active system that helps sustain continuity, identity, and adaptive capacity through relational expression. Through comparative literary analysis of *Shakuntala: The Play of Memory* by Namita Gokhale and *The Folded Earth* by Anuradha Roy, the approach and manner of patriarchal silencing and acknowledgement as embodied in memory are explored, with a focus on fragmentation and resilience. A broken emotional continuity marks Gokhale's retelling by *Shakuntala*; the deprivation of storytelling expression results in isolation and fragmentation, draining the self in silent endurance. Roy's *Maya* lets the memory unravel gradually with the help of landscape and human relationships. Her sorrow is still perceptible, her fragmentation is maintained relationally, so it is possible to endure without demanding wholeness. This contradiction reveals that memory wounds not intrinsically, but when the social system refuses its expression, hence making it either destructive or manageable. Sustainability is not created by eliminating the trauma but by caring informed ecologies that observe fragmentation. Redefining resilience is ethical endurance sustained by a relationship and not controlled.

Keywords: Memory, ecofeminist resilience, trauma, fragmentation, Namita Gokhale, Anuradha Roy.



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INTRODUCTION

The literature has become an important site that questions the role of trauma in both human life and nature in a world characterized by ecological destruction and systematic gendered violence. The growing climate crisis, which impacts women disproportionately, especially in the global south, requires a framework capable of examining the structural intersection between the harm of the environmental and patriarchal system of domination.

These systems are not independent entities but deeply interwoven forces that perpetuate trauma across generations and across geographies. This paper examines the idea of memory as a fragmented symptom of eco-gendered trauma and a site of resilience. It explores how landscapes are turned into an effective archive in which personal and shared trauma are written, logged, and reimagined through narrative fragmentation, focusing on the works of Namita Gokhale and Arundhati Roy.

The theoretical background of this investigation is an ecofeminist perspective. The early ecofeminism led by Vandana Shiva in her book *Staying Alive* (1988) had focused on the material relationship between women's subsistence and ecological management, a systemic relationship that colonialism and neoliberal extra activism have systemically undermined. The work of Shiva emphasized the fact that the traditional knowledge system of women was biased towards sustainable practices, which were shattered by the new system of industrialization that prioritized profitability over conservation. This analysis was further extended in later works by Maria Mies and Vandana Shiva (1993), who theorized the dual colonization of women and nature by capitalist patriarchy. They argued that the exploitation of natural resources and the marginalization of women were not incidental but a larger pattern of domination that considered both as fungible resources. This framework did not focus on the essentialist abstraction of women to a passive representation of nature, but rather placed them in an active role of opposition to environmental degradation.

The modern ecofeminism, as expressed by such theorists as Greta Gaard (2011), does not deny the material entanglement between women's bodies and the more-than-human world in a system of domination. The work by Gaard highlights how ecofeminism has been transformed to incorporate intersectional issues, drawing on the exploration of race, class, and colonial histories in examining environmental issues. As an example, she points out how indigenous women and women of colour are frequently the ones who suffer due to ecological crises. Still, their voices are sidelined in the mainstream environmental discourse. The development provides a sensitive net of understanding the interplay of gender and ecological violence, which can be used to unravel the intrigue within narratives that grapple with environmental and social trauma.

Trauma theory can also add to this exploration by shedding light on how traumatizing events disrupt the linear temporality and narrative integrity. Cathy Caruth's concept of "unclaimed experience" (1996) describes how trauma cannot be absorbed into the traditional system of memory, but it rebounds in fragmented form from memory and embodied reaction. Caruth argues that trauma is not merely an occurrence but a break that cannot be chronologically neglected; it expresses itself in forms that undermine the system of narration. Judith Herman's (1992) highlights the fact that survivors tend to undergo intrusive re-experiencing that disrupts the chronological memory constructions. Her clinical insights provide the idea of how trauma alters progress time, which keeps people in a continual loop of pain and memory. This observation is furthered by Maurice Halbwachs through the concept of how remembrance is a socially constructed, contextually situated phenomenon. Halbwachs proposes that landscapes themselves are a repository for how communities experience and process them.

The theory of multidirectional memory (2009) by Michael Rothberg provides an additional dimension that explains traumatic histories are transmitted between generations, as opposed to the isolationist perspective. A combination of these frameworks places memory as a conflictual and active process defined by power relations and material kinds of environment, which can be used to analyze how ecological and gendered trauma are engraved on bodies and





landscape. Resilience theory connects ecological and psychological aspects of recovery, and does not view resilience as individual strength but as a relational ability that arises through entanglements with the human environment. According to Walker et al. (2004), resilience is defined as adaptability, transformability, and the social-ecological system. In this regard, resilience does not mean returning to a past situation, but rather relationships with the environment in a manner that promotes sustainability and equity. This viewpoint can be compared to the ethics of care by Carol Gilligan (1993), which places greater emphasis on interdependence and resilience in growing through a network of care and mutual support. Through his work, Gilligan is opposing mainstream paradigms of individualism by arguing that human well-being is always connected to the well-being of our relationships with other human beings and the natural world. The recent work by Alice, Jebaselin, and Mohanraj (2024) illustrates how women's environmental activism in India embodies this relational resilience. This study highlights the role of grassroots movements led by women who are combating extractive logics with creativity and resistance, whether through reforestation initiatives or through movements against industrial pollution. Such convergence-theoretical stands allow a more profound grasp of how people and communities emerge from their trauma, not through a solitary healing process but by reconstituting their relationships with harmed ecologies.

LITERATURE REVIEW

Prankaj Solanki analyzes Namita Gokhale's *Shakuntala: The play of memory* through the feminist interpretation, dispelling the stereotype of the fallen woman. In comparing the protagonist of Gokhale with the passive *Shakuntala* in Kalidasa, Solanki states that the novel redefines the myths to establish female independence. Based on Simone de Beauvoir, the paper assumes that the protagonist has an identity against the patriarchal convention. She goes with Nearchus in search of knowledge. Gokhale turns the unfortunate picture of a fallen woman into an image of revolt. The text emphasizes authors such as Angadi and Nigam, and it highlights psychological depth. She ultimately redeems herself by moving beyond boundaries to become herself.

Akansha Srivastava explores the novel by Namita Gokhale through the prism of ecofeminism. Srivastava makes the argument that the patriarchal system oppresses women and nature at the same time, which relates their oppression by comparing the protagonist of Gokhale and the passive mythological character of Kalidasa. The paper emphasizes that *Shakuntala* in the forest signifies resistance. Drawing on the ideas of theorists like Vandana Shiva and Karen Warren, Srivastava argues that the division of memory mirrors the deterioration of the environment. The emphasis is placed on the role of gender and its connection to ecological systems. The forest is an area of feminine strength under nature- culture binaries. Finally, the paper concluded that the myth is reclaimed as a way of fighting for interconnected giving to women's powers by relating them to nature, as rebelling against the patriarchal dominance that was imposed on women.

Rahne and Gaurav study the rural narrative in *Shakuntala: The play of memory* by Namita Gokhale, which argues that women are reconnected with nature to resist the male system. The authors argue that Gokhale transforms the mythological persona of Kalidasa into a subversive rural life that questions patriarchal limitations. Placing the novel in the agrarian context of India, the paper highlights how life in a village, traditions, and gender expectations influence women's identity. Based on feminist theory, this investigation postulates that rural structures of oppression provide avenues of resistance. The independence, education, and mobility that *Shakuntala* seeks are symbolic of broader struggles for agency among rural women. The article concludes by arguing that literature has the potential to transform into social consciousness, and empowerment can bridge traditional values and modern feminist aspirations.

Zaidi and Bhatnagar examine psychological undertones in *The Folded Earth* by Anuradha Roy. The author uses the concept of the main character, Maya, and, with the help of theories such as reactance and dominance, discusses issues such as loneliness, dread of loss, and the desire to feel free to examine the effects of patriarchal influence on the emotional blockage characters experience. It claims that inner conflicts mirror larger social injustice. The author



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implies that the novel provides Catharsis and avenues to emotional health, underscoring the role of literature in comprehending human psychology and addressing modern struggles through reflective analysis of narrative.

Chauhan, Kumar, and Tyagi are ecofeminists who study the novel by Anuradha Roy, *The Folded Earth*, intersecting environmental degradation and gender oppression. By placing the trauma experienced by the protagonist Maya in the endangered Himalayan landscape of Ranikhet, the authors suggest that the patriarchal capitalist system simultaneously exploits women and nature. This is based on the critical intervention of Karen Warren and Vandana Shiva regarding the challenges of hierarchical dualisms, such as culture against nature and male against female, which justify dominance. The forest is a site of female opposition and subversion of patriarchal binaries. Maya's journey reflects the restoration of ecology and interdependence of struggles, Roy showing the idea of holistic egalitarianism schemes, making literature an essential component of ecofeminist discourse and social-ecological justice.

Vaishya discusses the concept of existential crisis in the novel *The Folded Earth* by Anuradha Roy through the lens of the psychological process of alienation, anxiety, and fragmentation of identity of the protagonist Maya. Based on the existentialist theory of Kierkegaard, Sartre and de Beauvoir, it argues that Maya is struggling with patriarchal subjugation, loss of spouse, and betrayal-based trauma, which reflect in the more general contemporary challenges in expressing the self. By setting the novel in a Himalayan town in Ranikhet, Vaishya assumes a search for freedom and a new woman who is finding her way in the modern social framework. Vaishya suggests that the novel by Roy brings a cathartic revelation about the human condition and that the experience of overcoming existential despair can lead to self-realization and emotional stability in the face of an oppressive system.

Existing criticism of Namita Gokhale and Anuradha Roy operates in fragmented categories such as feminist, ecofeminist, or psychological, without necessarily crossing them. Despite some foreshadowing of a correlation between memory and environment in *Shakuntala*, as well as gendered ecological oppression explored in *The Folded Earth*, neither of them elaborates on theorization about the functioning of fragmented narrative memory as a wound in the patriarchal ecological system. More significantly, resilience has not been strictly defined as an ecofeminist theory that can integrate psychological healing and ecological recovery. There is a gap in addressing how Gokhale and Roy encode the fractures of the memory not just as a thematic issue but as an embodied ecofeminist practice.

Theoretical Framework

This paper is mainly based on the ecofeminist philosophy of Karen Warren, which challenges the logic of domination that forms the basis of patriarchal hierarchies that suppress both women and nature at the same time. The structural perspective through which gendered violence and ecological degradation are set to be analysed as the result of the same roots of ideological origins of value-hierarchical thinking and value dualism proposed by Warren's culture versus nature, male versus female. To corroborate this materialist ecofeminism, by Vandana Shiva sheds light on exploitation and rural areas, and how women's traditional knowledge and relationship to the land become peripheral to the capitalist-patriarchal development.

Regarding the issue of memory, the fragmentation combines the trauma theory in which fragmentation is viewed not just as a psychological disruption but as a narrative representation of ecological disruption. Based on the criticism of the mechanistic worldview provided by Carolyn Merchant, the study posits that fragmented memory is a reflection of the disconnected relationship between human beings and the world. Important the concept of resilience is reimagined not as individual recovery but rather as ethical continuity through relationship. This combines psychological understanding of existential crisis and ecofeminist suggestions of holistic restoration. Through the intersection, the framework examines how the fractures in the memory in Gokhale's mythic revisioning and Roy's realist narration embodied the ecofeminist praxis. This lens reveals how memory cannot be erased and the trauma absorption problem in *The Folded Earth*. It also suggests that the literary form is involved in survival, such that recognition of fragmentation itself becomes a form of resistance of patriarchal silencing. The study bridges trauma





studies, environmental humanities and feminist theory to reconsider the agency and repair response to gendered and ecological vulnerability.

Analysis

In ecofeminist resilience theory, memory is not a traditional passive remembrance but an essential relational process that maintains continuity, identity, and collective survival. According to Vandana Shiva, who states in *Staying Alive*, “the destruction of nature is also destruction of culture and memory” (41), which shows memory is inherent in ecological and social fabrics. Sustainability of memory becomes achievable when it is held down within a patriarchal mechanism; it shatters the continuity it is expected to maintain. This dynamic is affected in opposition ways in *Shakuntala: The Play of Memory* (2005) by Namita Gokhale and *The Folded Earth* (2011) by Anuradha Roy, where the work of memory is either suppressed or used as a relational practice.

In the reconstruction of Gokhale, there is a systematic weaponization of memory through patriarchal silencing. Critical studies argue that Gokhale does not depict her *Shakuntala* as a woman whose trauma dissociation is caused by the institutional refusal to acknowledge her testimony (Srivastava 72, Gokhale 43). Her memories are broken into disconnected fragments due to an absence of communal witness or ecological foundation. Since her childhood, the epistemic hunger *Shakuntala* has been repressed. “I have kept myself for they were neither asked nor valued ... as the scriptures were forbidden to women” (Gokhale 11). This suppression is not a question of literacy, but the right to tell one's experience.

Shakuntala is not allowed to express her suspicion, “I was not angry with Srijan—he was a man, men were allowed many women... But the hurt and betrayal, the prickling of thorns under the sheath of my skin—I had never known or anticipated these feelings” (Gokhale 58). Memory here is internalized, unprocessed, raw, disconnected from relational continuity. In the absence of a sanctioned space to express pain, resilience would not be an option. It is a heartbreaking commentary on the way in which patriarchal culture uses the silence of women (Akansha Srivastava 80). Still, within the novel's diegesis, this expression is constantly frustrated by structural constraints.

On the other hand, Roy's *Maya* is the embodiment of memory as an ecological practise. Grieving is not linear, not solved, but persistently involved. At Michael's vandalized grave, “one broken bottle on it and another empty bottle ... The day lilies I planted had been dug out thrown aside (Roy 90). Instead, “I began to gather lily bulbs from all around the grave to replant them.” (Roy 91) Her psychological process of remembering restores the dislocated life to the damaged ground. The recollection is triggered by the sensory landscape, which does not overwhelm her as while walking through a forest pathway, she recalls, “a forest near Hyderabad where I had once gone with Michael... Broad-leaved trees, stacked close and deep, blocked out the sun... I plucked a red wildflower and stuck it behind my ear. We laughed a lot. I felt beautiful” (Roy 103).” Memory does not turn out to be a false intrusion but as a gentle place-based reprisal. Importantly, the memory of *Maya* is maintained by relational exchange; the acquisition of *Charu* to read is an indirect processing of non-presence, the performance of the birdcall by Diwan Sahib keeps her in touch in the present, and even the gossip of *Ama* makes her past of community time. “I sifted through my mind for whatever I could retrieve of him, reconstructing our years together: the way I pretended sleep so that he would bring tea to our bed each morning, tugging a tuft of my hair to wake me (Roy 125) reflects her inner turmoil, allowing her pain to move beyond her body and into the environment. She has to rely on the present sensory landmark, “the smell of damp earth,” (Roy 102) “the barbet calls all day from its lonely perch high in a leafless tree. Its plaintive, monotonous cry is the distillation of solitude and sadness (Roy 235). This constant movement between the past and present, self and the surrounding turns memory into a bricolage into a scaffold.

The presence of grief acknowledgement of *Maya* enables memory to be secured as a strength, unlike that of *Shakuntala*, who was forced into an isolation condition. The Himalayan scenery does not require abandonment; it is painful, and at the same time, gives rebirth. Planting a lily in a disturbed grave is an ecological remembrance, not through the narrative art of the story, but in the sense of repairing connection with a harmed ecosystem. Memory becomes folded into earth, community, daily ritual, a living system that makes it possible to survive without erasure.





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As Roy describes the wisdom of Diwan Sahib, “Corbett understood the jungle by looking, and he could tell you it’s story from the sounds he heard... He walked the forests barefoot when he was a boy. He understood the fall of every leaf and the meaning of a cloud (Roy 73). In the same way, Maya perceives in these forms the continuity of her own fragmented and persistent. Memory is not recoverable of the pre-traumatic wholeness, but adaptive reconstructive in fracture memory, as the Himalayan soil contains seeds for the next growth.

Fragementtion

In ecofeminist resilience theory, fragmentation is a signifier that does not imply complete breakdown but rather a set of three ruptures: loss of emotional continuity, internal disconnection, and the weakening of relational bonds. Fragmentation is not dangerous in its inevitability, as a social-ecological system is inherently disturbed, not in that the system does not accept a repair mechanism. The patriarchal capitalist regimes lead to an increase in fragmentation by destroying the same relationship threads that help to reintegrate. Gokhale and Roy use fragmentation at the formal and thematic levels to expose how memory suppression accelerates rupture and permits acknowledgement of how memory suppression delays collapse.

Fragmentation in *Shakuntala: The Play of Memory* is a process of self-deprecation under patriarchal silencing. Deprived of access since childhood, “the scriptures were for women” (Gokhale11), the consciousness of *Shakuntala* is broken down between the approved roles and the prohibited pleasure. Her first menstruation turns into a place of alienation of the body when her mother confines her in a cowhouse next to the dung and straw, declaring her “defiling the household fires when a holy man is visiting us! You are a woman now, you had better understand what that implies!” (Gokhale 31). The terrified young girl who thinks of drowning in blood is forced to break down the door and take into the forest a literal disintegration that reflects the psychological disintegration as her body turns into a foreign land to be patrolled by shame. This original break of filial continuity is argued by the betrayal of the relation when Srijan brings his cold eyes to challenge the sovereignty of *Shakuntala*. This disloyalty is sensorial, “the hurt and betrayal, the prickling of thorns sheath of my skin” (Gokhale 58). Most importantly, *Shakuntala* is unable to express this guilt; she runs away to the *Matrika* temple, where the silence is the only language she speaks. This fragmentation is relational; the marital bond is broken not by violence but by the approved erasure of her voice.

This break is not repaired by her flight with *Nerarchus*, but is increased. She throws away her silver anklets, “which weigh down your feet to keep you rooted in your home” (Gokhale, 103). It is not the liberation but the disintegration of selfhood, “The young woman called *Yaduri* had no history. She lived in the ceaseless present.” (Gokhale 129). Identity disintegrates in sensory immediacy served from the past or future. As *Kalidasa* is performing *Abhijaana Shakuntala*, she challenges her transgression in the reflection of myths. Through the heroine of *Kalidasa*, “even in disgrace ... of secret marriage,” she realized. “I had betrayed everything. I had renounced my name, I was no longer *Shakuntala*, only *Yaduri*, the unmentionable one. I had abandoned the husband whose true wife I was... the noble king *Dushyanta* had wives aplenty, and yet there was no slur in his love-making with *Shakuntala* ...only I stood condemned” (Gokhale 150). Fragmentation solidifies into an internalized judgment of the self, which splits into observer and observed.

This internal breakage leads to physical disintegration at *Kashi*, “a torn womb where my life and my daughter had been, now destroyed... the bull once again buried its horns in my stomach. The blood rushed out from my abdomen like a fountain, ... my feet” (Gokhale 188). In contrast to the absence of *Michael's* body in *Roy's* book, where memory remains present, *Shakuntala's* body is the visible fragment that marks the ultimate closure of a life broken into many pieces. More importantly, every rupture to isolation is irreparable; the broken door can never be repaired. Epistemic repression is maintained anklets are known away from mythic judgment, which is internalized and unrestrained. The patriarchal structure does not provide the relational scaffolding through which to reintegrate, and so such fragmentation here is closed without an existence.

Roy introduces fragmentation as something accepted and not concealed. Psychological fragmentation of *Maya* reflects the instability of the environment: “one broken bottle on it and another empty bottle propped against it.





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Shattered glass lay all around the grave. The day lilies I had planted had been dug out and thrown aside, their long leaves wilted, their light-starved tubers helpless under the sun" (Roy 90), but more importantly, fragmentation is still visible and part of everyday practice. In the process of replanting the lilies on the grave of Michael, "I began to gather lily bulbs from all around the grave" (Roy 91). But these fragments become relational anchors. The process of teaching Charu to read the letters of the Kundan Singh is a way to make fragmented literacy a collective meaning-making. The disjoint papers of Diwan Sahib incinerated rejected drafts into a place of collaboration. "I sat up with his paper ... overcome by a sense of loss, if it had not been overpowering, would have struck me as absurd" (Roy 134). In contrast to the solitary torture of Shakuntala Maya, it is fragmented in the observed community.

When the deer Rani of Puran was killed by a bureaucrat's inhumane actions, the hill, the theatrics of Ama, the gossip of the clerk, and the silent sorrow of Charu, fragmentation in this case is not hidden behind propriety but is contained in the social network. According to Roy's description of the monsoon, "Roads were reclaimed by nature as landslides... telephones died cutting off our town (Roy 154). But in this disintegration of the ecological discontinuity, community exists, people endorsing generators together, Ama sending kheer after quarrels, fragmentation is no longer internal division.

This opposition is a fundamental ecofeminist argument with trauma and environmental destruction, but it is devastating only when structures do not allow for fixing. As Mies and Shiva suggest, the logic that divides women and their bodies and knowledge. (18) Gokhale reveals such reasoning with the silenced fragmentation of Shakuntala Roy in the recognition of Maya's relational acknowledgment. When Maya realizes that Veer's betrayal and discovers Michael's name on the trekking documents, she loses her world. "I flung away my mass of blankets and sprang out of bed... I pulled out the heavy, plastic-covered bundle inside it: Michael's rucksack (Roy 244)

Even this disintegration takes place in observed space, the preoccupation of Ama with the silent reliability of the hillside. Fragmentation does not lead to breakdown due to the availability of care. As Roy's narrator reflects, "The eagles feel the change in air and light... They are lifted higher and higher by air currents as they wheel and arc and sail" (Roy 257). Fragmentation, as in the flight of the eagles, is an element of a greater relational pattern, not a conclusion but a stage in continuity. Fragmentation in Gokhale's vision was enhanced by silenced memory until the breakdown of resilience, a scathing critique of the system that requires a person to endure, but does not support them. Memory is not a psychological property, but an ecological repository in lilies that are replanted on graves in the slope of the Himalayas in grief literacy classes under monsoon clouds. This reframing makes resilience in place, not human adaptability as it is, but as relational emergence in a damaged ecosystem. Recovery is not restoration of pre-traumatic wholeness, but the adaptive transformation of the fracture, carrying seeds of the next growing thing, like soil after fire.

Resilience

Process memory and fragmentation are mutually influential, but resilience is a response to their interplay. In ecofeminist theory, resilience is not about "bouncing back" but about transformative reorganizing relationships in the damaged system (Walker and Salt 45). It involves recognizing weaknesses in interconnected networks instead of proclaiming control over disruptions. Gokhale and Roy set resilience as the critical moment of disjuncture, where patriarchal refusal of memory and care produces an unsustainable collapse in relationship recognition, making it possible in the moment of fracture. Loyalty is disastrous in Shakuntala. Memory is abolished, fragmentation, and the denial of any relational care, social, and ecological. When Kamalini is introduced, Srijan is a patriarchal gas lighter: "Do not ask any questions. She has been brought here as your handmaiden, and that is all. See that you treat her well" (Gokhale 58). Shakuntala, to find a way of repairing herself by visiting a temple, tries to find comfort in the forest, but her efforts are presented as transgressive. She escaped with Nearchus, and in the beginning, it seems to be freeing her. "I took to my changed circumstances with ease. Only the river travelled with me, its murmur in my life-blood" (Gokhale 129). The brutality of Nearchus, "sometimes he was rough and coarse" (Gokhale 134), is a reflection of violence in society. The redemption after coming back to Kashi is no better than condemnation. "Shakuntala's wanderings on the streets of Kashi and finally her death reasserts the sanctity and inevitability of the codes that





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define honour and morality for a woman" (1587126289.pdf 181). Hit by a bull, an image of uncontrolled patriarchal power, her broken physically and her mind was already torn apart socially. "Shakuntala may have been condemned by the society and culture in which she lived, but the new woman in her remained determined as ever to live life and die on her own terms" (Srivastava 188). But systematic denial of care cannot be overcome by this determination. The lack of resilience is not caused by personal weakness, and the social ecology is unable to provide a mechanism of repair, but instead provides a mechanism of punishment, which is transgression. This reflects what Shiva refers to as "maldevelopment." A system that requires endurance but rejects the resources of relational that would support adaptation (Shiva 52).

The Folded Earth, on the other hand, demonstrates resilience and shows non-linear emergences, which is low. Memories are painful; they remain fragmented, but grieving gives space in the relational network. The resilience of Maya does not show in the sense of moving on, but in proceeding with a scar. After replanting the lilies, she does not cure, though she incorporates it "I would talk things over with Michael as I sometimes did at his grave" (Roy 147). Her attention towards Charu's training her literacy, opposing the cruelty of Mr. Chauhan, becomes a resilience practice. When Puran dies of his deer, Rani Maya does not isolate herself but instead takes part in the group mourning. Even the sickness of Diwan Sahib turns into an object of relationship strengths. I sat up nights, placing ice-cold swabs on his forehead...object of I felt an unexpected, painful tenderness for him" (Roy 179). Crucially, resilience opposes neoliberal discourse of individual success. The continuity in Maya is supported by her factory job, her jam-making, and her newspaper meeting with Diwan Sahib; these pointless routines keep things going without needing recovery. As Roy writes of the monsoon, "Houses felt furry with fungus and damp ... The hills were a lush, brilliant green, and wild gladioli drooped everywhere in the rain. The forest was carpeted with pretty, mauve, orchid-like flowers. (Roy 154). But within ecological disintegration, there is a sense of resilience, neighbours who exchange the news, Ama can deliver food, and Charu maintains hope. Resilience does not mean restoration of pre-traumatic wholeness, but Roy describes it as a transformative adaptation within fracture.

This leads to a devastating but generative conclusion. Maya finds out that Veer has broken his vows and has left Michael at Roopkund, and her world shatters. However, her protests are of ecofeminist strength. She tears Diwan Sahib's will into "tinier and tinier pieces, until not an alphabet can be distinguished of the name" (Roy Ch. 21). This is not revenge but transformation through refusal. With the scattering of the fragments "like white butterflies dipping over the wild flowers in this garden gone to seed," she rejects patriarchal inheritance logic while affirming ecological continuity. Her last thought, "I have lost too much to care. I will find another and make it a home again" (Roy 257) express resilience not as rebuilding but as repetitive re-membling. In contrast to the fatal fragmentation of Shakuntala, the strength of Maya rises exactly in the nation of recognized damage. As the eagle's wheel overhead, "lifted higher and higher by air currents," Roy installs resilience as relational emerges in fragment yet generative ecologies.

CONCLUSION

Bringing Namita Gokhale and Anuradha Roy implies that fragmentation is not wound but rather the place of ecofeminist strength. By applying trauma theory through the logic of domination proposed by Karen Warren, the fractured narratives can seem not just a symptom of patriarchal ecological violence but as effective survival tactics. Gokhale's Shakuntala, for instance, the mythical silene is transformed into a subversive voice, reappropriating the power of agency by the act of broken remembering. The Maya of Roy, on the other hand, cannot be psychological healing as something that must be connected with the land. This perspective makes an individual psychological interpretation of the crisis of Maya, an internal phenomenon, complicated because resilience is externally relational. It connects human healing to the living world, disputing the idea of endurances as personal strength. Rather, resilience is a moral action that is maintained through connection. In this context, literary form does some repair work provide insights that connect trauma studies and environmental humanities. The study implies that it is not a restoration of wholeness, but an acknowledgement of the rupture, which will be navigated through gendered and ecological





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vulnerability. Resilience is created through the denial of trauma, but forms within caring ecologies that witness fragmentation, suggesting a transformative paradigm of identity in contemporary Indian fiction

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RESEARCH ARTICLE

A Psychoanalytic Reading of Children's Literature: An Exploration of the Inner World of Childhood in *The Secret Garden*

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ABSTRACT

Cultural conceptions of childhood and identity have shaped children's literature, which holds an outstanding place in the literary canon. Hidden worlds, talking animals, magical landscapes, and amazing adventures are not merely ornamental components; rather, they represent the child's emotional and psychological struggles in reality. This paper examines the psychological effects of childhood abandonment in Frances Hodgson Burnett's *The Secret Garden* through the lens of Attachment theory and Object relations theory and themes such as dependency, fearfulness, and abandonment are explored as impacts of insecure attachment patterns that were created in reaction against emotional neglect and parental absence. From a psychoanalytic standpoint, the novel explores relationship dynamics to externalize the children's shattered inner worlds. The 'secret garden' turns out to be a healing space where suppressed emotional needs are recognized and progressively resolved by creating safe connections. This paper confirms that children's literature can be a powerful platform for examining psychological conflict and emotional integration by exposing the unconscious aspects of abandonment anxiety.

Keywords: childhood, fearfulness, abandonment, anxiety, dependency.





INTRODUCTION

Childhood is a crucial stage in human development during which emotional, psychological, and social identities are gradually formed. Literature has long served as a medium through which the complexities of childhood experiences are explored and interpreted. Many literary works portray childhood not merely as a period of innocence but as a phase marked by loneliness, imagination, fear, and self-discovery. Children's literature, in particular, often reveals the inner emotional landscapes of young characters and reflects how environmental and social influences shape their personalities. One of the most significant works that portrays the psychological and emotional dimensions of childhood is *The Secret Garden* written by Frances Hodgson Burnett. *The Secret Garden* narrates the story of Mary Lennox, a neglected child who is forced to move from colonial India to her uncle's estate in Yorkshire after the death of her parents. Initially depicted as ill-tempered, lonely, and emotionally withdrawn, Mary gradually undergoes a remarkable transformation through her interaction with nature and the friendships she forms. Alongside Mary, the character of Colin Craven, her cousin who lives in fear and isolation, also represents the fragile psychological world of childhood shaped by adult influence and personal imagination. Through the experiences of these characters, Burnett offers a profound exploration of the emotional struggles and developmental processes that define childhood. A central element of the novel is the hidden garden itself, which functions not only as a physical setting but also as a symbolic representation of the children's inner emotional world. As Mary, Colin, and their friend Dickon work to revive the neglected garden, they simultaneously experience emotional healing and psychological growth. The garden becomes a transformative space where fear, loneliness, and insecurity are gradually replaced by hope, confidence, and companionship. In this way, Burnett illustrates the therapeutic power of nature and friendship in shaping the emotional development of children. This study aims to explore the representation of the inner world of childhood in *The Secret Garden* by analyzing the psychological development of the central characters and the symbolic significance of nature within the narrative. By examining Mary Lennox and Colin Craven's emotional journeys, the paper seeks to demonstrate how the novel portrays childhood as a dynamic process of transformation influenced by environment, relationships, and imagination. Ultimately, Burnett's work highlights the resilience of children and emphasizes the importance of nurturing emotional care in fostering healthy psychological growth.

The Secret Garden by Frances Hodgson Burnett have often focused on the novel's exploration of childhood psychology, the healing influence of nature, and the transformative power of friendship. Critics generally agree that the novel portrays childhood as a complex developmental stage shaped by emotional experiences and environmental influences. Through the characters of Mary Lennox and Colin Craven, Burnett presents children who struggle with loneliness, fear, and emotional neglect, while also demonstrating their capacity for growth and renewal. Several scholars have interpreted the novel through the lens of childhood development and psychological theory. Theories of cognitive and emotional development proposed by Jean Piaget suggest that children actively construct their understanding of the world through interaction with their environment. In *The Secret Garden*, Mary's curiosity and exploration of the garden reflect this process of learning and development. Her gradual transformation from a self-centered child into a compassionate and empathetic individual illustrates the role of environment and experience in shaping a child's emotional maturity. Other critics have approached the novel from a psychoanalytic perspective

influenced by the ideas of Sigmund Freud, emphasizing the impact of childhood trauma and repression on personality formation. Colin Craven's fear of illness and death, for instance, can be interpreted as the result of psychological conditioning and the influence of adults who constantly reinforce his perceived weakness. His eventual recovery demonstrates how emotional encouragement and positive belief can reshape a child's psychological outlook.

Additionally, studies in children's literature frequently highlight the symbolic role of nature in the novel. Scholars argue that the secret garden functions as a metaphor for the children's inner emotional world. As the neglected garden is gradually restored to life, the characters also experience emotional healing and personal growth. This parallel transformation underscores Burnett's broader message that nurturing environments and supportive relationships play a vital role in childhood development. While existing scholarship has explored various thematic



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aspects of the novel, this study seeks to further examine how the inner psychological world of childhood is constructed through character development, symbolism, and the restorative power of nature.

This study applies Attachment Theory and Object Relations Theory to understand the emotional and psychological experiences of the child characters in *The Secret Garden* by Frances Hodgson Burnett. Both theoretical perspectives emphasize the significance of early relationships in shaping a child's emotional development, identity formation, and perception of the world. By focusing on the bonds between children and their caregivers, these theories provide a valuable framework for examining how early emotional experiences influence behavior, personality, and interpersonal relationships. Attachment Theory, developed by John Bowlby, highlights the fundamental role of early emotional bonds between a child and their primary caregiver. Bowlby argues that attachment

is an innate psychological system that motivates children to seek closeness and security from caregivers during times of vulnerability (Bowlby 26). A secure attachment relationship allows the child to feel protected and supported, encouraging confidence and healthy emotional development. In contrast, when caregivers are emotionally distant, inconsistent, or neglectful, children may develop insecure attachment patterns that lead to anxiety, mistrust, or social withdrawal. These early attachment experiences significantly shape how children understand relationships and regulate their emotions as they grow (Bowlby 58). Attachment theory therefore provides an important lens for examining childhood behavior and emotional needs in literary representations of young characters. Complementing this perspective is Object Relations Theory, associated with psychoanalytic thinkers such as Melanie Klein and Donald Winnicott. Object relations theory focuses on the internal psychological representations that children form based on their early interactions with caregivers. In this framework, the term "object" refers not to a physical object but to a significant person, usually a parent or caregiver, whose relationship with the child becomes internalized in the child's mind (Klein 90). These internalized relationships shape the child's emotional world, influencing their sense of security, self-worth, and ability to form connections with others. As children develop, these internal representations guide how they interpret and respond to social relationships and emotional experiences (Winnicott 34). Together, attachment theory and object relations theory provide a meaningful framework for analyzing childhood development by emphasizing the lasting impact of early relationships on a child's psychological and emotional life

Childhood isolation and emotional neglect form one of the most significant psychological foundations in *The Secret Garden* by Frances Hodgson Burnett. The novel presents a detailed portrayal of how the absence of consistent emotional care during childhood can influence the psychological development and behavior of young individuals. The characters of Mary Lennox and Colin Craven illustrate how children who grow up without stable parental affection often develop emotional insecurity, loneliness, and difficulties in forming meaningful relationships. Their early experiences reveal the profound impact that neglectful environments can have on a child's inner emotional world. Mary Lennox's childhood is marked by profound emotional neglect. Raised in a privileged household in colonial India, she grows up surrounded by servants rather than attentive parents. Her mother shows little interest in nurturing or emotionally supporting her, and the responsibility of raising Mary falls largely upon the household staff. As a result, Mary develops an isolated and self-centered personality. Without the presence of affectionate caregivers, she fails to learn empathy, cooperation, or emotional sensitivity. Her behavior reflects the consequences of growing up in an environment where material comfort replaces emotional connection. The lack of secure attachment in her early life contributes to her feelings of loneliness and alienation when she later moves to Misselthwaite Manor. Similarly, Colin Craven's childhood is characterized by psychological isolation. Following the death of his mother, Colin is confined within the manor and raised under constant supervision by adults who treat him as physically fragile. Instead of encouraging independence, the adults around him reinforce his fears and anxieties, leading him to internalize the belief that he is weak and incapable of living a normal life. This environment prevents Colin from developing emotional resilience or self-confidence. His isolation not only separates him from other children but also limits his understanding of the world beyond the confines of his room. From the perspective of attachment theory proposed by John Bowlby, the absence of consistent emotional bonds during childhood can lead to insecure attachment patterns and psychological distress (Bowlby 68). The experiences of Mary and Colin demonstrate how



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emotional neglect disrupts healthy childhood development, shaping their personalities and emotional responses. Through these characters, the novel highlights the critical importance of nurturing relationships in fostering emotional stability and psychological well-being during childhood

“If you look the right way, you can see that the whole world is a garden.” (Burnett)

This line reflects the novel’s central idea that perspective, hope, and emotional openness can transform how one experiences life, just as the children’s inner worlds change as they heal and grow. In *The Secret Garden* by Frances Hodgson Burnett, the character of Colin Craven represents a complex portrayal of the inner psychological world of a child shaped by fear, isolation, and emotional insecurity. Colin grows up in an environment dominated by grief and overprotection following the death of his mother. Instead of experiencing a supportive childhood, he is confined within the walls of Misselthwaite Manor and constantly treated as physically fragile by the adults around him. This environment significantly shapes his psychological state, causing him to internalize the belief that he is weak and incapable of leading a normal life. Colin’s psychological condition is deeply influenced by the attitudes and expectations of the adults who surround him. His caretakers reinforce the idea that he is sickly and unable to move freely, which gradually forms the basis of his self-perception. As a result, Colin develops intense anxiety and emotional instability. He becomes prone to anger, frustration, and despair, often expressing these emotions through sudden outbursts. His behavior reflects a child struggling to cope with loneliness and a lack of emotional reassurance. Instead of developing confidence and independence, Colin’s upbringing encourages dependency and fear. From the perspective of attachment theory proposed by John Bowlby, Colin’s psychological struggles can be understood as the consequence of disrupted attachment relationships. Bowlby argues that children require consistent emotional support from caregivers in order to develop a secure sense of self and emotional stability. In Colin’s case, the absence of nurturing parental presence, combined with the constant reinforcement of his perceived weakness, contributes to his feelings of helplessness and vulnerability. Additionally, object relations theory associated with Melanie Klein helps explain how Colin internalizes the attitudes of those around him. The adults’ fearful and protective behavior becomes part of his internal psychological world, shaping how he views his body and abilities. Consequently, Colin’s inner world is dominated by fear and self-doubt. Through Colin’s character, Burnett vividly illustrates how childhood environments and early relationships play a crucial role in shaping a child’s psychological identity. In *The Secret Garden* by Frances Hodgson Burnett, nature plays a crucial role in shaping the emotional and psychological transformation of Mary Lennox. At the beginning of the novel, Mary is portrayed as a lonely, irritable, and emotionally withdrawn child. Her early childhood is marked by neglect and the absence of meaningful parental affection. As a result, she develops a cold and self-centered personality. However, her arrival at Misselthwaite Manor introduces her to a natural environment that gradually influences her emotional development. The Yorkshire moors and the hidden garden provide Mary with a new space where she can explore, observe, and interact with the natural world. Through these experiences, nature becomes a powerful healing force that helps reshape her inner emotional state. Mary’s initial encounters with nature awaken a sense of curiosity and engagement that had been absent in her earlier life. The open landscape of the moors contrasts sharply with the confined and artificial environment in which she was raised. Spending time outdoors allows Mary to experience freedom, fresh air, and physical activity, all of which contribute to her gradual physical and

emotional improvement. As she begins to explore the grounds of the manor, she develops a growing fascination with plants, animals, and seasonal changes. This interaction with the natural environment encourages her to move beyond her isolation and develop a sense of responsibility and care. The secret garden itself becomes the central symbol of Mary’s emotional healing. When Mary begins to nurture the neglected garden, she simultaneously begins to nurture her own emotional growth. Gardening requires patience, attention, and dedication, qualities that Mary gradually learns through her involvement with the garden. As the plants begin to grow and flourish, Mary also experiences a transformation in her personality. She becomes more energetic, compassionate, and capable of forming friendships. Her growing connection with nature encourages a sense of belonging and emotional balance that she had never previously experienced. From a psychological perspective, the restorative influence of nature can also be connected to theories of emotional development. Generally, the natural environments provide children with opportunities for exploration, independence, and imaginative engagement, which contribute to healthy psychological growth. Mary’s



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experiences illustrate how nature can act as a therapeutic space where emotional wounds begin to heal. Through her interaction with the garden and the surrounding landscape, Mary develops confidence, empathy, and emotional resilience. Nature functions not merely as a backdrop but as an active agent of healing and transformation. Burnett demonstrates that contact with the natural world can nurture emotional well-being and encourage personal growth, ultimately helping Mary rediscover joy, curiosity, and human connection. In *The Secret Garden* by Frances Hodgson Burnett, nature functions as a powerful agent of healing, and the secret garden itself becomes a symbolic and transformative space where emotional restoration takes place. The garden, which had remained locked and neglected for many years after the death of Mrs. Craven, initially represents grief, loss, and emotional stagnation. Just as the garden has been abandoned and left to decay, the children in the novel particularly Mary Lennox and Colin Craven experience emotional emptiness and psychological isolation. When the garden is rediscovered, it gradually becomes a space where both the physical environment and the inner lives of the children begin to change and flourish. The process of restoring the garden mirrors the emotional healing experienced by the characters. When Mary first discovers the garden, it is overgrown and forgotten, yet it still contains the hidden potential for life and growth. As she begins to care for the plants and remove the weeds, she also begins to shed her own feelings of loneliness and bitterness. The act of gardening encourages patience, responsibility, and attentiveness, allowing Mary to develop qualities that had previously been absent in her personality. Through her daily interaction with the garden, she becomes physically healthier and emotionally more balanced.

The garden also becomes a place of transformation for Colin Craven. Having spent most of his childhood confined indoors and convinced of his own weakness, Colin initially lacks confidence and emotional stability. When he is finally brought into the garden, the natural surroundings offer him a sense of freedom and vitality that he has never experienced before. The fresh air, sunlight, and living plants create an atmosphere that encourages him to believe in his own strength and recovery. The garden thus functions as a therapeutic environment where fear and insecurity gradually give way to hope and self-belief. From a psychological perspective, the healing power of the garden can be understood through the lens of emotional development and human connection with nature. Natural spaces provide opportunities for exploration, reflection, and emotional renewal. Within the novel, the garden becomes a sanctuary where the children are free from the restrictive expectations of adults and are able to develop their identities in a supportive environment. As the garden begins to bloom with new life, it symbolically reflects the inner growth of the children themselves. Therefore, the garden in the novel operates not merely as a physical setting but as a living symbol of regeneration and healing. It demonstrates how nature can restore emotional well-being, nurture imagination, and guide children toward psychological growth and self-discovery.

The theme of transformation is closely connected to the psychological development of childhood. The novel illustrates how children's personalities and emotional states are not fixed but capable of change when they are exposed to nurturing relationships and supportive environments. Through the experiences of Mary Lennox and Colin Craven, Burnett portrays childhood as a stage of growth where emotional wounds can gradually heal and new patterns of thinking and behavior can emerge. Their transformations demonstrate the resilience of children and their ability to develop emotionally when they receive care, companionship, and encouragement. At the beginning Mary Lennox is depicted as an isolated and emotionally detached child. Her early life, marked by neglect and lack of parental attention, shapes her into a self-centered and unpleasant individual. However, as she begins to explore the grounds of Misselthwaite Manor and later discovers the hidden garden, her personality gradually changes. The process of caring for the garden introduces her to responsibility, patience, and empathy. Through her interactions with Dickon and Colin, Mary learns the value of friendship and emotional connection. Her transformation reflects an important aspect of childhood development, in which social relationships and environmental experiences contribute to the formation of emotional maturity. Colin Craven undergoes an equally significant psychological transformation. For most of his childhood, Colin lives under the constant belief that he is physically weak and destined to remain ill. The adults around him reinforce this perception, which leads him to develop anxiety and feelings of helplessness. His psychological condition illustrates how a child's self-image can be shaped by external influences and repeated



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messages from authority figures. However, once Colin begins spending time in the secret garden and forming friendships with Mary and Dickon, his perspective gradually changes. The supportive environment encourages him to believe in his own strength and capabilities, leading to both emotional and physical improvement. From the perspective of attachment theory developed by John Bowlby, these transformations can be understood as the result of new emotional bonds and supportive relationships. Bowlby suggests that secure attachments help children develop confidence and emotional stability (Bowlby 89). As Mary and Colin begin to form meaningful connections with one another and with their surroundings, they experience the sense of belonging that was absent in their earlier lives. Thus, the novel emphasizes that childhood development is a dynamic and transformative process. Burnett ultimately presents childhood not as a static condition but as a period of growth in which emotional healing and psychological maturity can be achieved through care, companionship, and positive experiences.

The Secret Garden by Frances Hodgson Burnett can be effectively interpreted through the frameworks of Attachment Theory and Object Relations Theory. Both theories emphasize the importance of early relationships in shaping the emotional world and psychological development of children. By applying these perspectives to the novel, it becomes possible to understand how the absence of nurturing bonds initially affects the characters and how new emotional connections later contribute to their transformation. Attachment Theory, developed by John Bowlby, highlights the significance of early emotional bonds between children and their caregivers. According to Bowlby, children develop a sense of security and emotional stability when they experience consistent affection and responsiveness from caregivers (Bowlby 40). When such attachments are absent or disrupted, children may develop feelings of insecurity, anxiety, and emotional withdrawal. This theoretical perspective is particularly relevant to the character of Mary Lennox. Mary grows up in an environment where her parents remain distant and emotionally unavailable. Instead of receiving warmth and affection, she is largely raised by servants who respond to her demands but do not provide genuine emotional care. As a result, Mary develops characteristics often associated with insecure attachment, including irritability, loneliness, and difficulty forming relationships with others. Similarly, Colin Craven's psychological condition reflects the consequences of disrupted attachment. After the death of his mother, Colin grows up without consistent parental support and becomes surrounded by adults who treat him with excessive caution and pity. This environment prevents him from developing confidence and independence. His fear of illness and death illustrates the emotional insecurity that can arise when a child lacks stable attachment figures. From Bowlby's perspective, both Mary and Colin demonstrate how the absence of secure emotional bonds can shape a child's behavior and self-perception. Object Relations Theory further deepens the understanding of these characters' psychological experiences. Developed by psychoanalytic thinkers such as Melanie Klein and later expanded by Donald Winnicott, object relations theory focuses on how children internalize their early relationships with caregivers. In this framework, "objects" refer to significant individuals, usually parents or caregivers, whose interactions with the child form internal psychological representations that influence later emotional life (Klein 92). These internalized relationships shape how individuals perceive themselves and relate to others.

In the novel, both Mary and Colin initially internalize negative relational experiences. Mary's emotional coldness reflects her early experience of neglect, while Colin internalizes the fearful attitudes of the adults who constantly remind him of his supposed weakness. However, as the narrative progresses, new relationships begin to reshape these internal patterns. Mary's friendship with Dickon and her growing bond with Colin introduce supportive emotional connections that challenge her earlier experiences of neglect. Similarly, Colin's interactions with Mary and the experience of freedom in the garden help him develop a more positive sense of self. Thus, the application of attachment theory and object relations theory reveals that the transformation of the characters in the novel is closely linked to the formation of new emotional bonds. Through these relationships, the children gradually reconstruct their inner psychological world, moving from insecurity and isolation toward emotional stability and confidence.

In The Secret Garden by Frances Hodgson Burnett, the secret garden functions as more than a physical location; it operates as a transformative and healing space that nurtures the emotional and psychological development of the children. The garden symbolizes renewal, growth, and restoration, reflecting the gradual healing of Mary Lennox and Colin Craven. Initially, both children suffer from emotional neglect, loneliness, and insecurity due to the absence



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of supportive familial relationships. Their early experiences demonstrate how a lack of attachment and emotional care can affect childhood development. However, the discovery of the garden marks the beginning of a significant shift in their psychological states. The garden offers an environment free from the restrictions and expectations imposed by adults. Within this space, the children are able to explore, interact with nature, and build meaningful relationships with one another.

The act of nurturing plants and witnessing their growth encourages patience, responsibility, and optimism. As Mary participates in the restoration of the garden, she gradually develops empathy and emotional awareness. Similarly, Colin's exposure to the garden challenges the negative beliefs that had been instilled in him since childhood. Surrounded by the vitality of nature, he begins to believe in his own physical and emotional strength. From the perspective of attachment theory proposed by John Bowlby, the garden can be viewed as a setting that facilitates the formation of new and healthier emotional bonds (Bowlby 90). The friendships formed within this space provide the children with the sense of security and belonging that had previously been absent in their lives. In addition, object relations theory associated with Melanie Klein suggests that positive relational experiences allow individuals to reshape their internal emotional world (Klein 95). Through their shared experiences in the garden, Mary and Colin begin to replace feelings of fear and isolation with confidence and trust. The exploration of childhood in *The Secret Garden* reveals that emotional neglect and isolation can profoundly affect the psychological development of children. Through the characters of Mary Lennox and Colin Craven, the novel illustrates how early experiences shape a child's inner emotional world. However, the narrative also emphasizes the possibility of transformation when children encounter nurturing environments and supportive relationships. By applying attachment theory and object relations theory, it becomes clear that the healing experienced by the characters is closely connected to the formation of new emotional bonds and positive experiences. Ultimately, the secret garden symbolizes the restorative power of nature, companionship, and emotional care, demonstrating that childhood development is a dynamic process capable of growth, resilience, and renewal.

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RESEARCH ARTICLE

Black and White Resistance: Memory, Nation, and Womanhood in Marjane Satrapi's 'Persepolis'

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ABSTRACT

This paper studies how personal life and national history are connected in *Persepolis*, a graphic memoir by Marjane Satrapi. The story is set during the Iranian Revolution and shows the social and political changes that followed. The black-and-white drawings are not just a style choice; they help show the strong conflicts between the individual and the government, and between freedom and control. This paper focuses on three main ideas: Memory, Nation, and Womanhood. First, it explains how memory becomes a form of resistance. By sharing her personal experiences, Satrapi challenges the official version of history given by the state. Second, it discusses the idea of the nation through the eyes of a young girl growing up. The narrator loves her country but questions the strict and oppressive rules imposed in the name of religion and politics. Third, the paper examines how womanhood is represented. The female body, especially through the symbol of the veil, becomes a space where political and religious control is enforced. Satrapi shows how women resist these controls and search for freedom. In conclusion, this paper argues that *Persepolis* goes beyond a simple life story. By using the graphic format, Satrapi makes her personal struggle meaningful for people everywhere. The memoir shows that remembering the past is a powerful act, and that women play a central role in the fight for freedom and identity.

Keywords: Graphic Memoir, Memory, Nation, Visual literacy, Feminism, Resistance, Womanhood.

INTRODUCTION

Graphic memoirs combine picture and personal story telling. They have become an important literary form in the recent years. Among the most influential works in this genre is Marjane Satrapi's *Persepolis*, first published in French in 2000. Set against the backdrop of the Iranian Revolution (1979) and the subsequent Iran-Iraq War, the memoir



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offers account of growing up amid political instability. Unlike conventional historical narratives, Persepolis presents national history through the subjective lens of childhood memory, and make big political events easier to understand. The significance of Persepolis lies not only in its content but also in its form. Satrapi's use very strong contrast black-and-white imagery produces a visual language that the strong division in Iranian society after revolution. The memoir examines how personal memory, national identity, and gender politics intersect within everyday life. Through the experiences of young Marji, Satrapi reveals how strict government attempt to regulate both public behaviour and private identity. This paper argues that Persepolis functions as an act of cultural and political resistance. By showing memory, reimagining the nation through a child's perspective, and exposing the control imposed on women's bodies, Satrapi challenges dominant narratives about Iran, Islam, and female subjectivity. The following sections examine these themes in detail.

The Graphic Memoir as Political Form

Before analysing the core themes, it is important to understand why the graphic memoir format is particularly suited to Satrapi's project. Graphic narratives rely on the interaction between image and text, creating what scholars call "visual literacy." Readers must interpret meaning not only through words but also through visual cues such as framing, contrast, and spatial arrangement.

In Persepolis, the black-and-white palette performs several functions:

1. Moral and ideological contrast: The stark binary reflects the regime's attempt to divide society into rigid categories—faithful versus traitor, modest versus immoral.
2. Memory reconstruction: The simplified drawings mimic the fragmentary nature of childhood memory.
3. Universal accessibility: The minimalist style allows readers from diverse cultural backgrounds to engage with the narrative.

Satrapi herself has noted that black and white avoids exoticizing Iran. Instead of presenting an orientalist spectacle, the visual simplicity emphasizes emotional truth. Thus, the graphic form becomes inseparable from the memoir's political message.

Memory as Resistance**Personal Memory versus Official History**

One of the central concerns of Persepolis is the tension between personal memory and state-controlled history. Strict government often try to control history to protect their powers. In post-revolutionary Iran, school textbooks and public discourse promoted a singular ideological version of events.

Satrapi counters this by showing her own memories. Childhood scenes—family conversations, classroom experiences, street protest —collectively construct an alternative archive. These memory show that difference between what the government says and what the people actually experience. For example, while the state glorifies martyrdom during the Iran- Iraq War, Satrapi depicts the grief, fear, and confusion experienced by ordinary families. Memory thus becomes a political tool. By remembering differently, Satrapi refuses the erasure imposed by official discourse.

Fragmentation and the Child's Perspective

The memoir's episodic structure reflects the fragmented nature of memory. Rather than presenting a continuous historical timeline, Satrapi offers snapshots of experience. This fragmentation serves two purposes. First, it enhances authenticity. Childhood memory is rarely linear; it consists of vivid moments that stand out emotionally. Second, this broken structure makes the story feel more personal and less official. The child narrator openly admits confusion, curiosity, and contradiction. Young Marji frequently misunderstands political events, yet this very misunderstanding reveals the absurdity of ideological indoctrination. Her questions—about religion, class, and revolution—expose the inconsistencies within official rhetoric. In this way, the child's voice becomes subversive.

Family Memory and Intergenerational Resistance



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Memory in Persepolis is not purely individual; it is deeply familial. Marji's parents and grandmother play crucial roles in shaping her political consciousness. Through stories of imprisonment, protest, and exile, the family preserves a counter-history that resists state authority. The grandmother, in particular, symbolizes moral continuity. Her advice about dignity and integrity anchors Marji during moments of identity crisis. These intergenerational memories demonstrate how resistance is transmitted within private spaces even when public dissent is suppressed.

Reimagining the Nation

Love and Critique

A notable feature of Persepolis is the way it presents nationalism in complex and thoughtfully manner. Satrapi neither romanticizes nor rejects Iran outright. Instead, she presents a complex emotional relationship with the nation. Young Marji expresses deep pride in Iran's history and culture. She learns about ancient Persian civilization and initially supports the revolution's promise of justice. However, as the government becomes more authoritarian, her patriotic excitement gradually turns into critical awareness.

This shows that Iran cannot be seen in a simple way as only an oppressive country. Satrapi distinguishes between the Iranian people and the ruling regime, thereby reclaiming the nation from political absolutism.

The Nation Through a Child's Eyes

Viewing national transformation through a child narrator produces a powerful, it makes readers see political events in a new view. Political slogans and ideological rituals appear strange when filtered through Marji's literal interpretations. For instance, compulsory veiling in schools confuses the young girls, who initially treat their veils as play objects. This scene reveals how state power attempts to naturalize control, while children instinctively resist rigid discipline. The child's perspective also highlights the intrusion of politics into everyday life. Bombings, food shortages, and moral policing become part of ordinary childhood experience. By situating national trauma within domestic spaces, Satrapi demonstrates that political violence is never abstract—it reshapes intimate life.

Womanhood and the Politics of the Body

The Veil as Political Symbol

Perhaps the most widely discussed theme in Persepolis is the politicization of the female body. After the revolution, the Iranian government imposed mandatory veiling, transforming women's clothing into a visible marker of ideological conformity. Satrapi treats the veil not as a simple religious garment but as a contested symbol. For the state, it represents moral purity and national identity. The memoir repeatedly shows how the veil becomes a site of negotiation. Women adjust it, loosen it, or combine it with Western fashion, subtly resisting rigid control. These small acts demonstrate that power is never absolute; it is continually contested in everyday practices.

Growing Up Female in Revolutionary Iran

Marji's coming-of-age is shaped by gendered expectations. As she enters her teenage years, the regime increases its restriction on female behaviour. Moral guardians patrol the streets, monitoring clothing, makeup, and public interaction between men and women. Satrapi portrays this surveillance with both humour and critique. Scenes where women are stopped for "improper veiling" show how far the state interfaces in women's personal freedom. At the same time, the memoir acknowledges the real fear underlying these encounters. Women's bodies become a place where government control and personal freedom clash.

Feminist Resistance and Solidarity

Despite oppressive conditions, Persepolis foregrounds women's agency. Marji's mother participates in demonstrations; her grandmother offers moral guidance; female friends experiment with identity and style. These characters collectively challenge stereotypes of passive Muslim women. Satrapi's feminism is grounded in lived experience rather than abstract theory.

Resistance appears in multiple forms:

1. speaking openly within the family



**Yazhini**

2. participating in protests
3. pursuing education abroad
4. Asserting personal dignity in daily interaction. By highlighting these actions, the memoir shows that Iranian women are active and strong, not silent.
5. Visual Literacy and the Power of Black and White Minimalism and Emotional Impact

The visual style of *Persepolis* deserves close attention. Satrapi's drawings are deliberately simple, avoiding excessive detail. Because of this minimal style readers can pay more attention to emotional expression and symbolism. Black often represents repression, fear, or ideological rigidity, while white spaces suggest possibility and reflection. The interplay between these tones mirrors the memoir's thematic concern with binaries—freedom versus control, childhood innocence versus political violence.

Universality Through Stylization

Because the characters are not hyper-realistic, readers from different cultural backgrounds can easily identify with them. The stylized figures function almost like visual archetypes, enabling the memoir to reach readers from different countries. This universality is crucial to Satrapi's project. She aims not only to tell her personal story but also to challenge Western misconceptions about Iran. The graphic format, combined with the black-and-white palette, creates an accessible yet politically sharp narrative Silence, Panels, and Narrative Rhythm.

Equally important is Satrapi's use of panel structure. Moments of silence—wordless frames showing bombed buildings or solitary figures—carry significant emotional weight. These visual pauses allow readers to process trauma in ways that pure text might not achieve. The rhythm created by panel sequencing mirrors the uneven pace of memory itself. Fast-moving sequences depict chaos and fear, while larger static panels emphasize reflection and loss. Through these techniques, the memoir highlights the unique special strength of graphic storytelling.

Global Reception and Cultural Significance

Persepolis has achieved international acclaim, partly because it bridges cultural divides. For Western readers, it offers an insider perspective that counters media stereotypes about Iran. For Iranian and diasporic readers, it preserves a nuanced memory of revolutionary experience.

The memoir also expanded the legitimacy of graphic narratives within academic discourse. Once dismissed as popular or juvenile, graphic memoirs are now recognized as serious literary forms capable of complex political commentary. Satrapi's work has influenced subsequent graphic autobiographies dealing with war, migration, and gender politics. Its continued presence in university curricula demonstrates its lasting relevance.

CONCLUSION

Persepolis is far more than a personal coming-of-age story. Through the innovative use of the graphic memoir form, Marjane Satrapi constructs a layered narrative that intertwines memory, national identity, and womanhood. The stark black-and-white imagery functions as a visual metaphor for ideological conflict while also making the story universally accessible. The memoir shows that memory can serve as a powerful form of resistance against authoritarian attempts to control history. By presenting the Iranian Revolution through the eyes of a questioning child, Satrapi rehumanizes political events often reduced to abstract headlines. Furthermore, her portrayal of women's everyday negotiations with power challenges simplistic assumptions about Muslim female passivity. In the end, *Persepolis* shows that personal stories can change how we understand history. Remembering the past becomes an act of political courage, and women's voices emerge as central to struggles over freedom, identity, and national belonging. Even today, the book remains important because it shows how graphic memoirs can tell powerful stories of resistance.





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RESEARCH ARTICLE

Humanity in the age of AI: Preserving culture, Identity, values in Technological World

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ABSTRACT

The primary aim of the paper is to examine and assess the influence of artificial intelligence on human culture, identity, and values, while identifying strategies to safeguard essential elements of humanity, including ethics, traditions, social norms, and individual distinctiveness in the face of swift technological progress. This study seeks to facilitate a harmonious integration of AI that improves human well-being while preserving the cultural and moral integrity of societies. Humanity finds itself at a crossroads never seen before in an era dominated by artificial intelligence. Machines are acquiring knowledge, advancing, and currently influencing the planet in manners formerly designated for human capabilities. Although AI provides efficiency and capability, it simultaneously engenders significant apprehensions regarding potential losses in our culture, identity, and values during this shift. Technology possesses the capacity to both safeguard and undermine culture. This paper answer to the following question: When do we cease to be perceived as persons and begin to be regarded as data points optimized for consumption? Most importantly, AI functions devoid of inherent moral judgment. It lacks empathy, remorse, or compassion attributes that constitute the foundation of human ethics.

Keywords: Artificial Intelligence, Humanity, Technology, Healthcare, Culture, Identity, Education, Communication, Human Values.





INTRODUCTION

Artificial intelligence is no longer a concept that exists in the future; rather, it is a real force that is constantly transforming our reality. Their effect extends beyond the realms of economics and technology, into the cultural and ethical fabric of society, as artificial intelligence systems grow more and more integrated into everyday life. Within the scope of this study, the intricate relationships between artificial intelligence and human culture are investigated, with a particular emphasis on identity creation, cultural values, and societal standards.

Artificial Intelligence and Cultural Values

Artificial intelligence exerts a profound and complex impact on cultural values, contesting and redefining entrenched ideas, customs, and ethical paradigms. As AI technologies grow more integrated into daily life, they not only automate tasks but also actively influence the cultural fabric of countries globally. Cultural values including creativity, authorship, and originality are being reinterpreted by generative AI systems such as ChatGPT, DALL-E, and MusicLM. Previously seen as exclusively sacred and unreplicable, human creativity is now augmented by AI in the realms of art, music, literature, and humour. This prompts philosophical and ethical inquiries regarding the essence of authorship and the cultural significance of human vs machine-generated creations. It also compels society to reevaluate the criteria for genuine expression.

AI-driven search engines and content generating tools shape the creation and distribution of knowledge, impacting societal definitions of truth, authority, and expertise. Cultural norms pertaining to truthfulness, reliability, and academic integrity are undermined by deepfakes, algorithmic disinformation, and AI-generated texts. This requires a cultural reassessment of our methods for evaluating and validating knowledge.

AI systems trained on prevailing cultural data may inadvertently foster cultural homogeneity, elevating mainstream or Western-centric norms to the detriment of indigenous, minority, or regional viewpoints. Recommendation algorithms on services such as YouTube or Netflix frequently promote internationally popular content, thereby marginalizing region-specific art and storylines. This phenomenon jeopardizes cultural pluralism, an essential principle in heterogeneous communities. The influence of AI on labour and productivity affects cultural values associated with work ethic, merit, and self-esteem. Automation may diminish the value historically attributed to human labour and skill, particularly in sectors such as journalism, customer service, and education. Societies must reevaluate the nature of meaningful employment and the criteria for value assignment in an AI-driven economy.

The extensive implementation of AI surveillance systems, facial recognition technologies, and data-driven personalization undermines the significance of privacy. Cultural norms about autonomy and consent are transforming due to technology that surveil conduct in both public and private domains. In totalitarian governments, artificial intelligence is employed to ensure conformity; in liberal democracies, it incites discussions regarding the balance between convenience and civil liberties. Artificial intelligence presents civilizations with ethical quandaries that challenge conventional principles of equity, justice, and accountability. Algorithmic prejudice in criminal justice or healthcare can perpetuate structural disparities. Consequently, there is an increasing focus on AI ethics, accompanied by demands for culturally attuned design techniques that embody many moral traditions and value systems.

The most significant cultural transformation that AI introduces is a re-evaluation of the essence of humanity. The simulation of emotional intelligence, empathy, and decision-making by robots challenges entrenched societal assumptions regarding the distinctiveness and superiority of human cognition and morality. This evokes intellectual contemplation on dignity, personhood, and the soul principles profoundly rooted in religious and spiritual traditions.



**The Impact of Artificial Intelligence on Human Identity and Its Significance**

Artificial Intelligence (AI) is redefining the parameters of human identity affecting self-perception, interpersonal relationships, and societal definitions of humanity. As AI systems evolve to be more intelligent, adaptive, and integrated into daily life, they threaten fundamental elements of personal and societal identity, necessitating an understanding of their influence and the significance of maintaining human distinctiveness in the digital age. Artificial intelligence technology is integrated into platforms where individuals construct and articulate their identities social media, gaming, virtual reality, and online communities. These platforms shape users' decisions, conduct, and self-image through algorithmic personalization. Individuals start to conform their identity to algorithmic standards: they share information that yields high performance, employ filters to enhance appearances, and adjust language to maximize engagement. This establishes a feedback loop in which the human self is somewhat influenced by machine learning systems, prompting worries over the authenticity and autonomy of identity in AI-driven contexts.

Virtual assistants such as Siri, Alexa, or ChatGPT and AI-driven therapeutic bots are progressively included into human decision-making and emotional well-being. This indicates a transition in which individuals are no longer solely autonomous decision-makers but are collaboratively shaping thoughts and behaviours with AI. This influences not only cognition but also emotions and empathy essential components of identity. For instance, certain users develop emotional attachments to AI partners, which might satisfy psychological needs while also complicating conventional concepts of identity creation, particularly among young and vulnerable groups. The emergence of biometric systems (facial recognition, iris scanning, and DNA identification) and brain-computer connections has increasingly associated identity with data and quantification. The technification of the body diminishes identity to quantifiable metrics, undermining comprehensive and frequently spiritual or philosophical notions of the self.

Although these technologies may improve security or health results, they also provoke ethical dilemmas: Who possesses this identification data? Is it subject to manipulation? The responses carry significant ramifications for privacy, rights, and human dignity. AI systems frequently embody the cultural prejudices of its creators, who are mostly situated in Western, industrialized nations. Consequently, AI can marginalize non-dominant cultural identities through underrepresentation or misrepresentation. Language models may favour English terms and idioms, hence reducing the representation of minority languages and non-Western views in digital discourse. Simultaneously, AI possesses the capacity to safeguard and enhance cultural identity via translation tools, digital preservation of indigenous knowledge, or tailored cultural education. The impact of AI on cultural erasure or preservation is contingent upon deliberate design and inclusive data methodologies. Human identity transcends mere psychological constructs; it constitutes a moral, social, and political foundation. It affects the ways individuals derive meaning, establish groups, and seek justice. When AI impact's identity, it inherently moulds values, relationships, and power structures. Mental health and well-being: Individuals require cohesive narratives regarding their identities.

As AI advances, communities must proactively ensure that human identity is preserved, safeguarded, and enhanced, rather than diminished or commercialized, by intelligent computers.

Artificial Intelligence and Cultural Values

Artificial intelligence exerts a profound and complex impact on cultural values, challenging and redefining established ideas, customs, and ethical frameworks. As AI technologies grow more integrated into daily life, they not only automate tasks but also actively influence the cultural fabric of countries globally. Generative AI systems such as ChatGPT, DALL-E, and Music LM are redefining cultural values including creativity, authorship, and uniqueness. Previously, human creativity was seen singularly sacred and unreplaceable; however, AI currently participates in the production of art, music, literature, and humour. This prompts philosophical and ethical inquiries regarding the essence of authorship and the cultural significance of human vs machine-generated creations. It prompts cultures to reevaluate the criteria for genuine expression.



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The most significant cultural transformation brought by AI is a re-evaluation of the essence of humanity. The simulation of emotional intelligence, empathy, and decision-making by robots challenges entrenched societal assumptions regarding the distinctiveness and superiority of human cognition and morality. This evokes intellectual contemplation on dignity, personhood, and the soul principles profoundly rooted in religious and spiritual traditions.

The Influence of Artificial Intelligence on Ethics, Traditions, and Social Norms

Artificial Intelligence (AI) is not merely a tool for automation or efficiency it is a transformative force that is reshaping the ethical frameworks, traditional practices, and social norms that guide human life. As AI becomes more embedded in decision-making processes, interpersonal interactions, and cultural institutions, it exerts a powerful influence on how people think, behave, and relate to one another AI has introduced a range of ethical challenges that were previously uncharted. From autonomous vehicles deciding who to save in an accident, to predictive algorithms determining the likelihood of a person committing a crime, AI is involved in decisions that were once exclusively human and moral. Responsibility and Accountability: When an AI system causes harm, it is unclear who is ethically responsible the programmer, the user, the company, or the machine itself. This creates a gap in traditional moral systems built on individual agency.

Bias and Discrimination

AI systems can inherit or amplify social biases present in their training data. This has raised concerns about fairness in hiring, policing, healthcare, and education—challenging societal commitments to justice, equity, and human dignity. Autonomy and Consent: As AI gathers personal data and makes recommendations, it often does so without clear, informed consent. This undermines traditional ethical values centered on autonomy, privacy, and human rights. Thus, AI is not only challenging existing moral values but also prompting societies to reimagine ethical guidelines in light of machine involvement. Traditions are deeply rooted practices passed down through generations that give people a sense of identity, continuity, and belonging. AI interacts with tradition in two major ways: it disrupts certain practices while preserving or transforming others. Disruption of Rituals and Roles: For instance, in education, religious practice, or family roles, AI may replace traditional authorities (e.g., teachers, elders, priests) with algorithmic systems. This can weaken intergenerational bonds and the transmission of cultural wisdom.



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Preservation through Digitization: Conversely, AI is also used to document, translate, and revive endangered languages, texts, and oral histories. Machine learning helps in archiving sacred texts or reconstructing damaged historical sites, offering tools to support traditional knowledge systems. Cultural Sensitivity vs. Standardization: AI, when trained on global data, may ignore the cultural nuances of localized traditions. This risks standardizing behaviours across different cultures, thereby eroding unique traditions in the name of optimization or efficiency. AI thus plays a dual role: as both a threat to and a guardian of tradition, depending on how it is applied and governed. AI and Social Norms: Reshaping Behaviour and Expectations Social norms are the unwritten rules that guide behaviour in society how to act, communicate, and interact with others. AI technologies, especially those embedded in social media, communication apps, and workplace systems, are redefining these norms in profound ways. Shifting Communication Patterns: AI-driven platforms like chatbots, voice assistants, and AI-generated influencers are changing how people interact. The increasing use of non-human interlocutors normalizes interactions with machines, altering the meaning of conversation, empathy, and connection.

Behavioural Nudging: Recommendation algorithms and personalized content influence user behaviour by nudging them toward certain actions, beliefs, or purchases. Over time, these micro-influences can change societal attitudes, from consumer preferences to political views. Desensitization and Emotional Disconnect: AI-mediated environments may contribute to emotional desensitization and a decline in face-to-face social skills, especially among younger users raised in algorithmically filtered digital worlds.

Changing Norms of Work and Productivity: In workplaces, AI systems measure performance, predict behaviour, and assign tasks, reshaping expectations of productivity, discipline, and collaboration. This alters workplace culture and social hierarchies, often emphasizing efficiency over well-being. Artificial Intelligence is not only reshaping industries and infrastructures it is reconfiguring the ethical, traditional, and normative frameworks that define human life. While it offers opportunities to preserve cultural heritage and enhance ethical reasoning through data, it also introduces deep uncertainties about morality, social behaviour, and cultural continuity. To ensure that AI supports rather than undermines ethical values and traditions, it is essential to involve ethicists, cultural scholars, local communities, and policymakers in the design and governance of AI systems. In doing so, we can help shape an AI-integrated future that respects and reflects the diverse moral and cultural landscapes of humanity.

CONCLUSION

Artificial Intelligence is transforming human existence, cognition, and interaction. Although AI provides significant advantages in efficiency, invention, and problem-solving, its swift progression also poses challenges to established human values and ethical standards. Concerns including privacy, accountability, justice, transparency, and the risk of prejudice necessitate meticulous examination. Artificial intelligence should not supplant human judgement but rather enhance ethical decision-making grounded in empathy, respect, and justice. To guarantee a future in which technology benefits humanity, it is imperative to integrate ethical standards into AI development and application. A human-centered strategy that harmonises technical advancement with ethical accountability is essential for maintaining human dignity and promoting a just and equitable society.

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Table 1

Civic participation:	Identity is fundamental to social membership and engagement
Moral agency:	The capacity to make ethical decisions relies on a robust, autonomous self.
Cultural continuity:	Identity links generations and customs.

Table:2

Cultural Preservation:	AI can help preserve and revive endangered languages and customs
Personalized Experiences:	AI allows for customized educational, medical, and entertainment experiences
Empowerment:	When developed ethically, AI can give marginalized communities greater access to information and services, thereby empowering them

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RESEARCH ARTICLE

Cyclonic Agency: Storm Sovereignty, Ecological Renewal, and the Non-Human Turn in Carpentaria

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ABSTRACT

The Carpentaria by Alexis Wright gives the cyclone the status of an independent Indigenous law that exists beyond the meteorological event. The storm ecologically serves out the ecological justice of the extractive violence of the Gurfurrit mine, particularly in Chapter 13, "The Wash." The cyclone is not an occurrence of a natural disaster, but rather, it is an instrument of colonial resistance that shatters anthropocentric power. The life of Will Phantom demonstrates extreme symbiosis on a floating rubbish isle, where nature takes colonial waste. It recycles it into a form of plants growing out of rubbish and birds nesting in refuse. The reappearance of Norm Phantom is through a rearranged setting of water, which does not emphasise destruction, but continuity. The text is indicative of Indigenous ecocriticism, in which Country has a purpose in subverting traditional Anthropocene framings in which human beings are the masters of geology. Everything is brought into balance with the agency of the storm, which carries away the town of Despair, yet leaves the Pricklebush people who are in harmony with the conventional rhythms. The Uptown panic is quite different compared to the elders accepting the storm as a cleansing spirit. The history behind the establishment of this agency is based on the creation history of the ancestral serpent, meaning that its creators do not forget the land. The text offered by Wright makes us read nature not as a resource, but as a web of kinship that can bring about sovereignty by creating climatic force on it. The cyclone never merely destroys; it passes judgment, clearing out colonial existence to allow the ancient ecology of the Gulf to inhale once more. This is the twist of the plot that makes the non-human not a background; it is the historical force that is changing the Gulf Country.

Keywords: Ecocriticism, Indigenous Sovereignty, Cyclone, Anthropocene, Non-human Agency, Gurfurrit Mine, Colonial Resistance





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INTRODUCTION

Climate change is experienced as a great ecological turmoil, which interferes with the fragile ecological balance that exists between humans and non-human life in the Anthropocene (Nixon 4). Literature mediates this crisis by providing narratives that go beyond empirical evidence to produce moral responsibility for changes in the environment (Huggan 12). An example of this possibility can be seen in *Carpentaria*, a textual landscape in which the environment takes an active role instead of a passive contextual backdrop (Tiffin 20). In particular, Chapter 13, *The Wash*, presents cyclones not only as weather phenomena but also as agents of sovereign power that attempt to enforce Indigenous law on colonial trespass (Rose 56). This principle of Cyclonic Agency differentiates it from the typical pathetic fallacy; the storm is not a reflection of human emotion but a legal mechanism that restores the ecological balance (Morton 34). The Gulf of Carpentaria is a disputed territory in which there is a collision between multinational mining interests and ancestral sovereignty (DeLoughrey 89). As Wright determines, the ancestral serpent "came down from the stars... to crawl on its heavy belly" throughout the mudflats. A deep-time occupation of the land can be made that is not colonial in mapping (Wright, *Carpentaria*, ch. 1). This narrative is based on this creation story through a cosmology in which land and law cannot be separated. By contrast, the mine at Gurfurrit is extractive violence, where security men are involved in "searching the area for the body" to safeguard corporate interests against ecological facts (Wright, *Carpentaria*, ch. 11). This kind of surveillance brings out the conflict between the security of the corporation and conventional ownership. This trespass is the direct response to the cyclone. It is a non-human agent that destroys colonial infrastructure that sweeps away the town of Desperance, but leaves those who concur with Country (Haraway 45). Phantom lives in a rubbish pile on a floating island, thus showing adaptation to ecological rejuvenation and the connectedness of human life and non-human life (Wright, *Carpentaria*, ch. 13). This survival is a challenge to anthropocentric perceptions, indicating that kinship with the more-than-human world is the key to survival. The post-disaster landscape shows a restarted landscape, in which the gropers swimming under the vessel are indicative of a reversion to ancestral beat and the vulnerability of ecologies when they are overrun by industrialisation (Wright, *Carpentaria*, ch. 14). This kind of imagery emphasises the fact that there is an urgent need to have a concerted effort in combating environmental degradation. Eventually, the cyclone imposes a sovereignty of the storm, which requires responsibility. This paper contends that the cyclone is a juridical impact on the non-human turn that re-establishes the ecological equation of eliminating colonial infrastructure and reasserting Indigenous sovereignty over extractive capitalism.

Research Focus

The main purpose of the study is to examine the ways in which *Carpentaria* by Alexis Wright reflects the narrative about ecological and climate change in terms of the symbolic meaning of cyclone, its devastating yet regenerative power, and the consequences which these have on natural ecosystems and Indigenous sovereignty. This study explores the cyclone as a meteorological event but, more importantly, as an agent of Indigenous law that restores the ecological balance by eliminating colonial infrastructure. It analyses the text in terms of ecocriticism and the non-human turn to investigate how the concepts of storm sovereignty and environmental justice are interrelated in the Gulf Country. It aims to find out how extreme weather, as represented in literature, can contribute to a more general discourse about climate resilience and decolonial practice. The focal research questions may be:

1. In what ways does Wright use the cyclone (in particular, *The Wash*) to refer to the more general ecological implications of climate change and Indigenous justice?
2. How does the novel demonstrate the breaking of the cycle of nature and ecological balance by destroying the mine and the town?
3. How does the human experience as depicted in the survival of Will Phantom on a floating island reflect the greater ecological and environmental disasters represented by the agency of the cyclone?





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These questions inform the discussion of the narrative techniques used by Wright to discuss the issues of anthropogenic destruction and ecological regeneration.

The Cyclone as a Symbol of Ecological Disruption

The cyclone in *Carpentaria* is not merely a meteorological phenomenon; it is an independent agent of Indigenous law that upsets the ecological models of the West. Whereas Western ecocriticism frequently views extreme weather as a calamity that signifies the failure of the environment (Buell 12), Indigenous epistemologies view these forces as purifying agents that allow order to be reinstated (Whyte 45). Wright contrasts these perspectives and introduces the storm not as anarchy but as a consequence of justice. The storm, which enters the novel, is described as, "The giant sugarbag man of the skies walked from horizon to horizon, carrying storms and hazes of madness" (Wright ch. 10). This personification is in line with Plumwood's argument that it is important to realise that nature also possesses agency as a prerequisite to environmental culture (Plumwood 88). In contrast to the passive action in colonial literature, the cyclone in Wright is active and pursues the Gurfurrit mine, destroying infrastructures such as pipelines and hangars. The destruction is total: "The whole mine, pride of the banana state, ended up looking like a big panorama of burnt chop suey" (Wright ch. 11). This particular appeal highlights the anarchic nature of extractive capitalism, which reflects the fact that postcolonial ecocriticism must deal with the exploitation of resources (Griffiths 102).

The cyclone is an allegory for the instability of the systems, showing the instability of colonial trespass systems. Through ecocriticism, as Garrard explains, the intersections of environmental narratives and political power must be discussed (Garrard 55). The violence of the storm in *Carpentaria* is a direct response to the country's violation by the mine. The intensity is stated in the story: "The storm hit. Wind and rain fell in horizontal sheets across the valley" (Wright ch. 13). This is the physical force that reflects the social upheaval needed to decolonise land, as the author Tuck argues that decolonisation is not a metaphor but a material process (Tuck 25). The symbolism of the washing away of Desperance is that the presence of colonialism is washed away, and as a result of this action, the Anthropocene becomes indigenised, thus making Indigenous sovereignty the central theme (Todd 78). This is the obliteration under which the text highlights: "History could be obliterated when the Gods move the country" (Wright ch. 13). In this case, the "Gods" symbolise the forces of the ancestors, who reclaim space where an industry takes in, which echoes Kerridge's perception of writing the environment as the recognition of non-human participants (Kerridge 34).

Moreover, the aftermath of the cyclone outlines the vulnerability of the natural systems, which is a core concept of the discussion of the paper on the flight behaviour model of ecological equations (Prajapati 95012). Similar to the migration of the monarch butterfly, which is an indication of disruption in the work of Kingsolver, the cyclone in Wright represents the boundaries of what humans can do. The post-storm landscape is characterised as "the shores of a flattened landscape which the cyclone had left in its wake" (Wright ch. 14). Such a process of flattening re-establishes the ecological balance by eliminating the noise of industrialisation. According to Westling, these narrations are a revelation of the green breast of the new world, where nature regenerates following the termination by humans (Westling 110). The justice of the storm is in line with the queer ecologies by Mortimer-Sandilands, where non-normative forces to heteronormative colonial systems are disrupted (Mortimer-Sandilands 67). Finally, the cyclone in Wright shows that the crisis of ecological disaster is not only an emergency but also a medicine. According to Buell, this is a violent restoration that the environmental imagination should consider (Buell 25). The novel, therefore, goes beyond the warning to enactment, in which Country resists the frailty that extractive industries have imposed upon it.

The Floating Island as a Reflection of Human Lives

The survival of Will Phantom on the floating rubbish island is a prime example of radical symbiosis between human resilience and ecological regeneration. After the cyclone, Will is marooned on a floating waste city, which is now littered with human waste (Wright ch. 13). This metamorphosis resembles Dellarobia Turnbow's experience in *Flight Behaviour*, in which nature is shaken. The human position is renegotiated (Prajapati 95014). It is the same way the

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migration of the monarch butterflies changed, which is also an indicator of environmental instability; therefore, the displacement of Will will be an indicator of a break in the colonial system, which will create the need to adapt (Houghton 12). The cyclone is a cleansing mechanism that eliminates colonial infrastructure, similar to how climate change interferes with human-established cycles (Wright ch. 13).

Man-made debris is quickly taken over by nature. Plants sprout on rubble, and birds nest on rusted hulls, depicting ecosystems' ability to adapt to human impact (Wright ch. 14). Peanuts, mangroves, and tomatoes grow in decay, showing biodiversity's ability to adapt to unusual niches (Jackson 45). Will is no longer a political activist but an ecological scholar who quantifies stars and currents to get ahead (Wright ch. 14). This change indicates the need to combine scientific observation with local knowledge to learn about climate crises (Menzel 88). It is his alienation that makes him keen on non-human rhythms, questioning the blindness that centralised powers tend to exhibit (Prajapati 95013). He knows how to steer by the stars, and he is the student of the sea and not the master of the sea (Wright ch. 14).

Ecological displacement is compared to the displacement of Will in a very clear way. The cyclone destroys the town of Desperance, as climate change sends species all over the planet (Wright ch. 13). The vulnerability of human constructions to forces of nature, viewed in the life of Will, is the central theme in conservation biology (New 102). The only way he can survive is by reading the ecological equation and being aware that human destiny is connected to environmental well-being (Prajapati 95012). First, Will has to endure human ignorance as he dreams of being rescued instead of becoming accustomed to the climate, like communities that refuse to accept climate realities (Prajapati 95014). He is concerned that the island will go to pieces, as society is afraid of ecological collapse (Wright ch. 14). Nonetheless, his mastery of the island later proves that he is able to transform personally by being involved with the environment (Wright ch. 14).

Eventually, the island becomes a place of individual enlightenment, as Will realises that he has been reliant on the more-than-human world (Prajapati 95014). It's rubbish island, which had already been a symbol of consumption, turns into a refuge, demonstrating that nature is still present even when people destroy it (Houghton 25). The narrative of Will encourages everyone to take ownership to ensure that the planet is safe, which is encouraged by calls for sustainable futures (Jackson 50). His survival is not corporeal but spiritual, based on the land-healing ability (Wright, Ch. 14). Wright, through Will, shows that natural systems have to be humbled in the process of adaptation (Menzel 90). The floating island is a symbol of survival and calls on readers to address the ecological disasters that are defining our world (New 110). The fact that Will returns indicates that he reconciled with nature rather than overthrowing it, and his journey from activist to survivor is complete (Wright, Ch. 14). Biological research proves that this kind of adaptation is the key to the survival of species under altered climatic conditions (Bradley 105). The behaviour and metabolism of insects change with environmental stressors, just as physiological changes occur in Will (Boggs 22). His raft also plays a structural role that resembles insect exoskeletons, which offer protection (Chapman 45). Such resilient ecosystems should be a priority in conservation (Corbet 88).

The Role of Indigenous Knowledge in Understanding Climate Change

Western scientific surveillance is commonly based on detached technologies, such as helicopters and satellites, to monitor changes in the environment; however, such approaches often fail to reflect the sentient agency of the land. In *Carpentaria*, Indigenous epistemologies provide a more sensory alternative to digital data, prescribing smell, sight, and ancestral memory over digital data. Although the mine uses helicopters to scan the Gulf, Indigenous characters use embodied knowledge of Country. For instance, Mozzie Fishman does not rely on maps to detect the sources of water but rather smells the air, feeling the presence of moisture "coming out of wet ground and plants a hundred kilometres away" (Wright, *Carpentaria*, ch. 5). This sensory knowledge challenges Western conservation models, which believe in measurement rather than relationships. According to Whyte, Indigenous climate change research focuses on relational accountability as opposed to the collection of data (Whyte 45).



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The convoy of Mozzie Fishman is such an example of this epistemology on the road, and it is moving on Dreaming tracks that are not subject to colonial borders. Their trip is not only geographic but also spiritual, retaining law over thousands of kilometres. This compares to the stagnant infrastructure in the mine, which aims to mine and not preserve. According to Rose, these ethical entanglements identify the need of human beings to perceive themselves as belonging to the ecology of the land but not as one controlling the land (Rose 56). Exceptional navigation by the stars and sea currents by Norm Phantom further demonstrates this by denying the technological superiority of the mine. He reads the "star of the fishermen that was setting low in the northern horizon" to steer his boat by relying on the patterns of the heavens instead of the GPS (Wright, Carpentaria, ch. 14). This act is consistent with Todd's statement that Indigenous people live in worlds in which non-human beings, such as stars and fish, are not passive in governance (Todd 78).

The novel is a criticism of how Western science cannot anticipate ecological justice, especially in the case of cyclones. Although the meteorologists are monitoring low-pressure systems, Pricklebush interprets the storm as a force enforcing the laws of the ancestors. The cyclone operates as a "sovereign agent of Indigenous Law" that reinstates the ecological balance by eliminating colonial infrastructure (Wright, Carpentaria, ch. 13). This view reminds Plumwood of the critique of human exceptionalism, in which it is argued that nature has an agency that is dismissed by Western rationalism (Plumwood 88). This knowledge is further based on the creation of the landscape by the ancestral serpent, which forms a deep-time claim that pre-colonial mapping has no place (Wright, Carpentaria, ch. 1). These accounts legitimise Smith's call to decolonise methodology by making Indigenous voices central to environmental arguments (Smith 12).

It is vital to combine local knowledge and science; however, according to Carpentaria, Indigenous law offers a more precise approach to ecological fitness. The technology in the mine is unable to predict the resistance of the land; however, the intuition of Norm helps to save his life. As mentioned by Haraway, creating kinship with non-human beings is the only way of surviving in the Anthropocene (Haraway 45). This is confirmed by the fact that the mine was destroyed by a cyclone, demonstrating that even extractive capitalism is not resistant to the sovereignty of ecology. The non-human turn, introduced by Morton, comes to life here when the storm is a juridical force (Morton 34). Finally, the story written by Wright insinuates that conservation efforts in the West cannot work without the moral foundation of Indigenous law. DeLoughrey points out that such spatial sovereignty is encoded in Pacific literatures, as they opposed colonial incursion (DeLoughrey 89). Griffiths also notes that postcolonial ecocriticism should be able to discuss the exploitation of resources using Indigenous perspectives (Griffiths 102). Tuck cautions that decolonisation is not a figurative procedure but a concrete one of land retribution (Tuck 25). Therefore, Carpentaria assumes that the only way to be truly ecologically resilient is to relinquish Western hegemony to Indigenous peoples.

Climate Change, Indigenous Sovereignty, and Ecological Equity

The theory of environmental justice assumes that disadvantaged communities are disproportionately victims of ecological degradation, which is a major concept of the Gulf of Carpentaria (Bullard 15). This injustice has been experienced extremely in Carpentaria between the Pricklebush people and Uptown, where the Gurfurrit mine drains the wealth, yet the Indigenous people are exposed to toxicities. The infrastructure in the mine has scratched the land. However, the Pricklebush still stand "dumped... without any sign of lock, stock or barrel" near the town tip, exposing them to hazardous conditions excluded from colonial spaces (Wright ch. 1). This locationism reflects environmental racism, in which Indigenous bodies become objects of risks that white citizens do not share. The cyclone, however, is a force of ecological equity, which destroys the infrastructure of the mine and cleanses Desperance. As Wright describes, "history could be obliterated when the Gods move the country" (Wright ch. 13). This natural force creates a level playing field, destroying both the colonial town and the extractive machinery, pointing out that the country itself is seeking revenge against extractive capitalism.

Indigenous sovereignty is first a recasting of Country as not property but a rights-bearing entity, which has intergenerational rights, challenged by Western property rights. Intergenerational equity lays emphasis on ensuring



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that ecological resources are conserved in order to have an equitable relationship between the present and the future generation (Jonas 12). The creation of the landscape by the ancestral serpent in the novel creates a deep-time assertion that dates back to colonial cartography (Wright ch. 1). This is the opposite of Native Title claims under colonial law, as seen in the case of Joseph Midnight working with the mine and Mozzie Fishman following native law. Midnight's side wants financial reimbursement, and Fishman's convoy is concerned about the sacred ceremony, which shows the contradiction between legal and spiritual sovereignty (Wright ch. 5). As tensions such as these are indicative of the fight for ecological equity, where Indigenous law provides a platform of equilibrium lacking in Western conservation theories.

The devastation of the cyclone highlights the instability of colonial possessions in comparison with Native ecological information. As Uptown residents, the people panic, and the pricklebush are cognising of the storm as a cleansing spirit that imposes Indigenous law. The fact that Will Phantom survives by living on a floating rubbish island is a sign of adaptation in ecological renewal, in which plants grow in rubbish, and birds nest on debris (Wright ch. 14). This strength struggles against anthropocentric perceptions in that sovereignty is in kinship with the more-than-human world. To achieve environmental justice, there is a need to appreciate Indigenous epistemologies as systems of managing climate crises. According to Rob Nixon, slow violence usually hides the direct effects of environmental degradation on the vulnerable masses (Nixon 3). Finally, *Carpentaria* assumes that fairness will eventually be achieved once the colonial systems are eliminated and Country will be able to breathe once again. This sovereignty is imposed by the storm, which eliminates the colonial footprint to enable the ancient ecology of the Gulf to regain balance (Wright ch. 11). This change of narration makes the non-human not the background, but the force behind the historical change in the Gulf Country (Huggan 22).

The Cyclone's Path and the Future of the Planet

Cyclone in *Carpentaria* is a prophet of aggravated climate facts, and the destruction of the colonial infrastructure to display the irreversibility of Country. Wright does not represent the storm as a single weather phenomenon but as a repetition of a spiritual force that restores the ecological balance. When the waters go down, the town of Desperance is destroyed. A town like that is left without a trace "flattened landscape which the cyclone had left in its wake" (Wright, *Carpentaria*, ch. 14). This demolition is an indication that one is transitioning into an Indigenous ontology in which land is an agent that humans are unable to guide and one that disrupts the Western beliefs about environmental management. The violence of the storm is not accidental; it is a retaliatory act against the extractive violence of the mine, implying that the policy of climate in the future should take into consideration a non-human form of juridical power.

The survival of Will Phantom on a floating island of rubbish is the best illustration of the uncertainty of the future in the Anthropocene. He is using a floating island of garbage, in which nature takes back human waste, a sign that there can be adaptation in the face of destruction (Wright, *Carpentaria*, ch. 13). The fact that he chose to stay on the raft instead of going back to the mainland immediately highlights the indecisiveness that victims of climate displacement have. The island turns into a microcosm of a planet that is struggling with waste and regenerating, in which case, "plants grew on wreckage, and birds nested on rusted hulls" (Wright, *Carpentaria*, ch. 14). It is a symbiosis that indicates the posthumanist view of life, in which survival relies on becoming ensnared in the rubbish instead of being cleansed. The future is not that we can go back to purity, but it will be a bargaining with the aftermath of industrial breakdown.

The weakness of human infrastructure contrasts with the persistence of the country. The Guffurst mine, which was once a symbol of economic dominance, ends up as burnt chop suey at the mercy of the storm (Wright, *Carpentaria*, ch. 11). This failure explains how extractive industries are exposed to the power of nature. The loss of physical markers does not take away Indigenous attachment to place, as the appearance of the Norm Phantom in the lost town points out the strength of Indigenous connections to place. This tenacity is founded on the creation narrative of the ancestral serpent. It implies that the land is aware of its creators despite efforts by colonialism to forget them





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(Wright, *Carpentaria*, ch. 1). The memory of the land continues to exist longer than the short-lived existence of the town, claiming that Country exists beyond colonial mapping.

Finally, the novel suggests acknowledging non-human agency in climate policy. The cyclone is a juridical power that adjudicates trespass to the land. This is in line with ecocritical ideas of granting nature rights and moving beyond anthropocentric conservation. The agency of the storm is a restorative force that cleanses the town, except for those who were consistent with the rhythms of tradition. Wright's story requires anthropocentrism to be replaced by ecocentrism, in which climate action acknowledges Indigenous sovereignty. The future lies in the recognition that the country retaliates against ecological violations. The planet is talking to humanity, and it should be the one to listen before the next wave comes to destroy the last few bastions of denial. The path of the cyclone is not only destructive but also a guideline for survival.

CONCLUSION

In the end, Alexis Wright, with her book *Carpentaria*, decides to give a new meaning to the cyclone as a sovereign force, implying Indigenous Law enforcement. This study shows that the storm is a form of juridical power that replaces the ecological balance by erasing colonial infrastructure and reinstating the agency of the land. However, in contrast to Western systems that perceive extreme weather as a state of climate instability, the cyclone in the novel is a system of corrective action to extractive violence. This view requires a shift from anthropocentrism to ecocentrism, in which the country is viewed as a rights-caring being that can make judgments of trespass against encroachment. This research highlights the importance of considering Indigenous knowledge systems in solutions to global climate problems. Western science does not recognise sentient agency, but Indigenous epistemologies perceive the environment as a kinship network with a temporal foundation in deep time. According to *Carpentaria*, ecological resilience is only achieved when colonial systems are broken down, allowing ecologies to re-establish order through spiritual renewal. The path of the cyclone shows that the primary factor of human survival is connected with non-human agency and the health of the ecosystem.

In conclusion, the novel urges responsibility to protect the planet, not by controlling it, but by honouring storm sovereignty and ancestral cycles. The future lies in considering that the country rebels against ecological violations. The next wash would destroy edifices of denial, and humanity needs to be sensitive to the warnings of the land. Through this interconnected web of life, it is the one that resonates with the rhythms of Country that learns that the non-human is the key to changing history. This balance must be guarded by being humble and recognising humanity as a single thread in an ecological carpet, in which nature is powerless.

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RESEARCH ARTICLE

Dislocated Belonging: Spatial Liminality and Psychological Alienation in the West African Narrative of *Swing Time*

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ABSTRACT

This study explores Zadie Smith's *Swing Time* as a phenomenon of spatial liminality and psychological alienation, focusing on the protagonist's journey to a West African country. The passage is a masterful metaphor for the displacement of the narrator in Gambian/Senegalese terrain, resulting in an identity crisis larger than that experienced in post-colonial contexts. This paper discusses themes of dislocation, adaptation, and the interdependence of diasporic and local identities by examining the connection between the narrator's broken sense of self and the novel setting, which is the West African region. The study draws attention to Smith's employment of the West African narrative to express not only the precariousness of belonging to a culture but also the necessity of reassessing celebrity humanitarianism. Moreover, the paper examines how aid and knowledge can be useful in solving identity crises, how social inequality and psychological degradation interact, and the significance of combining personal and political viewpoints. Overall, this study asserts that *Swing Time* not only raises awareness about the effect of the colonial past on identity but also suggests a comprehensive methodology for comprehending the sense of belonging, as ensuring the future of cultural integrity is the obligation of humankind.

Keywords: Spatial Liminality, Psychological Alienation, West African Narrative, Postcolonial Identity, Dislocated Belonging



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INTRODUCTION

The issue of identity displacement has taken the 21st century by storm, with serious implications for the individual, society, and the global diaspora. The growing pace of globalization, including growing cultural dilution, extreme economic inequalities, the crisis of migration, and the disappearance of traditional biodiversity, represents growing evidence of a more unstable mental state. The core of such a challenge is the concept of spatial liminality, which is applied to establish the complicated and intertwined interactions between the physical spaces of the earth, human actions, and the cultural resources that societies depend on (Turner 95). This research article attempts to understand the dynamics of psychological alienation in terms of spatial liminality and how such human interventions as celebrity humanitarianism, neo-colonial aid, and industrialization upset the fragile equilibrium of cultural ecosystems. One of the most pressing global questions of our epoch is the identity crisis, and literature has been a significant instrument in the exploration and raising of awareness of the widespread consequences of the same.

Swing Time (2016) by Zadie Smith is one such literary work, a novel that closely intertwines the topics of race, dance, and human experience (Smith 12). This analysis will examine how *Swing Time* employs the West African narrative and the narrator's visit to the Gambia and Senegal as main symbols to examine the psychological effects of dislocation. The novel space of the West African region helps to gain access to the interconnectedness of the diasporic world and the role of changing environmental conditions that destabilize the delicate sense of identity (Gilroy 45). This plot line underscores the conflict between the protagonist's British upbringing and her heritage, which forms a kind of liminality in which the status of belonging is negotiated at all times. With an uncertain future ahead, it is important to establish in-depth knowledge of the psychological equation to inform global quests for cultural resilience, sustainable development, and identity justice. Through this inquiry, the paper will contribute to the discussions regarding the pressing need for a collective global response to identity crises.

Swing Time shows that the aspects of space liminality, African geography, and human experience are interconnected in depth. The description of altered flight behavior by Smith is a strong metaphor for related changes in the psychological state caused by colonial legacies (Bhabha 112). The novel also makes one think about the way in which human beings interpret and react to changes in the environment and encourages people to take more action to conserve the environment. As the studies and research used in the review emphasize, the migration and flight behavior of butterflies is complex in the face of a changing climate, which makes further ecological research and activities crucial in order to sustain threatened species (Casteel 78). However, in the setting of Smith's story, such migration resembles the experience of a person who is displaced due to reasons outside of their control. With natural habitats becoming uncongenial, human and non-human species either have to adapt, move, or become extinct. This paper examines the theme of dislocation, adaptation and interconnectedness of diasporic and local identities by analyzing how the sense of self has been broken by the narrator due to the location that is the West African setting of the novel. The study emphasizes the way Smith employs the narrative of West Africa as a means of displaying the vulnerability of cultural belonging as well as the necessity of a new reconsideration of celebrity humanitarianism.

Research Focus

This study examines how *Swing Time* portrays the meaning of the psychological and spatial story through the symbolic employment of West African locations, liminal spaces, and the connotations they bear on both the natural ecosystem and human beings. Based on the ideas of spatial liminality, this paper explores how the narrator is displaced in the Gambian landscape as a symbol of the postcolonial identity crisis and the instability of cultural affiliations. The research questions might include the following:

- How does Smith apply the West African space (the village/school project in particular) to represent the psychological impact of dislocation in the general sense?



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- How does the novel bring out the imbalance in natural cultural cycles and psychological balance brought about by neo-colonial aid?
- How does the human experience, presented in *Swing Time*, reflect on the greater ecological and environmental crisis as represented by the moving patterns of migration of the narrator?

Spatial and Psychological Themes in *Swing Time*

Smith's *Swing Time* recounts a thrilling journey of intersecting psychological systems and the reality of the impact of displacement of space. The unnamed narrator is led to West Africa, where the scenery is not only an adjunct but also a force that interferes with her psyche. This voyage resembles the environmental disturbances occurring in climate fiction, in which a changing environment shifts and affects people's lives. As proposed by Homi K. Bhabha, cultural identity may be shaped in the in-between spaces, creating liminality, through which the narrator experiences the foreign country (Bhabha 2). The Gambian and Senegalese environments turn into transitional places where the interracial identity of the narrator is brought to the fore, leading to the dislocation of her own self.

The introduction of the pop star Aimee by the narrator disrupts the local ecosystem, similar to how external forces create chaos in the natural equilibrium. The School Project, which is supposed to train girls, is viewed as an imposition of outsourced will in a local space. It is a type of neo-colonial aid in which the donor's vision supersedes local needs. Gayatri Chakravorty Spivak feels that such interventions tend to make the subaltern be silent because the voice of the locals is lost in the noise of the agenda of the benefactor (Spivak 28). The project is not natural; it is being imported like an invasive species, changing the environment. The physical landscape of the school is modified by its construction, although the social ecosystem is modified, and dependency is created, which never existed before Aimee begins to work on it.

In addition, the description of the natural world and local culture focuses on weakness and defensibility in the face of human influence, in particular, the influence of celebrities. With the introduction of Aimee, the village is turned into a platform for her humanitarian brand, and the local culture will become vulnerable under her whims. Her capricious focus makes the community addicted to her, which shows the instability of celebrity-driven aid. According to Achille Mbembe, power structures in the postcolony tend to place local people in the status of being vehicles of foreign rule, denying them the agency to act (Mbembe 102). The villagers are viewed as subjects of grace, as opposed to partners in development. This contrast reveals how local traditions are weak in the face of the economic strength of Western celebrities.

The changing perception of the village by the characters reflects the slow realization of climate change encountered in ecological stories. The narrator comes to understand that what she is going through is a bigger identity and privilege crisis. She exists in an in-between world, not completely an insider or an outsider, and this pushes her to address the issue of her complicity in the power structures involved. Simon Gikandi emphasizes the fact that maps of Englishness usually do not capture the presence of hybrid identities, which results in the fact that people such as the narrator are stuck between worlds (Gikandi 5). This mental alienation is as harmful as the real one brought about by the school project. The personal struggle that the narrator experiences is the wider contradiction between worldwide movements and national grounding.

The novel remarks on the sense of urgency of environmental and cultural action, preaching the sustainability of humanitarian assistance. The intrusion of natural cycles into villages is a vivid example of the frailty of ecosystems against human activities. Similar to climate change, effective aid spans collective responsibility and requires mutual respect and sustainability. Smith demonstrates that aid is another disruption unless the cause of inequality is considered. The narrative of the narrator highlights the urgency to bring back the equilibrium when there is no chance of holding back once beauty and the human soul are irreparably ruined (Smith 315). It is through this that the West African story is a powerful teaching of how all living systems are interconnected and how acutely all ecological and social problems must be tackled in a holistic manner.



**Shyma and Catherine Anna Pushpam****The West African Space as a Symbol of Dislocated Belonging**

The village in Zadie Smith's *Swing Time* serves as a powerful representation of vulnerability and stability, equivalent to the monarch butterfly in ecological stories. The village is a social ecosystem that can be easily disturbed, and the interrupted migration of the butterfly is an indicator of environmental instability. A narrative breakthrough, which occurs as the narrator is brought to this liminal zone through the humanitarian efforts of pop star Aimee, brings about a dramatic change in her conventional trajectory out of London and New York. This is not just physical but also psychological displacement because the narrator has to face her own displaced belongingness in the diaspora. Cultural identity, as Stuart Hall argues, is not a given but a question of becoming as well as being and is continuously changing through the interaction of history and culture (Hall 225). This change is tested in the village, where the instability of the narrator's identity is shown once she is removed from her Western setting.

The narrator is a metaphor for the frailty of the natural systems and the outcomes of manmade environmental alterations, that is, through the prism of neo-colonial aid. Aimee's school project, being well-motivated, is an intrusive species in the local social order that interferes with the traditional cycles of community life. This relationship can be seen as the so-called contact zone, as outlined by Mary Louise Pratt, in which unequal cultures come into contact and engage in conflict under the circumstances of coercion and extreme inequality (Pratt 7). Humanitarian aid in place of local needs, being an external will of the space, reflects the manner in which industrialization affects ecological balances. Physical forces do not challenge the strength of the village but instead, are challenged by the introduction of material wealth and expectations, pointing to how human interference can easily disrupt fragile social ecosystems, much like climate change can alter physical ecosystems.

These power dynamics have implications on a larger scale, as demonstrated by systemic destabilization in the village. The balance of the community is shaken by the presence of the Western contingent, whereby the inherent tensions of race, class, and the distribution of resources are revealed. According to Edward Said, imperialism is not only a past phenomenon but also a discursive phenomenon that creates a sense of geographical consciousness and cultural identity (Said 12). In the novel, the Western presence reinstates colonial hierarchies, according to which the locals are placed in the position of grace receivers instead of being the same partners. The narrator notes that the project is making dependencies that change the social fabric in a way that may not be sustainable after the withdrawal of external funding. This disruption of the system highlights the instability of the postcolonial space in the face of global capital, in which the control of local agency is frequently undermined by the pressures of foreign donors.

The presence of the narrator is a wake-up call to her and society, pulling her to confront less visible forms of disruption, such as power relationships and privilege. She is in an intermediate place, neither an insider nor an outsider, and can thus observe the tension between Aimee's vision and the village's reality; hooks continues to suggest that marginality may actually be a place of resistance and radical possibility, thus providing a viewpoint that those at the center are unable to see (hooks 150). From such a perspective, the narrator starts to perceive the power structures she condemns as having some complicity in her own person. Her metamorphosis is in line with the change in the village environment; she is torn between the old and the new, denial and acceptance. She needs to balance her Western background with her hereditary origins and realizes that her identity is torn apart.

This is demonstrated by the West African space in *Swing Time*, which demonstrates the intricacy of dislocated belonging in a globalized world. According to James Clifford, cultural identities are being determined more by traveling and translation than by rootedness, producing routes but not roots (Clifford 5). The process described by the narrator is an illustration of such a change because she has to work out the contradictions between her diasporic identity and the realities of the village. The novel implies that one cannot reclaim one's true belonging by returning to the past or by humanitarian intervention but must have a delicate sense of the forces of history and politics that are in play. Robert Young also creates one more argument that postcolonialism is a persistent process of power and knowledge negotiation in which the history of colonizing people still affects modern relationship (Young 45). Via the image of the village, Smith condemns the fact and face of celebrity activism as shallow and urges people to have a more profound reaction to the structural disparity that characterizes the relationship between the Global North and



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South. The ultimate departure of the narrator is not a solution but a continuous process of finding one way of living in these spaces of dislocation, in which identity, like the ecosystem, is a process in constant motion.

The Narrator's Journey as a Reflection of Psychological Alienation

The author uses the experience of the narrator in the West African village as a turning point that reflects Dellarobia's realization in *Flight Behavior*. At first, she perceives the journey in the context of Aimee's celebrity humanitarianism; however, the nature of the village provides her with an encounter with her own dislocated identity. According to Frantz Fanon, the colonial state establishes psychological disintegration in that the subject is always seen through the gaze of the other (Fanon 82). The narrator understands that her individual life is related to the crises of identity and privilege all over the world, saying, I felt like a shadow (Smith 15). This enlightenment is in line with the concept of diaspora space by Avtar Brah, where identity is built through the overlapping of various histories and places (Brah 157).

First, the narrator and Aimee are both unwise and in denial about what is going on in the village. The school project undertaken by Aimee was foisted without local consultation, similar to the denial of climate change in the community, where short-term comfort is prioritized at the expense of long-term sustainability. According to Ahmed, emotions also shape the surfaces of individual and collective bodies and define the borders between "us" and "them" in most cases (Ahmed, 2012, p. 10). The narrator notices Aimee's dismissal of the needs of the locals when she realizes that they were in the goddamn African continent! (Smith 315). This is the rejection of the precariousness of the local inhabitants and an unequal distribution, which Butler calls the differential allocation of grievability (Butler, 2015, p. 34). The narrator shifts to a state of doubt and acknowledges that her presence is also part of this imbalance.

The narrator is not an outsider or an insider but is defined by psychological alienation. According to Julia Kristeva, this condition entails being a stranger to oneself, in which the foreigner inhabits the subject (Kristeva 1). The narrator is in a liminal space, perceiving the tension between the village as perceived by Aimee and the reality of the village, yet does not identify with either. She notes, "I occupied a liminal position, neither fully insider nor outsider" (Smith 280). Her half-breed status adds to this alienation by attributing a so-called poetics of relation that is founded on the concept of opacity, as opposed to transparency, as proposed by Édouard Glissant (Glissant 190). She is unable to comprehend the village, as is the vice versa, leaving her in a suspended state of belonging.

The story comments on the fact that identity crisis, similar to climate change, is not a faraway problem, and it surrounds everyone, regardless of their status. The story of the narrator highlights the fact that psychological estrangement is a universal situation that is part of the post-colonial experience. Leaving, she accepts that identity is in a continuous state of movement, and she says that identity, as well as the ecosystem, is continuously in a state of flux (Smith 450). This interdependence implies that to protect the integrity of culture, a common vulnerability must be considered. The alienation of the narrator, therefore, serves as a satiric reflection of the greater human state in which belonging is always a negotiated act based on race, class, and geography (Brah 205). From this perspective, *Swing Time* demonstrates that psychological alienation is not a phenomenon with an individual essence but with a structural one, which requires a communal reaction to the crisis of identities that determines the future of the planet.

The Role of Knowledge and Postcolonial Equity

The role of scientific interpretation in *Swing Time* is represented by the character of Fernando Carrapichano, in Zadie Smith, which is similar to the role of other experts, such as Dr. Byron, in the stories about ecology. He attempts to decipher the demands of the village with numbers and logistics; however, in many instances, he collides with the instinctive, celebrity-oriented style of Aimee. Fern perceives the mismatch between the project's plans and local reality and notes that when it comes to school funds, no one was aware of the amount of money that had been transferred (Smith 285). This obscurity illustrates the difficulty in determining local needs without being integrated with external agents. Arturo Escobar believes that development projects have a tendency to introduce foreign models that do not acknowledge local realities, making complex social problems appear as technical ones that can only be solved by professionals (Escobar 45). The example of Fern's frustration with the microcredit scheme, when mothers



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conceal children to avoid debt collection, illustrates the failure of bureaucratic aid to align appropriately with lived experience (Smith 290). Local knowledge is crucial for tackling such complexities. Lamin and Hawa have a feeling that the village's social structure is not in need of external assistance. The example of Hawa choosing to marry into the Tablighi Jamaat, or even a localized negotiation of modernity and tradition that people outside this community perceive as retrogression, is an example of a local negotiation of modernity and tradition. Linda Tuhiwai Smith underlines that indigenous knowledge systems should be honoured and not supplanted by Western methods that tend to be universal (L. T. Smith 112). This combination of old knowledge and new analysis is essential to long-term intervention. Still, it is the first thing to be ignored by donors who want to see visible improvements instead of cultural nuances. This combination of old knowledge and new analysis is essential to long-term intervention. Still, it is the first thing to be ignored by donors who want to see visible improvements instead of cultural nuances.

Ecological equity deals with the disproportionate distribution of identity crises and economic shifts in marginalized communities. The village is a poor place, and the school project turns into a point of social inequality instead of a resolution. The collapse of the microcredit scheme illustrates that financial instruments can make people more vulnerable instead of mitigating it in cases where the context is disregarded. According to Rob Nixon, this is referred to as slow violence, in which, over time, environmental and economic degradation will disproportionately harm the poor, even if invisible to the world (Nixon 2). Poverty results in the children of the villagers being pulled out of school because the villagers failed to pay their loans, and the effect of economic pressure is directly reflected in the deprivation of education and a disadvantage in the long term. Environmental justice claims that the weak are the first to be affected by a crisis. The rural population in West Africa experiences environmental deterioration and economic changes without the safety of urban centers. According to James Ferguson, development often depoliticizes poverty and disregards structural inequalities by presenting them as technical problems (25). Aimee's celebrity humanitarianism circumvents these mechanisms and provides temporary solutions, but not solutions to the causes of village precarity. Her attention to the symbol of the school does not capture the politics of the school economy, as when the opening ceremony gives precedence to matters of spectacle over content (Smith 300). This divide is accentuated by the contrast between New York's city outlook and The Gambia's rural life.

The rural/urban gap highlights the conflict between the global mobility of Aimee and the immobility of the village in terms of poverty. Aimee perceives the project through the prism of potential and branding, whereas the villagers have to struggle with the issue of survival. According to Chakrabarty, historical difference means the recognition that not all societies of the world are subject to the same temporal logic of modernity or development (Chakrabarty 254). The narrator understands that Aimee lives in a bubble of eternal prosperity. In contrast, the village exists in a limited world where the problem of money makes things disappear, which is the bottle that covers more serious problems in the system (Smith 395). Ultimately, the equity demanded is to fill the epistemic gap between the knowledge of the benefactor and the reality of the recipient.

Liminality and the Future of Identity

West African space in *Swing Time* depicts the sophistication of dislocated belonging in a globalized world. The fact that the narrator's migration is interrupted by identity crises reminds us of the fragility of the planet, in which identity is as vulnerable as an ecosystem. The space is not a container, according to Edward Soja, but a social product that constructs human identity, implying that the liminal status of the narrator is shaped by the geopolitical forces surrounding her (Soja 54). Her process symbolizes the future of every species in a world where human activities are dominant, and the permeations of self and other are becoming more porous. The narrator can see that her existence in the village is not unbiased; she observes, "I was, literally, nowhere good for" (Smith 395), emphasizing that she has broken the local social ecology.

Such disturbance is an indication of the impact of colonialism on the fine-tuning of cycles, just as climate change puts seasonal cycles out of step. Neo-colonial aid is a warm climate, which requires adaptation or death. According to Derek Walcott, the colonial experience forms a rift in history that people are forced to tackle, a rift that usually splits them into fragments of self (Walcott 36). This is what the narrator feels when she is looking at the school project, and



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she sees how "the future according to him is just as fixed as the past" (Smith 390), an indication of stagnation due to external influence. Her appearance is a prophet of social change, forcing society to acknowledge that the power relationships have changed. The village is an intersection of conflicting identities, just as Doreen Massey suggests that space is an environment of multi-trajectories (Massey 9).

Emigration is a representation of a crossroads on the planet. The Earth is as stuck at a critical point in its identity path as butterflies are. The narrator is on this edge and admits that identity as an ecosystem is always in a state of flux (Smith 450). This liminality is structural and requires a group reaction, not an individual. According to Caren Kaplan, travel-related stories tend to expose the injustices of movement and facilitate a reassessment of who is able to move and why (Kaplan 12). The fact that the narrator finally leaves but does not reach a solution is an indication that he is continuously exploring these displaced spaces. Finally, the novel demands individual action. As kings cannot go on alone, humanity must collaborate to solve the problem of identity. Michelle Wright thinks that through ongoing negotiation and not fixed roots, a diasporic identity is constructed, and there should be shared responsibility (Wright 88). The narrator realizes that protecting cultural integrity requires consideration of shared vulnerability. She questions her own complicity and states, "I occupied a liminal position, neither fully insider nor outsider" (Smith 280). In this light, *Swing Time* explains that it is not only a personal but also a structural alienation and requires unity to the crisis of identity that defines the future of the planet. The process of healing the narrator becomes a metaphor for the necessity to create balance before it is too late, and both the landscape and the human soul will be damaged.

CONCLUSION

In Zadie Smith's *Swing Time*, the protagonist's departure to West Africa serves as a compelling metaphor for identity crisis and displacement. Considering the concept of spatial liminality, the novel raises the issues of mental instability, human displacement, and the necessity of scientific and social intervention. The new experience of the narrator depicts a larger ecological calculation that humanity must respond to: the relationship between human actions and the environment is fragile, and the future of cultural integrity, as the novel indicates, will depend on humanity's behavioral response to such identity crises. This paper examines how Smith's narrative connects the scientific, ecological, and social viewpoints of belonging and how the problem of belonging is complex; each individual and group should be responsible. West African space is brought in as a point of entry for the interconnection of the diasporic world and how changing environmental conditions destabilize the fragile equilibrium of identity.

In this light, the trip of the narrator is not only in its beauty and frailty of culture but also in its recollection of the great transformation occurring in our world. *Swing Time* offers a wrenching comment regarding the future of identity under the influence of neo-colonial disruption through the symbol of West African space and interrupted social cycles. Social imbalances, as the narrator alienates, are not accidental events but elements of a wider international problem that affects not only human but also non-human life. Ecological destruction and the loss of cultural biodiversity that endangers the well-being of the planet in the narrator's journey is now metaphorically a search for roots. Similar to the migration of the butterfly in ecological literature being an indication of environmental distress, the dislocation of the narrator is an indication of distress in the culture.

In this research paper, the focus is on how Smith uses the migration of the narrator to discuss the overall environmental issues of the novel and the need to identify and address the identity crises that define the future of the planet. Through knowledge of such disruptions, *Swing Time* challenges the reader to look at the long-term effects of inaction and the necessity of shared responsibility in ensuring a sustainable future for all living species and identities. The preservation of cultural integrity must consider a vulnerability that is common to everyone. Hence, the importance of identity as an ecosystem is under continuous transformation and needs careful management to avoid irreversible loss. Finally, the paper concludes that *Swing Time* needs to take a holistic approach to the concept of belonging, and it is the duty of humankind to protect the future of cultural integrity against the disruptive powers of globalization and displacement.





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RESEARCH ARTICLE

Ecofeminism and Environmental Ethics: A Natural Science Perspective on Ecology and Gender in Kavita Kane's *The Fisher Queen's Dynasty*

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ABSTRACT

The Fisher Queen's Dynasty, a novel written by Kavita Kane, will be the primary focus of this paper. The protagonist, Satyavati, is reimagined in the novel. This mythology describes Satyavati's rise from a poor fisherwoman to Hastinapur's brave queen. Her journey is told here. The image of water, rivers, and the Earth's ecosystem begins to explain ecology, gender, and sustainability. Image is a gateway. This study compares Kane's imaginary cosmos to India's river networks' ecological reality. The research will focus on water pollution, biodiversity loss, and environmental degradation. Ecofeminism and environmental science were used to analyse this study. The research uses official Indian environmental data from the Central Pollution Control Board (CPCB) and the National River Conservation Plan. It improves research accuracy. This method guarantees maximal research accuracy. Data shows a link between literary symbolism and India's aquatic ecosystem disasters. They correlated to generate this relationship. The collected data helped create this correlation. This study explains Satyavati's relationship to water supplies, representing patriarchal governance and anthropocentric socio-culture in the real world. Study was found to represent reality. This analysis shows large water bodies. Satyavati may be linked to many waterways. The study found that mythology actively promotes sustainable development and ethically humanizes environmental science. This was their conclusion. Based on their investigation, researchers concluded this. The researchers concluded this from their findings.

Keywords: Ecofeminism, Aquatic Ecology, Environmental Ethics, River Pollution, sustainability.





INTRODUCTION

By 2023, the Central Pollution Control Board expects over 80% of India's surface water bodies to be polluted, putting 13% of its aquatic species at risk. India is undergoing a major environmental disaster. Environmental studies show India's ecological equilibrium is nearing a tipping point. According to Lawrence Buell, "the environmental crisis is a crisis of the imagination". Indeed, India is nearing a major event. People have traditionally believed that the natural system will fail owing to their views of nature, resource consumption, and responsibility. Literature expressed this belief. Buell writes, "Literature has long served as an early warning system for environmental catastrophe". These difficulties have been happening for a long time, but scientific measures and policy studies only recently learned about them. Literature may raise environmental and ethical awareness through plot and symbolism. Literacy shows awareness. Ecofeminism connects environmental science and literary studies, making it beneficial. Ecofeminism links global women's oppression to environmental degradation. According to Gaard, ecofeminism links the subjection of women to nature. (The Gaud) The merchant hypothesis links these events to patriarchal and hierarchical organizations that promote power, control, and abuse. Ecofeminism faces scientific, ethical, and cultural challenges from environmental degradation (Plumwood). This enhances ecofeminism knowledge. They use culture, society, and the environment to their advantage. This paradigm lets academics study gender, power, and nature narratives (Gaard). Expanding the environmental discussion beyond facts enhances the profession. This feminist Mahabharata adaption by Kate Kane is called *The Fisher Queen's Dynasty*. Kavita Kane's status as a writer may facilitate the application of this ecofeminist technique. Satyavati, a resident of a fishing community, recounts her story. The protagonist of the book, Kane, values rivers, fish, and ecosystems significantly. Satyavati is influenced by natural rhythms that safeguard the environment. She possesses strength and empathy; nonetheless, her closeness to water renders her susceptible (Plumwood). Satyavati's affinity for water symbolizes her connection to nature. Kane demonstrates that nature influences individuals' objectives, aspirations, authority, and fortitude. Kane embodies nature. The narrative employs rivers, oceans, and fishing areas to illustrate the evolution of human ideals and their associated obstacles. Satyavati's ascension from fisherwoman to queen illustrates the transition of humanity from harmonious coexistence with nature to its domination and exploitation for profit. Humanity has evolved with time, as exemplified by Satyavati. Shiva states

REVIEW OF LITERATURE

In the course of this research, the novel *The Fisher Queen's Dynasty* written by Kavita Kane is analyzed to see whether or not it contains any ecofeminist components. This viewpoint is frequently disregarded in contemporary feminist reinterpretations of myth, and by doing so, this study explores a substantial research gap that has been left unexplored as a result of this oversight occurring. The ecofeminist concepts of Vandana Shiva and Carolyn Merchant are utilized in this study, which, in contrast to past research (Kumar, 2020; Sharma, 2022) that focuses on gender and power, makes a relationship between the enslavement of women and the exploitation of the environment. This connection is established by applying the principles of ecofeminism. Specifically, the focus of this investigation is on the connection that exists between the two. In the film *Staying Alive* (1988), directed by Shiva, and in the film *The Death of Nature* (1980), directed by Merchant, an instance of the domination of patriarchal capitalism over women and the environment is provided. The decade of the 1980s saw the publication of both of these masterpieces. According to Ghosh (2019) and Nayar (2002), this study places Kane's account within the body of knowledge that pertains to aquatic ecology. The Indian eco-critical discourse, which acts as a source of inspiration, is the source of inspiration for this work. Furthermore, it provides a framework that integrates the natural sciences and the humanities in order to promote sustainability through myth and narrative. This framework is offered by the initiative. As a transdisciplinary framework, this framework is being discussed. There is a connection that can be drawn between the water symbolism in the book and the empirical environmental data that pertains to the river systems in India. In this way, it is possible to accomplish the objective that was defined. This is an illustration of how



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literature may be used to translate ecological calamities into circumstances that can be understood on an ethical and emotional level.

Objectives

1. To apply ecofeminist theory in order to conduct an analysis of the ecological symbolism embedded throughout *The Fisher Queen's Dynasty*.
2. To determine whether or whether there is a correlation between the water and fertility depictions in literature and the scientific data on aquatic environments in India.
3. To suggest that retellings of mythical stories can be used as educational tools for improving ecological understanding and environmental consciousness.

METHODOLOGY

The methodology utilized in this investigation is a qualitative mixed-method approach, which combines scientific interpretation with textual content analysis.

Literary Component

One of the key sources that should be evaluated is Kavita Kane's *The Fisher Queen's Dynasty*, which was published in 2017. Environmental ethics, ecofeminism (Shiva, 1988), and deep ecology (Naess, 1973) are the three components that comprise the analytical framework. Ecofeminism was developed by Shiva in 1988. Some of the topics that are discussed in this work include the imagery of rivers, the symbolism of water, fertility, the pollution of the environment, and the exploitation of women differently.

Scientific Component

Secondary data resources include, among other things, information regarding the environment that is obtained from the Central Pollution Control Board (2023), the Ministry of Jal Shakti (2022), and the National River Conservation Plan (NRCP, 2021). • The following variables were investigated: biochemical oxygen demand (BOD), dissolved oxygen (DO), and river pollution indices for the Ganga and Godavari basins, which are rivers that are comparable to Satyavati's ecosystem. These rivers are located in India. These waterways can be found on the subcontinent of India. It is via the examination of the facts, which includes the assimilation of thematic findings, that the convergences between scientific ecology and literary imagination are brought to light.

ANALYSIS AND RESULTS**Water as a Feminine and Ecological Entity**

The fact that Satyavati was born to a fisherwoman and that her identity is intricately linked to the river is a powerful indication of the mother function of water that is present throughout the novel. Satyavati's identity is closely linked to the river. To supply sustenance, to give birth, and to cycle continuously are all functions that fall within this category. It is impossible to separate the personalities of Satyavati and the river because they are inextricably linked. According to the ecofeminist point of view, the consequences of patriarchal and anthropocentric policies and systems are seen to be present in both the bodies of women and the bodies of water. Readings that are derived from this point of view give the impression that this is the case. Kane's portrayal of the river as "a body that breathes, murmurs, and mourns" is a personification of aquatic ecology, and it is consistent with ecofeminist interpretations of the term. This imagery is a representation of the river's ability to breathe, murmur, and mourn. The Central Pollution Control Board (2023) has concluded that forty-six percent of the river sections in India that are being monitored have levels of contamination that are greater than the safe limits. This information was obtained from the river sections that are being under surveillance. The "tainted waters" that, in a symbolic sense, suffocate the globe that marked the beginning of Satyavati's existence immediately come to mind when one considers this metaphor. The evidence that demonstrates that this metaphor is correct comes from the scientific community as a whole.



**Radhika et al.,****Exploitation of Nature and the Female Body**

The government's commercialization of natural resources is reflected in Satyavati's diminishing level of autonomy as she travels from the river to the palace. This happens when she makes her journey from the river to the palace. Vandana Shiva's thesis, which states that the patriarchal system of capitalism objectifies both women and nature, is supported by this narrative, which is consistent with the thesis. This highlights how urbanization and industrialization exploit riverine systems for the goal of economic profit, hence generating disturbances to both water cycles and biodiversity. This is an example of how ecology illustrates how these two processes work together.

Restoration and Ecological Ethics

One of the topics that connects with ecological resilience is the author's contemplations on the cyclical nature of time and regeneration, which are presented in the final chapter of the book. The final reflection of Satyavati shows a return to equilibrium from an ethical position. Ethical relations with nature are grounded in balance, reciprocity, and restraint, says Plumwood. Rivers possess an inherent capacity for self-recovery when anthropogenic stress is reduced. This is akin to the scientific approaches utilized in river restoration programs (NRCP 2021) that lay a focus on an individual's capacity for self-purification and ecological recovery.

DISCUSSION

Kavita Kane's stunning environmental metaphor glorifies nature. A huge departure. This is very unusual. Environment is used to combine mythology and ecological guidance. Environment is a metaphor and reality in the story. Satyavati symbolizes fragile, sustaining water. Story makes Satyavati liminal. Nature is fragile when mistreated but robust and life-giving when revered. Her identity embodies ecofeminist power-nurture duality. Her identity is dual.

The development of Satyavati from fisherwoman to queen symbolizes human-nature connection. Change represents relationship evolution. She grew up with subsistence, interdependence, and ecological balance. As she grows to power, this connection becomes one of control and extraction, analogous to the historical move from human-nature alliances to anthropocentric exploitation. This happens when she develops power. Her success alters her. This may suggest a change from ecological balance to hierarchical domination than "human to human." This interpretation is supported by evidence. This is one journey view. This method mimics unbridled ambition and resource exploitation's environmental damage. Kane's account illustrates how literature predicts ecological facts before environmental science research confirms them. The Fisher Queen's Dynasty's beautiful story addresses ecological imbalance, resource exploitation, and environmental unfairness. Family history.

Mythology reinterpreted. After extensive research, recent scientific discoveries corroborate these patterns. Unlike scientific models, literature may predict and explain environmental disasters by capturing their emotional, ethical, and cultural dimensions. Literature forecasts and interprets. Literature may forecast and understand environmental calamities. Ecofeminism highlights patriarchal regimes' enslavement of women and nature. Recent ecofeminism has grown. Recent years have seen ecofeminism rise. Evidence and emotional, ethical, and spiritual links to the environment are emphasized in this movement. The environment affects all these qualities, according to movement. Ecofeminism integrates science and personal experience. Ecofeminism fights science denial. Sustainable solutions require cognitive awareness and ethical innovation, according to ecofeminism. Political ecofeminism. Satyavati's water, reproduction, and existence reliance is ecofeminist. Relational ethics, reciprocity, and care may increase ecological awareness. Ecofeminists say profit-driven, technocratic development has ignored women's intuition and daily knowledge of natural resources. Women's competence derives from natural resource contact. Kane's story revives epistemology. Satyavati is portrayed as a moral and ecological guru. Creative writing, indigenous epistemologies, and cultural narratives in environmental discourse are highlighted. A narrative analysis explains this. This strategy affects environmental ethics and sustainability education scientifically and pedagogically. These impacts are significant. Literary linkages foster ethical, scientific, and ecological awareness. The writing of Kane can.





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To promote sustainability, ecofeminist literature connects students and researchers emotionally and intellectually. This applies to sustainability specifically. Environmental disasters can be cultural, gendered, and ethical. Ecological justice. Kane's story shows how mythology and literature warn of environmental hazard. Ecological justice, human responsibility, and sustainable life are promoted. The story of Kane is interpreted. Discourse calls for data-driven environmental narratives. The tale says so. Historically, these stories have warned against exploiting women and the environment. The effects were explained.

CONCLUSION

In The Fisher Queen's Dynasty, Kavita Kane uses Indian literature's ecological consciousness to overcome mythical recounting. This is the situation in mythical recounting. This action is possible because of "mythical retelling". This would be impossible without this word. Aquatic ecology and feminine identity may help explain the relationship between human ethics and environmental preservation in the human community. This understanding is achieved by combining the two areas. When viewed in light of scientific facts about biodiversity loss and river pollution, the book becomes a narrative mirror of the ecological reality. Thinking about the book changes it. This transformation occurs when the book and discoveries are related. The switchover occurs here. This reading presents this reading from a variety of fields to show that literature can bridge environmental science and public ecological consciousness and help academic institutions and society achieve environmentally sustainable practices. Reading will proceed as follows. This reading will be interpreted as follows. This reading is here because it was offered. This presence prompted this reading.

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RESEARCH ARTICLE

The Drought Within: Eco-Psychoanalysis and Magical Realism in Tayo's Trauma in Leslie Marmon Silko's *Ceremony*

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ABSTRACT

The *Ceremony* by Leslie Marmon Silko is related to the psychological destruction of a World War II veteran named Tayo and the destruction of the ecology on the Laguna Pueblo reservation. This paper employs an eco-psychological approach to examine how Tayo's PTSD is an internal drought, reflecting the lifelessness of the soil outside. With the help of magic realism, Silko blurs the boundary between the surrounding environment and psyche, implying that the key to the problem is to reconfigure the self and the environment in the way they should be. It interchangeably mixes Pueblo mythology, such as the narration of think-woman, with modern theory of trauma, and the drought is not merely meteorological but somatic, an expression of grief of the people and individuals. This is because it takes Tayo on a journey of white smoke of dissociation to holistic healing; The *Ceremony* is a vital psychosomatic healing agent introduced by people like Betonie. In the analysis of the most significant motifs, rain, jungle fever, and the witchery poem are the most significant ones. This paper contends that magical realist techniques employed by Silko justify indigenous epistemologies, whereby mental health cannot be discussed without mentioning the ecological balance. Eventually, the repetition of the rain can be seen as the successful beginning of Tayo's inner rite of passage and demonstrates that human consciousness and the living earth are inseparable, and the only way to survive is to acknowledge this fact. The text redefines the concept of healing as a process of association between a human and a non-human being in the novel.

Keywords: Eco-psychoanalysis, Magical Realism, Trauma, Drought, Indigenous Epistemology, Healing.



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INTRODUCTION

The nexus between ecological crisis and psychological trauma is becoming a more acknowledged concept in contemporary discourse. Post-traumatic stress disorder (PTSD) is no longer perceived as an issue of inner malady only, but one that is reflected in the destruction of the environment. Leslie Marmon Silko published *Ceremony* in 1977, and it was reissued in 2006, which is a seminal work on this intersection. The novel revolves around Tayo, a mixed-heritage World War II veteran, who returns to his home filled with battle fatigue. The narrative meaning of Silko is its denial of the separation between the land and the psyche of human beings and the view that the only way to heal is through integrating the land in its entirety. The internal fragmentation of Tayo is physical, as he needs to heal the feminine and communal traditions to rebalance (Allen 45). According to this ontological model, material reality is directly affected by human thinking, which is one of the major tenets of eco-psychoanalysis.

The issue statement touches on the ways in which human-related factors, namely war and colonialism, interfere with the psyche as well as the ecosystem. Tayo experiences the effects of his trauma physically in the form of a drought; he believes that he prayed for the rain to stop, and in year six, there was no rain. This relationship implies that natural barrenness is caused by human violence. Their displacement of the veterans can be seen when Tayo sleeps in the hospital like the “white smoke,” which is empty and invisible. An invisible tongue creates his speech in treatment, and this depicts the dissociation that is experienced by Cathy Caruth in *Unclaimed Experience* (Caruth 151). This separation is worsening with colonialism; Emo expresses the anger, screaming that they took the land, and all. This kind of dispossession forms its own psychological scar equivalent to the crippled terrain, a dynamic that, according to Bill Ashcroft, defines post-colonial literatures (Ashcroft 22).

This study states that drought is a metaphor for psychological trauma; hence, recovery will involve eco-psychoanalytic treatment. Traditional medicine is failing because the world is delicate and requires rituals that acknowledge interconnectedness. The text states that without stories, the community will be powerless against the forces that are moving towards destruction. Jace Weaver stresses the fact that Native survival and revival depend on storytelling (Weaver 112). Healing entails the integration of the self and the natural world, going beyond war dissociation. Eco-psychoanalysis is the paradigm through which one can interpret how internal grief can be externalized in the form of climatic changes, which means that a solution must be offered to both the mind and the environment simultaneously. According to Greg Garrard, ecocriticism should examine such material links between the text and the earth (Garrard 89). Tayo had to understand that he had to remain busy and motionless to survive the fragmentation.

In this paper, I will be working in three parts. First, it breaks down the symbol of drought, discussing how the dryness within Tayo is mirrored in the dryness of the outside world. According to Robert Nelson, landscape is a visionary power of Native fiction (Nelson 67). Second, it examines *Myth* and *Ceremony*, which attempts to determine how the new rituals that Betonie undergoes through the integration of modernity and tradition are used to heal the psyche. According to Betonie, the hogan pre-dates the white people and was constructed many years ago. He focuses on adaptation, which declares that things that do not move and develop are dead things. Linda Krumholz recommends that the books and the healing process are intertwined in the work of Silko (Krumholz 234). Lastly, it deals with Colonialism and Equity, where the extraction of resources represents the endgame of the witchery. Betonie tells him that the people have to do it. Kenneth Roemer emphasizes the ethnohistorical background of such opposition (Roemer 105). The conclusion reiterates the statement that the only way to survive is by recognizing that the human consciousness and the living earth are interconnected. According to Ts'eh, you can always keep remembering what you saw, and then nothing is lost. Finally, *Ceremony* reinvented the meaning of the healing process as a way of human-nonhuman relationship and gave a map of ecological and mental strength in a disjointed world. The paper highlights the fact that rituals have to evolve to be resilient so that they can surmount the stagnant annihilation of witchery. According to Charles Silet, this shifting narrative form is supported by Silko in his collection





of essays (Silet 78). Louis Owens also contributes that mixed-blood identities manoeuvre these fates by way of such renewal (Owens 134). The novel ends with the prayer of balance: Sunrise, receive this offering, Sunrise.

Research Focus

The central objective of this research is to examine how *the Ceremony* is indicative of eco-psychosocial trauma discourses by being symbolically represented as drought, magical realism, and the implications of each to both natural ecosystems and humans. The text by Silko assumes that it is impossible to disconnect psychological fragmentation from the devastation of the environment. This paper explores the intersection of post-traumatic stress disorder in Tayo and the barren land of the reservation, suggesting that the solution to the condition of the self is to reconnect with the land. Through the lens of the interaction between indigenous mythology and modern trauma theory, this paper will consider the role of human-made forces, such as war, in destabilizing both the psyche and the ecosystem. The method confirms native epistemologies in which the aspect of mental health is closely interconnected with the ecological balance. The research questions that have been adopted at the core of this analysis are as follows:

1. How does drought (and, in this case, the internal and external deprivation of rain) represent the larger psychological consequences of trauma as employed by Silko?
2. How does the novel point to magical realism as a way to reveal the violation of natural cycles and ecological balance?
3. How does the human experience depicted in *Ceremony* reflect the ecological and environmental catastrophes represented in the barrenness of the land?

In this inquiry, this paper will contribute to the reasons that there is a desperate need to provide a holistic approach to the trauma crisis, which will lead to staying alive by recognizing the interdependence between the living earth and human consciousness.

Eco-Psychoanalytic Themes in *Ceremony*

Ceremony by Leslie Marmon Silko creates an ontological structural system in which human thought affects material reality, as seen when "Thought-Woman, the spider, named things and as she named them they appeared" (Silko 1). This connection is the basis of the eco-psychoanalytic approach to the trauma story of Tayo, in which the psyche and the environment are constitutive as a key idea in Indigenous worldviews, made up of the spiritual and material inseparable (Allen 45). When Tayo returns after World War II, he is experiencing battle fatigue, which is a state of psychological disintegration in the form of physical illness (Silko 11). This expression concurs with the theory of trauma, in which the unresolved experience of violence haunts the victim, who experiences somatic symptoms (Caruth 151). The novel does not emancipate this psyche from the land and assumes that it is healed in a wholesome manner (Silko 12). The inner disintegration of Tayo is visceral; "He could feel it inside his skull—the tension of little threads being pulled..." (Silko 12). According to this system of ontology, material reality is directly affected by human thought, which is one of the main principles of eco-psychoanalysis and ecocritical analysis (Garrard 89).

The problem statement is concerned with human-induced variables, including war and colonialism, which disrupt the psyche and ecosystem. Tayo's trauma is expressed physically; he thinks, "So he had prayed the rain away, and for the sixth year it was dry" (Silko 13). This implies that human violence is the cause of natural sterility. The displacement of the veterans is also seen when Tayo appears in the form of drifting white smoke in the hospital, being unseen and empty (Silko 14). During his treatment, "He was invisible. His words are formed with an invisible tongue..." (Silko 16). Colonialism leads to this fracture; the land suffers with the veteran. The text asserts, "You don't have anything if you don't have the stories" (Silko 2). The community is powerless to stop the forces of destruction without a narrative. This indicates the role of the landscape in Native fiction, where identity is in place and narrative (Owens 134).





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This paper argues that the drought is a representation of psychological trauma; therefore, it requires eco-psychoanalytic therapy. Conventional medicine fails because of the following reasons. "This world is fragile" (Silko 35), demanding rituals that recognize interrelatedness. The process entails restoring the self in the world of nature and dissociating from war (Silko 12). Tayo must realize, "He had to keep busy; he had to keep moving..." (Silko 12). This convergence is manifested in the hallucination of Josiah in the jungle. In the film, Tayo perceives his uncle as part of the enemy soldiers, and it blends home and war. He saw his uncle fall, and he identified him as Josiah, and he continued shaking him by the shoulders and telling him to quit crying and by the time Rocky started shaking him, it was still Josiah on the ground (Silko 11). This vision links the death of the land to the death of men during the war.

This constant rain was as detested to Tayo as the jungle green rain, rather than the miles of marching or the Japanese grenade that was murdering Rocky (Silko 13). The ecological crisis is seen as internal grief. Finally, *Ceremony* reinvents healing as a social activity. The rain symbolizes the achievement of Tayo's internal Ceremony. As Ts'eh notes, "As long as you remember what you have seen, then nothing is gone" (Silko 239). The novel ends with a prayer of moderation: "Sunrise, accept this offering, Sunrise" (Silko 243). The only way to survive is to realize the unity of the human mind and the living earth. The story uses Pueblo mythology to interact with contemporary trauma theory, and the drought is not only a meteorological phenomenon but also a somatic manifestation of the grief of individuals and the community. The fact that Taylor (Tayo) goes through the white smoke of dissociation to complete recovery supports *Ceremony* as a psychospiritual treatment (Krumholz 234). Using the analysis of major motifs, it is suggested in this paper that Silko's magical realist techniques provide an authentication of indigenous epistemologies in which the mental health of people is deeply interconnected with an ecological balance. Therefore, the text redefines the process of healing as a non-human to human relationship in the novel.

The Drought as a Symbol of Trauma

Silko supposes that psychological trauma does not occur in an internal space but is a phenomenon that discharges in the surrounding world. The drought, which is the main theme in the novel, is a literal expression of the post-traumatic stress that Tayo faces. When Tayo returns from the war, he faces a landscape that reflects his inner barrenness. The story mentions explicitly, "So he had prayed the rain away, and for the sixth year it was dry" (Silko 13). This relationship indicates that natural barrenness cannot be triggered by any means other than human violence. The guilt that Tayo shows towards the death of his cousin Rocky and his survival changes into a conviction that he is the only person who can stop life. This interrelates to Indigenous worldviews of the environment and psyche as constitutive of each other (Allen 45). The disturbed rain patterns of the land can be viewed as a metaphor for mental imbalances, as the mind of the veteran is no longer able to relax. And this drought within prevents growth, as the drought outside prevents the corn from rising. The six years of dryness are the years of war, not the years that go on by loss instead of harvest.

Natural systems are weak, comparable to the fragility of a veteran's mind. Old man Ku'oosh warns Tayo, "But you know, grandson, this world is fragile" (Silko 35). This weakness extends to Tayo's mind, termed as battle fatigue, in which mental disintegration is manifested in physical illness (Silko 11). The internal fragmentation of Tayo is corporeal: "He could feel it inside his skull—the tension of little threads being pulled..." (Silko 12). It is this undisowned experience that haunts the survivor with somatic symptoms, a fundamental principle of trauma theory (Caruth 151). This tension is similar to the drought pressurizing the land, which is pressurizing his psyche. This tension was reflected in the environment; the mule had become very thin, and the goat and kid were forced to walk more miles every day to find weeds or withered bushes to graze on (Silko 13). The pain inflicted on the animals is the trauma of the community. The cycle of the blind mule around the dry windmill is a symbol of stagnation in people who are no longer connected with their life source. According to ecocritical analysis, these landscapes provide the material effects of human disturbance (Garrard 89).

Another symptom reflected in the landscape is dissociation. Tayo writes about his position in the hospital: "For a long time he had been white smoke" (Silko 14). Such invisibility is comparable to the dry wells and infertile hills, where there is no life. The white smoke never thought of itself; it was dissolving into the white world of bed sheets



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and walls. During his treatment, "He was invisible. His words are formed with an invisible tongue..." (Silko 16). The famine makes the land infertile and silent. They are left in the hands of their narrative, which is shattered, and the mind is shattered. The text asserts, "You don't have anything if you don't have the stories" (Silko 2). The rain is brought by stories, and in the absence of that, the drought continues. The silence of the veterans is a factor that adds to the dryness because the silence is caused by the unspoken trauma that the veterans go through, and this prevents the water of healing from flowing. The hospital tries to treat him with medicine, but the land is the only one that can cure the drought of the soul.

This interconnectedness must be accepted in healing. The process that Tayo is going through entails a transition between the white smoke of dissociation and the recovery of the whole body. He is aware that memory sustains life: "As long as you remember what you have seen, then nothing is gone" (Silko 239). The miracle of rainfall is an indication of the achievement of Tayo's internal *Ceremony*. The last prayer in the novel is a prayer to balance: "Sunrise, accept this offering, Sunrise" (Silko 243). Finally, the drought is a symbol of the effects of being out of touch, and rain is a symbol of establishing harmonious contact between human consciousness and the living earth. In the novel, the text redefines the concept of healing as an act of relationship between human and non-human beings. Reading and healing are inseparable processes in Silko's work, which necessitate the combination of myth and reality (Krumholz 234). Tayo passes the drought and, by doing so, demonstrates that the mind and land are one. This ritual is used to re-establish the balance that led to the dryness caused by witchcraft.

The Role of Ceremony and Myth in Understanding Trauma

In *Ceremony*, Leslie Marmon Silko places Indigenous knowledge systems as important healing processes on par with scientific investigation. The novel claims that the story is medicine, as the old man says, "You don't have anything if you don't have the stories" (Silko 2). This ontological structure starts with the poem of creation: "Thought-Woman, the spider, named things and as she named them they appeared" (Silko 1). Here, storytelling functions as therapy, reconstructing the fractured psyche through myth. An example of this indigenous adaptive science is the medicine man Betonie in his home: "This hogan was here first. Built long before the white people ever came" (Silko 125). His ritual area combines contemporary rubbish with archaic ritual, full of "bundles of newspapers... telephone books... Santa Fe Railroad calendars" (Silko 126). This synthesis shows that rituals need to change in order to endure the colonial dislocation.

Betonie tells Tayo that he must not stand still: "Things which don't shift and grow are dead things" (Silko 126). He also focuses on general responsibility to heal: "The people must do it. You must do it" (Silko 126). This flexibility is important since the trauma that the community is experiencing is structural, which is based on witchery. The witchery poem demonstrates the origin of such destruction of the world: "It's already turned loose. It's already coming" (Silko 132). This power causes nature to be alien to humanity, which makes it certain that "The world is a dead thing for them, the trees and rivers are not alive" (Silko 133). The witchery is based on stagnant devastation, and the indigenous *Ceremony* is based on active development. The healing of Tayo entails his becoming aware of this pattern through the sand painting and star maps. He has to realize that the destruction can be avoided, provided that the story is continued. The ritual ends in a reconciliation of the oneness between human and non-human. Tayo finishes the ritual with the recognition of the dawn: "Sunrise, accept this offering, Sunrise" (Silko 243). Finally, according to Silko, the struggle to survive is based on the recognition of the mutuality of human awareness and the life of the Earth. The healing process is redefined as a relationship between human and non-human in the novel. Tayo can survive drought, thereby demonstrating that the mind and land are interconnected. The ritual reinstates the balance, and the dryness is ended with witchery. As Ts'eh notes, "As long as you remember what you have seen, then nothing is gone" (Silko 239). Memory keeps being alive in opposition to forgetting the trauma. The story of the Gambler demonstrates the theft and the necessity to restore the stolen clouds. Sun Man tells the clouds, "Come home, children, come home" (Silko 225). This reappearance means ecological and psychological recovery.





Colonialism, Veterans, and Ecological Equity

The *Ceremony* by Silko is a critique of the collision between colonialism and environmental destruction and how Indigenous veterans are the most affected by ecological injustice, a trend that Louis Owens observes is key to the mixed-blood experience of American Indian novels (Owens 134). The novel suggests that survival lies in narrative because "you don't have anything if you don't have the stories" (Silko 2). Such dependence on narratives supports the point that Jace Weaver makes that community survival depends upon the reenactment of native stories in the face of loss (Weaver 112). The trauma that Tayo suffers is connected with the land; "so he had prayed the rain away, and for the sixth year it was dry" (Silko 13). This drought also targets the reservation disproportionately, as the white ranchers exploit the mountains. "The white ranchers called this place North To p..." (Silko 229), sealing off areas that were traditionally Indigenous with a wolf-proof fence to keep Indians away. Shouting, this violence, is internalized by veterans such as Emo. "They took our land, they took everything!" (Silko 86). Destruction is their coping system; "cash from disability checks earned with shrapnel in the neck..." fuels their drinking (Silko 120).

The Witchery poem discloses the extent of this exploitation throughout the world. It prophesies the consumption of uranium: "They will lay the final pattern with these rocks... and explode everything" (Silko 135). This prophecy comes to pass in the uranium mine in Laguna. "Cebolleta people salvaged lumber... but they had no use for the barbed wire..." after the mine closed (Silko 240). The atomic bomb links world war in nations to the misery at home; "Trinity Site, where they exploded the first atomic bomb..." is only miles away (Silko 246). The veterans fall prey to this witchery. The cost of death is as portrayed by the death of Harley: "Harley's body hanging from the fence..." (Silko 250).

The ecological equity requires the acknowledgment of the victimized; drought and war are against the marginalized. However, it can be cured through moderation. "Sunrise, accept this offering, Sunrise" (Silko 243). In the novel, colonial exploitation is portrayed as breaking natural cycles, and Indigenous knowledge can put them back on track, which is connected to the claim by Paula Gunn Allen that restoring tribal worldviews is the key to recovery (Allen 45). The case of the veterans demonstrates that social justice cannot be discussed without environmental justice as well as social justice. The violence is still remembered in the land. The individuals cannot forget the tales. The wickedness relies upon forgetting. The *Ceremony* of Tayo breaks the cycle. The mine is still an eyesore and represents permanent removal. Only when Tayo defies the story of the witchery does the drought stop. The rain returns to the valley.

The pendulum swings towards the individuals. The ritualism restores equity. The narratives outlived death. The land endures mining. The individuals do not give up as a result of the war. The linkage between the uranium and the drought is obvious. The destroyers make money, and the people are starving. The soldiers lose their lives to a country that does not even accept them. The *Ceremony* mends the division between man and land. The earth is responsive to prayer. The rain falls on the mesas. The narrative moves on to trauma. Memory is a way to recover the share of equity. The land is alive again. The individuals are powerful as a team. The witchery is unsuccessful in the end. The world returns to balance.

Restoring Balance: Healing and Interconnectedness

The *Ceremony* resolution is a symbol of regaining balance between the psyche of a human being and the natural world, which is the final stage of the eco-psychoanalytic journey of Tayo. Upon completing the *Ceremony*, the *Ceremony* itself indicates that Tayo has completed the *Ceremony* by discovering the spotted cattle, which symbolize the rediscovery of native heritage against colonial theft. He discovers that the scheme of the witchery is finished at the uranium mine and that "human beings were one clan again, united by the fate the destroyers planned for all of them" (Silko 246). This acknowledgment enables him to discontinue the grip of the witchery without further spreading violence. Tayo does not destroy the circle of destruction by refusing to kill Emo, who knows that failing to do so will make the schemes of the destroyers fruitless. The sensation overwhelms him as he walks slowly down to the shaft of the mine: "the pattern of the *Ceremony* was completed there" (Silko 245). The presence of the spotted cattle proves that Josiah's and Tayo's dedication to the land was successful.



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Psychological healing is reflected externally in the rain returning, which confirms the connection between internal conditions and external environments. The drought was first occasioned by Tayo, where trauma "he had prayed the rain away, and for the sixth year it was dry," dies when he becomes part of the land again (Silko 13). The rain symbolizes the end of inner struggle and the cleansing of the conscience. Ts'eh confirms this relationship towards the end and says, "As long as you remember what you have seen, then nothing is gone" (Silko 239). Memory keeps life alive in opposition to the loss of trauma and colonial memory loss. The ground reacts to the ritual; the clouds come together in the process of completing Tayo's duty. According to this eco-psychoanalytic resolution, the ecological balance is a condition that predetermines mental health. The sterile land became a somber manifestation of sorrow, which was cured with the help of rites. The mountain could not be lost in their possession, since this form of property was in them and thus could not fade away with a change of ownership (Silko 245).

The interrelation between human consciousness and the living earth is completed in the final scene, which resembles the beginning of the novel. Tayo offers a prayer to the dawn: "Sunrise, accept this offering, Sunrise" (Silko 243). This ritual restores the sun's place as a living being, not a celestial one, thus restoring reciprocity. The story begins with the tale of Thought-Woman, in which "whatever she thinks about appears," constituting that narrative forms reality (Silko 1). At the conclusion, Tayo turns into a narrator, which means that the *Ceremony* is perpetuated outside the text. Betonie's warning that "things that do not shift and grow are dead things" leads to this adaptation to modern menaces (Silko 126). The ritual must adapt to the witchcraft of the atomic era.

The future implications are based on the salvation of the story and the instability of the world. As a reminder to Tayo at the beginning, Old Ku'oosh tells him that this world is delicate and that it needs care and attention at all times (Silko 35). The community lacks stories to hold them. "You don't have anything if you don't have the stories" (Silko 2). The novel is not a closed circle but rather a continuation of the gift to the natural world. The spotted cattle are able to survive as Tayo overcame the logic of exploitation of the destroyers. The balance between human action and the natural law is restored, which is why the rain falls. According to Silko, the only thing that helps one to survive is to recognize these links. The witchery poem warns that "It's already turned loose. It's already coming," however, the ritual balances this annihilation by creation (Silko 132). Finally, the process of healing is a relationship between humans and non-humans. Tayo's experience helps to realize that the restoration of the self is impossible without the restoration of the land. The future is vague and depends on the continuation of this harmony. The *Ceremony* is never actually completed but evolves with every generation, which will ensure that the fifth world will survive despite the powers of death.

CONCLUSION

Finally, *Ceremony* by Leslie Marmon Silko reinvented the process of healing as a type of relationship between human and non-human beings. In the novel, psychological recovery cannot occur outside the context of the natural world. The story of Tayo's recovery of self proves that the recovery of land is irrevocably connected to the recovery of self. Silko breaks the boundaries between the psyche and environment, questioning the ideas of Western approaches to individualized therapy by implying that the act of reciprocity with the living earth is the way to become well. The theorizing shows that the drought is a somatic manifestation of trauma, in which internal sterility is a reflection of ecological destruction.

On the other hand, the *Ceremony* is a process of integration, which involves the combination of myth, memory, and landscape in a bid to heal war-induced fragmentation. Witchery is symbolic of the power of detachment, which encourages devastation and separation from the natural orders. The *Ceremony* that Tayo completes interrupts this cycle, and the return of rain symbolizes the success of his internal healing. These results support the urgency of interdisciplinary responses to trauma crises that are both psychological and ecological in nature. Modern methods of mental health do not always take into account the environmental context of human suffering. Silko argues that the only way to resolve a problem such as PTSD is to accept that human consciousness is intertwined with the living





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earth. The solution is to realize that when the land is destroyed, the human spirit is destroyed. Lastly, literature is important in leading the world towards psychological stability and cultural sustainability. *Ceremony* provides a guide to finding paths in the proliferation of contemporary trauma using indigenous epistemology. These texts promote a more profound concept of resilience by circumscribing narratives that uphold the association between individuals and location. Ultimately, the novel reminds us that the only way to survive is to uphold the balance between human actions and the laws of nature so that stories can persist even after trauma.

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RESEARCH ARTICLE

A Feminist Reinterpretation of Sita in Chitra Banerjee Divakaruni's The Forest of Enchantments

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ABSTRACT

This volume addresses wider problems of how Myths are reinterpreted to contest societal conventions and regain peripheral voices. This chapter situates Divakaruni's oeuvre as an essential intervention in gendered mythological discourse. The conventional portrayal of Sita has always been that of a dedicated lady whose existence revolved around her husband, Lord Ram. This perspective has influenced our civilisation over the millennia, resulting in individuals must observe Hindu mythology as a foundation for dharma, masculinity, and heroism. Chitra Banerjee Divakaruni's innovative reinterpretation of the Hindu epic Ramayana offers an overlooked perspective on Sita, providing a feminist analysis of the myth. Divakaruni, a diasporic writer of Indian origin, has integrated the notion of myth with contemporary elements, particularly feminism, in a really impactful manner. Traditional narratives of the Ramayana often highlight Ram's valour; yet, Divakaruni modifies this perspective to emphasise Sita, presenting her as an independent, intelligent, and emotionally resilient person instead of a compliant, dutiful partner. In doing so, the novel reconfigures the myth to confront the issues with gender roles, patriarchal frameworks and women's rights. The narrative has been addressed by mythology. Lord Ram and his wife Sita in a patriarchal context, where she needed to demonstrate her innocence by leaping into the flames. Individuals have accepted this rendition of the epic without attempting to explore the underlying existence of Sita. Divakaruni portrays Sita's character audaciously. Providing her with a personal narrative that questions the prevailing myth. Myths possess a profound



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influence on societies, contributing to their dynamic formation while instilling diverse values such as bravery and love, valour, among other qualities. Myths often create societal norms, particularly with gender roles and familial dynamics. Figures, for instance, Sita from the Ramayana is shown as an archetype of femininity, promoting conventional ideals of feminine loyalty, compliance and altruism. Divakaruni composes a work that not only honours the past while inspiring a reimagined future for the representation of women in literature and other domains.

Keywords: Ramayana, Sita, Feminist reinterpretation, Mythology, Culture, Resilient Woman

INTRODUCTION

As archives of moral principles and sociopolitical beliefs, mythological stories have had a significant impact on Indian society's cultural values and social standards. The Ramayana, which is credited to Valmiki (c. 5th century BCE), is a classic epic that has had a significant impact on gender roles, dharma, and moral principles for millennia. Its main female character, Sita, is traditionally depicted as the archetypal pativrata, representing selflessness, obedience, patience (titiksha), and unflinching devotion (bhakti). Despite their traditional veneration, these values have been sharply criticized by feminists for upholding patriarchal systems that restrict women's independence, agency, and uniqueness (Niranjana; Thadani). A thriving surge of counter-narratives has surfaced in recent decades, in which modern writers challenge established hegemonies by subverting canonical texts from subaltern perspectives and elevating underrepresented voices. According to Rich's (1972) theory of "re-vision," this feminist mythic revisionism refracts tradition through the prism of gender justice. The work of Chitra Banerjee Divakaruni This approach is demonstrated in *The Forest of Enchantments* (2019), which presents a polyphonic retelling of the Ramayana from Sita's point of view. Divakaruni frees Sita from mute iconicity by giving her narrative authority, allowing her to reclaim subjectivity: "I had learned early that a woman's life is a tapestry woven from the threads of silences" (45).

Sita is reimagined by Divakaruni as a complex, self-reflective protagonist who struggles with her path from her idyllic Mithila upbringing to the arduous vanavas, Ravana's kidnapping, and the controversial agnipariksha. Her emotional strength, astute intelligence, and unwavering perseverance in the face of adversity are highlighted throughout the book. Divakaruni's version of Valmiki's Sita, who remains a symbol of *streedharma*, eschews the submissive archetype in favor of a woman who questions social norms and affirms her dignity: "I am not a prize to be won or lost" (156). "Is love a chain that binds, or wings that free?" Sita asks as she investigates the ontology of marriages. (312)—and develops sympathetic bonds with characters such as Surpanakha ("We are all exiles in our own ways, sisters in suffering") and the animistic beings of the forest ("You have taught me to root deep, unyielding").

In addition to humanizing Sita, this reworking vigorously questions patriarchal assumptions found in conventional Ramayana interpretations, such as the sanctification of gendered servitude and the exclusion of female interiority. *The Forest of Enchantments* stimulates modern feminist conversation by elevating a tapestry of female epistemologies, including Sita, Mandodari, Tara, and Kaikeyi. As Sita declares, "In our stories, we find the strength to rewrite the endings" (234), it redefines legendary womanhood from selfless simulacra to independent agents. Divakaruni's book connects epic antiquity with contemporary gender activism within postcolonial and Dalit feminist contributions (such as Volga's *The Liberation of Sita*), promoting critical discussions on consent, ecological kinship, and narrative sovereignty in Indian literary studies.



**Vijayavalli and Suriyanarayanan****Dynamic Nature of the Ramayana**

The literature on reinterpretations of the Ramayana emphasizes that the epic is not a static, unchanging text but rather a dynamic, contested place. The "multivocal nature of the Ramayana" is highlighted in Paula Richman's groundbreaking book *Many Ramayanas: The Diversity of a Narrative Tradition in South Asia*, which shows how various, occasionally antagonistic, versions of the story are produced by regional, historical, and ideological contexts. Character, event, and meaning are continuously reshaped, as Richman points out that "the appropriation of the story by a multiplicity of groups meant a multiplicity of versions through which the social aspirations and ideological concerns of each group were articulated." Instead of viewing later feminist and subaltern retellings as singular deviations, such work creates a critical framework for comprehending them as a part of a larger tradition of re-interpretive engagement.

Women's Retellings in Oral Traditions

Building on this understanding of multiplicity, Nabaneeta Dev Sen's seminal work "When Women Retell the Ramayana" explores how women recast the epic to emphasize Sita's feelings and commonplace experiences, especially in oral and folk traditions. According to Dev Sen, women's songs and stories "focus on different elements of the story, like Sita's experiences," including marriage, pregnancy, separation, and abandonment, whereas canonical versions typically favor a male heroic stance. By emphasizing household suffering and affective work, these alternative narratives—which are frequently passed down through lullabies and ritual songs in Bangladesh and India—unsettle androcentric conceptions and create room for a sympathetic, gendered reading of Sita. The Ramayana becomes "a dynamic site of cultural renewal, symbolic inversion, and feminine re-creation" as a result of these women's retellings, according to later critics.

Volga's Radical Feminist Reinterpretation

Volga's *The Liberation of Sita*, originally written in Telugu, presents a radical reinterpretation of Sita's journey as one toward self-discovery and ideological freedom from the patriarchy centered around Rama. Through her interactions with women like Ahalya, Surpanakha, Renuka, and Urmila, Sita develops a critique of institutions such as marriage, caste, and war, ultimately realizing that "each of these trials is meant to liberate you from Rama... to secure you for yourself." Critics highlight that Volga's work emphasizes "agency as an integral aspect of sisterhood," employing rich symbolism to illustrate that liberation is both a personal and shared experience, with Sita's metaphorical freedom representing a wider feminist reclamation of previously silenced voices. Consequently, the text demonstrates how mythology can be used to confront objectification, standards of beauty, and the glorification of suffering.

Divakaruni's Narrative Innovation

In modern Indian English literature, Chitra Banerjee Divakaruni's *The Forest of Enchantments* continues and expands the tradition of feminist retelling. Similar to Volga and the women highlighted by Dev Sen, Divakaruni repositions Sita at the center of the narrative, but she achieves this by employing a consistent first-person novelistic style that emphasizes inner thoughts, emotions, and moral consideration. The novel grants Sita the power of narrative as she describes her journey from Mithila to her ultimate return to the earth, thus transforming her from merely a symbol into a self-aware individual capable of questioning, resisting, and reinterpreting her situation. While some critiques recognize the book as a "mythological reinterpretation" that engages in the feminine recreation of Sita, there is a need for more in-depth analysis of its particular narrative techniques—elements such as focalization, intertextual allusion, and the development of female solidarity, along with their wider feminist implications, are still relatively underexplored in current scholarship.

Addressing the Scholarly Gap

This gap, especially the absence of detailed analyses that connect *The Forest of Enchantments* with Richman's multivocal approach, Dev Sen's exploration of women's retellings, and Volga's radical interpretation of Sita, represents a notable deficiency. To address this shortcoming, the current study provides a comprehensive analysis of



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Divakaruni's novel to clarify how its stylistic choices and thematic elements contribute to, complicate, and enhance existing feminist discussions surrounding Ramayana traditions within South Asian literary contexts.

Scholarly Gap in Narrative Analysis

While existing scholarship explores feminist adaptations of mythological stories—like those by Richman, Dev Sen, and Volga—there is a lack of focused research that specifically analyzes the narrative strategies employed by Chitra Banerjee Divakaruni in *The Forest of Enchantments* to reshape Sita's identity. Most studies tend to adopt a broad perspective, examining general feminist reinterpretations of the Ramayana tradition, but rarely delve into how Sita's first-person narration—characterized by introspective focalization, polyphonic intertextuality, and subversive metafictional reflexivity—transforms her from a passive *pativrata* archetype into an active storyteller who creates her own *svakatha* (self-narrative).

Overlooked Formal Innovations

For example, although critics acknowledge thematic empowerment, they ignore formal developments such as Sita's dialogic interactions with silenced figures (such as Mandodari and Surpanakha), which create a counter-hegemonic narrative on ecological agency and female solidarity. Deeper understanding of how Divakaruni's book combines mythic revisionism and postcolonial feminism is limited by this analytical elision. In order to fill this gap, the current study closely examines the text and explains how these narrative strategies—interior monologue, narrative rupture during the *agnipariksha*, and ecological symbolism—reclaim Sita's voice and present her as a strong, introspective narrator who challenges patriarchal *dharma* and reconfigures gendered epistemology in modern Indian English literature.

Research Objectives

Through the following integrated objectives, this study undertakes a multifaceted investigation into Chitra Banerjee Divakaruni's *The Forest of Enchantments*:

Feminist Reinterpretation of Sita

First, to outline the feminist reinterpretation of Sita's character, explaining how Divakaruni subverts Valmiki's archetypal *pativrata* through introspective monologues, subversive motifs, and humanizing interiority that position her as a locus of resistance against patriarchal inscription.

Narratological Transformation

Second, using narratological techniques like focalization, metafictional breaks during the *agnipariksha*, and dialogic interactions with characters like Surpanakha, to examine how Sita's first-person narrative voice transformed her characterization from a voiceless symbol of suffering to a reflexive, agentic narrator.

Solidarity and Agency

Third, to analyze Sita's solidarity with Mandodari, Tara, and animistic forest beings as enactments of sisterhood, physical autonomy, ecological sovereignty, and ethical disobedience of epic binaries in order to examine the novel's polyvalent images of women's agency.

Broader Contributions

Lastly, to assess the text's contributions to larger feminist discourse, placing it in the context of postcolonial mythic revisionism alongside academics such as Richman and Volga, and analyzing how it reconfigures consent paradigms, gender epistemology, and narrative sovereignty in modern Indian English literature.

By operationalizing these goals through in-depth textual and theoretical study, the novel's interventionist potential is revealed and important gaps in Divakaruni studies are filled.





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Interrogative Framework for Feminist Analysis

The following interrogative framework, which was painstakingly developed to examine the feminist aspects of Chitra Banerjee Divakaruni's *The Forest of Enchantments*, serves as the foundation for this study:

Reinterpreting Sita's Character

By transforming the traditional *pativrata* archetype into a poly-dimensional subject whose introspective monologues ("I had learned early that a woman's life is a tapestry woven from the threads of silences" [Divakaruni 45]) and ethical discussions reveal layers of intellectual agency and emotional resilience previously hidden in Valmiki's epic, how does Divakaruni reinterpret Sita's character through a feminist lens?

Subverting Patriarchal Depictions via Narration

How does Sita's first-person narration use subversive intertextuality, metafictional reflexivity, and focalization?—challenge long-standing patriarchal depictions in the Ramayana, such as the *agnipariksha* as a purity test and the sanctification of wifely subservience, redefining her as an independent storyteller who questions marital ontology ("Is love a chain that binds, or wings that free?")?

Portraying Polyvocal Women's Solidarity

How are the experiences of women portrayed in the book through polyvocal solidarity, as seen by Sita's sympathetic conversations with Surpanakha ("We are all exiles in our own ways, sisters in suffering"), Mandodari, and Tara—that emphasize communal resistance against dehumanizing binaries, physical autonomy, affective work, and ecological kinship?

Bridging Postcolonial Revisionism and Activism

Lastly, how does the book bridge postcolonial revisionism (à la Richman and Volga) with modern Indian English literature by introducing gendered epistemologies, consent discourses, and narrative sovereignty that are relevant to current cultural activism? How does this contribute to the lineage of feminist reinterpretations of mythological narratives?

Methodology Overview

This study examines Chitra Banerjee Divakaruni's feminist reimagining of Sita in *The Forest of Enchantments* using a qualitative research methodology based on thorough textual analysis. Using feminist literary theory as the main analytical framework, it methodically decodes gender, power, and agency representations in the narrative by drawing on postcolonial feminist paradigms (such as Chandra Talpade Mohanty's decolonial intersectionality) and narratological techniques (such as Gérard Genette's focalization and Mieke Bal's narrativity).

Primary Analytical Technique

The fundamental technique is close reading, which involves carefully examining the main text line by line in order to analyze narrative voice, characterization, and thematic themes that reconstruct Sita's subjectivity from passive archetype to agentic narrator.

Three-Stage Analytical Procedure

Textual Deconstruction

Textual deconstruction first identifies significant passages that exemplify Sita's first-person *svakatha*, such as dialogic ruptures (e.g., with Surpanakha: "We are all exiles in our own ways, sisters in suffering") and her reflective monologues during exile ("I had learned early that a woman's life is a tapestry woven from the threads of silences" [Divakaruni 45]). These are examined for subversive focalization, in which Valmiki's externalized *pativrata* gaze is subverted by interior perspective.



**Vijayavalli and Suriyanarayanan****Thematic Coding**

Second, thematic coding uses intersectional feminist lenses to trace themes of ecological sovereignty (Sita's forest kinship: "You have taught me to root deep, unyielding"), polyvocal sisterhood (Mandodari, Tara), and bodily autonomy (*agnipariksha* reframed as violation), quantifying recurring lexicons of resistance through qualitative content analysis.

Intertextual Contextualization

Third, Divakaruni's inventions are contrasted with classic Ramayana versions and comparanda such as Volga's *The Liberation of Sita* through intertextual contextualization.

Secondary Sources and Sampling

Secondary sources include critical articles, peer-reviewed publications like the *Journal of Commonwealth Literature*, and academic monographs like Richman and Dev Sen—use purposeful sampling from JSTOR, MLA International Bibliography, and Google Scholar to offer theoretical support and historical context.

Validity, Ethics, and Contributions

By ensuring interpretative validity through the triangulation of primary text, theoretical frameworks, and comparison retellings, positivist biases present in mythic studies are reduced. In Indo-Anglian feminist praxis, faithful citation (MLA style) and recognition of cultural specificity are ethical considerations. Scholarly gaps in formalist-feminist studies of modern Ramayana fiction are filled by this hermeneutic bricolage, which operationalizes Divakaruni's narrative strategies without gathering empirical data.

Key Findings from Textual Analysis

Chitra Banerjee Divakaruni's textual analysis strong results from *The Forest of Enchantments* support its status as a feminist intervention that transforms Ramayana customs.

Transforming Sita's Representation

First and foremost, the book drastically alters Sita's traditional representation by giving her introspective, first-person narrative power. This transforms the silent *pativrata* archetype into an articulate protagonist who writes her own *svakatha*. Divakaruni's homodiegetic narration gives Sita hermeneutic sovereignty even though she serves as a metaphorical vessel of *streedharma* in Valmiki's epic, which is characterized by perseverance and silence: "I had learned early that a woman's life is a tapestry woven from the threads of silences" (Divakaruni 45). According to Genette's typology of focalization, this metafictional strategy reverses the externalized masculine gaze in the epic, allowing Sita to narrativize her exile, kidnapping, and *agnipariksha* as crucibles of self-definition rather than as passive trials. By depicting Sita as an epistemically independent subject who challenges Rama's *dharma*-bound choices, such reclamation upends patriarchal elision, as seen by her moving question, "Is love a chain that binds, or wings that free?" (312).

Sita's Reflexivity and Ecological Kinship

In addition, the book presents Sita as a perceptive and emotionally strong character who methodically challenges societal norms. Divakaruni's Sita exhibits critical reflexivity, departing from conventional interpretations in which Sita internalizes injustice, as demonstrated by her stoic submission during Lanka's captivity: "I am not a prize to be won or lost" (156). This claim during Ravana's kidnapping challenges the epic's commercialization of femininity by reframing her as a moral agency rather than as property. In ecological kinship metaphors, such as "You have taught me to root deep, unyielding" (89), the forest becomes a maternal ally, demonstrating her tenacity. Divakaruni presents Sita's *vanavas* as a place of subversive empowerment rather than punishing exile, invoking ecofeminist paradigms (à la Vandana Shiva) through such animistic iconography. Sita explores blind *pativrata*-ism in marital ontology as part of this intellectual awakening, promoting a proto-feminist ethic of reciprocity above unilateral devotion.





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Polyphonic Amplification of Female Voices

The novel's polyphonic amplification of disadvantaged female voices, which gives peripheral characters previously unheard-of psychological depth and intersubjective solidarity, is a noteworthy discovery. Sita's sympathetic perspective humanizes Kaikeyi's schemes: "In her eyes, I saw the reflection of my own unspoken longings" (112). Instead of emerging as the quintessential villain, Kaikeyi is revealed as a lady damaged by dynastic ambition and spousal neglect. Lakshman's abandoned wife, Urmila, is the epitome of sacrificial excess; "While they fought battles of swords, I waged mine in dreams" (201). Most provocatively, Surpanakha creates a pan-female union by going beyond demonic caricature: "We are all exiles in our own ways, sisters in suffering" (187). By destroying Valmiki's dichotomies of *sati* vs *rakshasi* and anticipating Volga's sisterhood in *The Liberation of Sita*, these dialogic exchanges create a counter-hegemonic sorority. Divakaruni creates a gynocentric narratological network that emphasizes affective labor, bodily autonomy, and communal rebellion by focusing through Sita's internal perspective.

Broader Implications and Contributions

Together, these conclusions shed light on *The Forest of Enchantments'* crucial role in feminist mythic revisionism. Divakaruni's formal innovations—subversive focalization, intertextual reclamation, and thematic intersectionality—redefine epic femininity from sacrificial icon to narrative architect in contrast to panoramic surveys of Ramayana multiplicity (Richman). By connecting gendered oppression to environmental degradation (e.g., Lanka's desolation reflecting Ravana's dictatorship), the novel's ecological feminism expands on Mohanty's borderless praxis. By promoting consent-centric reinterpretations amid resonances, it challenges Hindutva uses of Rama-Sita imagery in modern Indian discourse. Its global readership amplifies subaltern epistemologies, but its Indo-Anglian accessibility may marginalize vernacular feminist voices. In the end, Divakaruni's work serves as an example of how narrative agency sparks epistemological disruption, encouraging researchers to expand their analyses to include comparative digital retellings or performative adaptations.

Comparative Literary Studies

Comprehensive, comparative studies of Ramayana retellings across language, regional, and diasporic literary traditions may help future research on feminist mythological revisionism by highlighting similarities and differences in Sita's refiguration. For example, comparing Volga's Telugu *The Liberation of Sita*, Nabaneeta Dev Sen's Bengali folk-inflected essays, and Kavita Kané's multilingual verse novels (like *Lanka's Princess*) with Chitra Banerjee Divakaruni's Indo-Anglian *The Forest of Enchantments*—whether through polyvocal sisterhood in Volga's dialogic vignettes or Divakaruni's sustained *svakatha*—could clarify how vernacular versus cosmopolitan idioms modulate feminist agency.

Transcultural and Digital Approaches

Including variants from Southeast Asia, like the *Kakawin Ramayana* in Indonesia or the *Ramakien* in Thailand, researchers could examine how postcolonial hybridity transforms *pativrata* iconography in the context of globalization by delving into transcultural debates of Sita's subjectivity. Digital humanities techniques such as network analysis of female intertextuality and corpus stylometry could quantify subversive patterns in these corpora, filling in gaps in cross-cultural narrative frameworks.

Socio-Political and Reception Studies

Scholars should also look into the socio-political ramifications of these reinterpretations on current Indian discourses about gender roles, cultural identity, and performative nationalism. Through discourse analysis of social media, graphic novels (like Aditya HR's *Sita's Curse*), or theatrical adaptations like Nautanki re-visionings, empirical studies could link Divakaruni's ecological feminism—Sita's animistic alliances signifying resilience—with era activism and Hindutva contestations over Ramayana iconography. By using surveys or focus groups to track changes in views of consent, autonomy, and *streedharma*, ethnographic investigations into reader reception—concentrating on urban Indian women, diaspora communities, or Dalit feminists—could evaluate how these texts spark identity renegotiations.



**Intersectional and Subaltern Expansions**

Future research should compare Sita's reclaiming with subaltern retellings as Dalit *Ramaji Katha*, assessing their interventions in caste-patriarchy nexuses. Intersectional lenses (caste, class, queerness) are still understudied.

Pedagogical and Theoretical Innovations

Critical myth-busting might be promoted pedagogically by incorporating these books within postcolonial literature curricula, with action research monitoring students' epistemologies both before and after participation. Theoretically, hybrid models for examining embodied resistance in mythic fiction might be produced by combining ecofeminism (Shiva), queer theory (Thadani), and affect studies.

Archival and Broader Contributions

Lastly, premodern precursors may be discovered through archival excavations of unpublished women's Ramayana manuscripts from local Pandavani traditions, enhancing the lineage of feminist re-narration. In addition to addressing monolingual biases in Divakaruni research, these paths put Ramayana studies at the forefront of international gender and cultural criticism.

CONCLUSION

This study affirms that *The Forest of Enchantments* by Chitra Banerjee Divakaruni is a seminal feminist reimagining of Sita, giving her the narrative authority and psychological depth necessary to undermine the patriarchal framework of the Ramayana. Divakaruni initiates an epistemological break by replacing Valmiki's externalized, symbolic pativrata—relegated to emblematic silence and selfless endurance—with a homodiegetic first-person *svakatha*: "I had learned early that a woman's life is a tapestry woven from the threads of silences" (Divakaruni 45). According to Genette's narratological paradigm, this formal innovation reclaims Sita as a reflexive recorder of exile, kidnapping, and *agnipariksha* by reversing focalization from Rama's heroic exteriority to her introspective interiority. Sita is no longer a passive conduit for *streedharma*; instead, she becomes a perceptive, emotionally strong woman who challenges marital ontology, asking, "Is love a chain that binds, or wings that free?" (312)—and claiming physical autonomy: "I am not a prize to be won or lost" (156). By situating Sita as a powerful symbol of dignity, autonomy, and ethical rebellion, this refiguration contradicts canonical representations in which her agency is limited by *dharma*-bound conformity.

The novel's feminist telos is further reinforced by the polyphonic amplification of female subjectivities. Through Kaikeyi's humanized aspirations and Sita's sympathetic solidarity, which is demonstrated in her conversation with Surpanakha ("We are all exiles in our own ways, sisters in suffering"), Divakaruni creates a gynocentric counter-narrative that challenges the epic dichotomies of *sati* vs *rakshasi* through the dream-vigil of Urmila and the regal melancholy of Mandodari. This reclaiming is extended by ecofeminist tropes, in which the forest maternalizes Sita's resiliency ("You have taught me to root deep, unyielding"), fusing environmental ontology with gendered subjection *à la* Shiva's praxis. In addition to humanizing marginalized women, these strategies create a sororal epistemology that foreshadows group resistance to patriarchal mythology.

The Forest of Enchantments, which bridges Adrienne Rich's "re-vision"—the act of looking back to see differently—with postcolonial feminist interventions, is a literary and cultural example of how mythical narratives can be remade to highlight women's perspectives (Rich 18). By redefining permission, agency, and narrative sovereignty in the context of India's gendered polity, Divakaruni's book innovates through continuous novelistic form in contrast to panoramic assessments of Ramayana plurality (Richman). While its Indo-Anglian accessibility globalizes subaltern epistemes, it intervenes against the Ramacentric appropriations of *Hindutva*, resonating with Dalit feminist critiques and #MeToo demands.



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This approach affirms the novel's interventionist vitality while filling in scholarly gaps in formalist-feminist Divakaruni critique. Its thematic universality encourages transnational extensions, although its Anglophone scope may obscure vernacular nuances. In the end, Divakaruni sheds light on the malleability of myth as a platform for gender justice and calls for continued scholarly investigation of how these retellings spur cultural transformation, turning Sita from a silenced icon to an architect of unwritten endings: "In our stories, we find the strength to rewrite the endings" (234).

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RESEARCH ARTICLE

Reversing Jairaj's Place from Margin to Center: Challenging the Performativity of Masculinity in Mahesh Dattani's Dance Like a Man

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ABSTRACT

This paper explores the construction and deconstruction of male identity through the character of Jairaj in Mahesh Dattani's play, *Dance Like a Man*. Drawing upon Judith Butler's theory of gender performativity, the study questions whether "manhood" is an innate essence or a rehearsed performance dictated by patriarchal expectations. In the play, Jairaj's passion for Bharatanatyam—a craft traditionally marginalized as feminine or "unmanly" by his father, Amritlal—places him at the periphery of traditional masculinity. By analyzing the conflict between individual desire and societal "scripts" of manhood, this research seeks to move Jairaj from the margins of gender discourse to the center of a new identity paradigm. The paper argues that true identity is often suppressed by the "practice" of being a man, suggesting a need to rediscover the self beyond the rigid lenses of patriarchy.

Keywords: Mahesh Dattani, Gender Performativity, Masculinity, Patriarchy

INTRODUCTION

Mahesh Dattani is one of the leading Indian playwrights and has achieved significant success in contemporary drama. He attributes much of this success to having his own theatre company, Playpen, which allowed him to explore challenging topics without the need for external societal sanction. Dattani's works primarily focus on 'family dramas dealing with various urban issues'—matters he describes as 'invisible issues' that are present in society but often ignored or unacknowledged. Actually, Dattani is a fearless writer who writes freely about the prejudices faced by society; his plays offer the audience a universal appeal of change and acceptance which serves the humanity at large. The writer is a social visionary who thinks about the humanity at large breaking all the barriers of inequality, gender discrimination, transgender issues, homosexuality, woman issues ...and educate millions of Indians about the prejudices that they keep in their heart about the issues which only give rise to resentments. Tanu Pant in her article rightly states—"He has chronicled the social victim and the follies, foibles and prejudices of Indian society". Mahesh

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Dattani has beautifully portrayed the modern issues of his times and has done full justice to the characters to make them realise their position in the social front in the end the plays. John McRae illustrates "The plays of Mahesh Dattani bring Indian drama into the 1990's with a vengeance. They are the plays of today, sometimes so actual as to cause controversy, but at the same time they are plays which embody many of the classic concerns of world drama'. Mahesh dattani is famous for using unconventional issues and presenting the human relationship and cultural values on the stage through actors' performance which connect the each and every people with reality. He uses the unique strategies, tools and techniques which play an important role in his plays and this is enough to win the heart of common people. I observed how issues which were in 'margin' comes to the dominance of 'center' As Asha Kuthari Chaudhuri comments, "The preoccupation with 'fringe' issues forms an important element in Dattani's work – issues that remain latent and suppressed, or are pushed to the periphery, come to occupy centre stage"

Regardless of the fact that Indian English Drama was looked down upon as an 'unwanted piece' of literature for several decades, it gradually attained identity and authenticity through the portrayal of both rural and urban Indian scenarios with the inclusion of various social issues. Reluctantly enough the audience started responding to the Indian English Drama as it proved to be a novel form of entertainment and awareness. "After centuries of indifference and initial efforts Indian English Drama now stands poised to acquire an identity and authenticity to find its own roots, so that it can rise to the challenges of articulating and sharing with the community to which it belongs a creative vision and portray the complex human situation. Into artistic assets Indian English drama is determined to prove that it belongs to a race with a rich and varied dramatic tradition, when drama enjoyed the status of the fifth veda. With the establishment of the East India Company in the latter part of the 17th century, the Indian English Drama started to flourish. The colonial empire gave impetus to the Indian English Drama. Along with the vernacular plays, Indian English Drama represented the contemporaneity of vivid facets of Indian society. After reading English literature even after reading Indian literature all knows literature gives voice to the voiceless. This is a place where one can find themselves. But problem is in acknowledgement. Jairaj is the main protagonist of the play 'Dance like a Man', he is that mentioned 'man' of the title. But why he is being told to dance like a man. Is dance has different setup or different forms and rules for man or for woman. Or is it that the very art dance doesn't suit man? Then who is wrong? the man? Or the people who defines 'man'? Very challenging indeed the very title of the play but not more than the identity of the 'man'.

If history is being written and it is meant to be read then narrative has been read so that it be reversed one day. And one can ask why this reversal? Is this necessary? It is necessary as it proves that if someone fails in fulfilling societal duties still he or she be successful if he or she has achieved victory as a human being. All here will ask that Patriarchy is the one we are fighting against but somewhere fighting is as much important as the support. Why it is that most come to attack Patriarchy but few in support of this "new man". We have to understand that it is an age where defend of one is more important than attacking the opposition. For that reason some voice should be restored. If Jairaj's voice gets the central position if he escapes the periphery of Subaltern then there will not be more Jairaj. Actually Patriarchy is name of huge ideological construct where everyone is subject. It's not necessary that always it runs by men as sometimes it runs by women. Ratna just like Nana in Ama Ata Aidoo's "The Girl Who Can" be the subject of Patriarchy. Although Ratna is not subject to Patriarchy but still she was responsible behind Jairaj's marginalised voice. Somewhere she too failed in becoming the best life partner who could share the pain of her husband's. In Rassundari Devi's 'Amar Jibon' the struggle of Rasusundari Devi was alone. If readers felt disappointment from the part which her husband played in her life then they definitely felt disappointed by Ratna. Marriage or any relation between man and woman should not be made in binaries. This creates the whole problem. Where not only women but in few cases men too seek for equality but find nowhere. If one's voice is under suppression for long years then slowly they start losing it.

One's free man starts becoming victim. This victimisation is not only happens in wider space like bigger society but sometimes happens in very personal relations like family and marriage. If in Henrik Ibsen's 'A Doll's House' Nora felt her whole life was nothing but a doll's house to her husband then what was Jairaj's life to his father and wife. Wasn't it too a doll's house. They challenged him in the way they wanted. Individual should be supported as much





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as a mass .Minority should be given same respect as the majority .If somewhere there's lapse then life becomes ' old Play House ' (written by Kamala Das) where one loses ' will ' and ' reason ' and every speaking of their reflects only ' incoherent replies ' (Kamala Das).But this are not incoherent by nature , they only become incoherent to the listener. As Gayatri Chakravorty Spivok said it's not that Subaltern can not speak it is only that their voice never be heard .Listeners never hear them so they remain voiceless .But Jairaj's voice being heard in everydepth which indeed reversal of his place .He replaced the center and became the voice to be heard by everyone.

Jairaj first appeared on a stage when he was already married and father of one grown up girl .But his wife said " you stopped being a man to me ..." (23) She said he is a ' boy ' to her .Was it insulting to the very identity of ' man ' or insulting to his very existence? In ' God of Small Things ' Arundhati Roy wrote " World has other way of breaking men ..." then are this the way of breaking them ?If someone comes out to be different exactly the one they want to be not what others want them then are they not fixed for the identity of ' man ' or ' woman ' .For a long time it is thought that men only men if they strong , if they can have their voice, if they never cry then those who are weak , who are voiceless and who even cry are they not men ? Then who are they ? And who are this people who are defining them? Does it signify that a plot grows out of characters. Since drama presents us directly with scenes, which are based on people's interactions, characters play a pivotal role in the genre and thereby need a close scrutiny. The characters in the plays can generally be divided into major characters and minor characters depending on how important they are for the development of plot. Nevertheless, both in their own way, and with their characteristic traits, create an indelible impression on the mind-sets of the audience apart from contributing immensely to the development of the plot.

As Mahesh Dattani writes of the contemporary scene, the characters contain the modern sensibility. His characters are rooted in the urban cosmopolitan setting of modern middle class in India. Pranav Joshipura writes, "Modern drama has no heroes. It has no exceptional human beings. It is peopled with average men and women with their ordinary peculiarities" . In Dattani's plays too, there are no male heroes or female heroines. But, there are central characters in his plays that are under the microscopic lens of the dramatist. In this sense they may be called protagonists. They are ordinary human beings who exhibit the crisis, meaninglessness, confusion, frustration, disintegration, bickering relationship and disillusionment of the twenty-first century. The characters display the hiatus between what the individual aspires for and the harsh reality of what he achieves what he professes and what he practices, what he really is and what he really would like to be taken for. The point makes all the difference. A person interprets the first phrase of each perception as the "reality" of gender if they think they are witnessing a man dressed as a woman or a woman dressed as a man. The simile introduces a gender that is perceived as an illusionary appearance since it is devoid of "reality. We think we know the truth in these instances where a seemingly genuine world is connected to an unreal one, and we see gender's secondary appearance as nothing more than a hoax, joke, deception, or illusion. When Amrit al , Jairaj's father at one point of the play asked Ratna's help to " grow up " jairaj or make him " a man , "what it meant ? What readers should think that Jairaj isn't man and why because he dances .Then dance meant for women ? Or certain dance meant for only women? There for long time women were confined in four walls as it was thought that they were meant for this .

When they started coming outside they were hurled as ' slut ' or as ' mad woman in the attic 'they were not suppose to speak forget about giving voice to their needs and desires .But is it that there all should be fixed ? Why not exception be normal ? Amritlal is a wonderful example to the male dominated society that creates and reserves masculine ethics and limitations. There fixed criteria to be a ' man ' same for a ' woman 'in his mind .For example men aren't supposed to have ' long hair ' and if they have it they aren't 'normal man ' .There even fixed ways of walking for a man and man aren't suppose to walk like women .As Amritlal questioned about guruji's identity as a ' man ' in the play "I definitely do object to the people you are associating with ...your guru ? What kind of family he is from ? ...why does he wear his hair so long ...I have never seen a man with a long hair ...I mean normal man ...I have also noticed the way he walks "(41) Amritlal approves of the marriage between Jairaj and Ratna, according to Jairaj, "because it suits(his) image –that of a liberal minded person, to have daughter-in –law from outside his community"With the help of Ratna, Amritlal successfully achieves his desire to stop his son from dancing





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bharathanatyam If one reads “ Return of the Native “ (written by Thomas Hardy) then they find that Eustacia too failed to fulfill societal expectations of being a ‘ woman ‘ throughout the novel she came out to be a over seductive , an unwomanly woman .She was rebellious who could say “Women Have Done Much For Themselves In Histrionic Dress. To Look Far Below Those Who, Like A Certain Fair Personator Of Polly Peachum Early In The Last Century, And Another Of Lydia Languish Early In This, Have Won Only But Ducal Coronets Into The Bargain, Whole Shoals Of Them Have Reached To The Initial Satisfaction Of Getting Love Almost Whence They Would. But The Turkish Knight Was Denied Even The Chance Of Achieving This By The Fluttering Ribbons Which She Dared Not Brush Aside.”

‘Dance’ is a passion for Ratna, an undying one that propels her character since beginning and throughout the story influencing her actions. It is a device to gain success and become famous for her. There is a hint that she married Jairaj in the first place just because he too was interested in dancing and thus would let her dance without causing any trouble. Driven by the pact she had with Amritlal, she does not even hesitate to demolish the career of Jairaj as a classical dancer and consequently destroying his life as well, just for self-benefit. Where Jairaj only follows his heart, Ratna here follows her mind as well, which is sometimes overpowering her heart. She sees dance to be a source of earning money as well as fame. She perceives it to be a basis of establishing respect among the peers and the world of dance. She continually plays with her husband's emotions and tries to guide his life in the manner best suited for her. She does not merely stop at controlling the life of her husband consequently leaving him to become just a soul-less zombie; she tries to take over the life of her daughter Lata as well, moulding her into a reflection of herself. Ratna wants Lata to become whatever she desired for herself and could not be, to get whatever she could not get and tries tooth and nail to establish her as a Bharatnatyam dancer without even asking her once if she wanted all of this or not. Ratna never seems to worry much about what others want; her desire is always the priority. Somehow in the very particular house of Amritlal, years after his death, the agent of patriarchy seems to be shifted from being a man to a woman. Jairaj, despite being a man holds no authority and neither tries to; instead, Ratna fits in part quite well and seems to be running the legacy of Amritlal's patriarchy in the household.

One of the fixed criteria to judge a man is his ‘ income ‘ .In the play this question too asked by Amritlal why Jairaj dances as it gives him ‘ no income ‘ .He asked “ Do you know where man's happiness lies ?” (51) and the answer which Amritlal had given is “ being a man “ . So , again question comes on Jairaj ‘s identity as a man . Bharatanatyam as a dance form has a long history But in a word it originates from Lord Shiva but later through Devadasi pratha and all it was internalised by women .That much so that it was impossible for some “ narrow minded individuals with fancy pretentious ideals “ to think any man performing the dance .If truth to be told then there problem wasn't with any particular man but with the identity of ‘ man ‘ which that man carries .By some divine rules they undertook that man are for lofty things not for the thing women do .In the note of the play , Devanesen said “ by some unwritten rule it was understood that this was my chair and nobody will sit on it “ About his inheriting his father's chair .This ‘ chair ‘ here carries the symbol of ‘ authority ‘ as the ‘ shawl ‘ in the play.But what this ‘ authority ‘? very part of man's identity ? In Zora Neal Hurston's ‘ ‘ Sweat ‘ Fisher woman's husband used to beat her .Was he man ? In “ Collector of Treasures “ (written by Bessie Head) , Garesco returned in Dikelini's life to prove his masculinity.Was he man ? Bessie Head said Garesco was phalocentric misogynist man for whom women meant only sex where love had no meaning.

Dikelini was so helpless “she couldn't walk away from her husband as she had children to care for and the forced compromise she ends up with – a life in prison for murdering him – hardly suggest a solution- Dikelini named after her mother's tears symbolises the struggle of a people who have a long way to go before the cycle of violence .Can be replaced by a spiral of peace .” This story by Bessie Head is important to the present context of my discussion as it too dealt with the ‘ identity of man ‘ .As Bessie Head said in ‘ Collector of Treasures ‘ “There were really two kinds of men in the society.The one kind created such misery and chaos that he could be broadly damned as evil .If such a man watched the village dogs chasing a batch on heat , they usually moved around in packs of four or five .”Then society will accept such man as a ‘ man ‘ but not the one who is the other one ‘marked by “gentle, loving, responsible men, with the standard gendered role “According to Foucauldian genealogies of power, discourses regarding gender





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generally prefer the conventional classification of 'normal and 'abnormal 'sexuality and tend to regulate and normalize or chastise those who perform beyond the proper limit of gender norms (Loxman). The normal gains its authority by repetition of these conventional norms that signifies the bodies as real or natural and this re-enactment empowers the otherwise fragile connection between the body and its gendered codes. .

Hence being a man for Amritlal would be to embody manly features like short hair, to play cricket and definitely not dancing. He considers dance to be a woman's affair. So the dance teacher with long hair and the sound of Jairaj's dancing bell is despicable to him. Connell's idea of masculinity as a "combination with two" becomes incoherent due to a specific hegemonic pattern in the extremely biased interplay between masculinity and what it debunks, which is essential to its persistence as a stabilising factor of multiple patriarchies in what Butler refers to as a "phallogocentric worldview" (Singh). Throughout the play, there is continuous power control between the genders. Jairaj's identity crisis and frustration again reflected when he blames Ratna for crushing his identity and dignity: "Bit by bit. You took it when you insisted on top billing in all our programmes. You took it when you made me dance my weakest items. You took it when you arranged the lighting so that I was literally dancing in your shadow. And when you called me names in front of other people. Names I feel ashamed to repeat even in private. And you call me disgusting" (72) Ratna assert for creating her name and fame in dancing. She marries with Jairaj so that she can use resources and dancing hobby of Jairaj as a ladder to touch the heights of her career. Some audience may feel negative about her character. But Dattani refuses to assign the blame or the status of the 'wronged' party to any one: "I refuse to have protagonists in a fixed role as victim.

If you have a victim, it implies that there is a persecutor and it also implies that you will eventually have rescuer" (Chaudhuri). Ratna is not, as many would suggest, depending upon the interpretation of the production, the negative presence in the play. Dattani has often been considered as a 'woman hater' by critics, but, according to him: "... my women protagonists fight, scheme and get a piece of the action albeit at great personal cost. These are seen as 'negative' qualities, sadly by some women too. You may talk about post feminism in Western society, but really we have yet to see feminism find expression in Indian society. (Dattani) The last lines of the play reverberate perpetually "We were only human. We lacked the grace. We lacked the brilliance. We lacked the magic to dance like God" (76) of course, Jairaj like Paul Thebalo (in 'Collector of Treasures' is gentle, loving, responsible then why he has failed being a man because of his dancing but why? If Lord Shiva can dance then why not Jairaj? Another question is on the value of 'dance'. It is called as a 'craft of prostitute'. Amritlal said "many of them have given up their art as you call it and have taken to selling their bodies" Viswas although Liberal minded still at one point had objections for particular form of dance "it is erotic" (61) he said by referring Asthapadi. But he didn't know that Jairaj too did it "there's nothing crude about it I too did the same item" But reality was that viewer's too looking for women dancers so Jairaj had to opt for disguise He disguised as a female.

But once dance was over there was radical change and the same viewers who earlier were looking for female dancers were now busy in appreciating Jairaj's dance "they liked it even more when they found out I was a man" (61) But we can't under-estimate the questions this incident raises. It raises questions on male as a dancer? What society gives them? What opportunity they have? Are they not marginalised? Jairaj that Subaltern from whom his identity has been snatched away. If his father thought he needs to be "worthy of" (53) Ratna and he needs to be responsible Then why his father didn't think what Jairaj wants. Can't readers too ask that why not Jairaj be given the 'independence' to do what he 'wants'. In deconstruction, Jacques Derrida argued that the traditional binary opposition of "center" and "margin" is not fixed, but rather, the "margin" can become the "center" and vice versa through a process of challenging established hierarchies and revealing the instability of meaning. Derrida critiques the tendency in Western thought to privilege a central, stable point of meaning (the "center") and marginalize other perspectives or interpretations (the "margin"). He suggests that meaning is not inherent or fixed but is constructed through relationships and differences, and that the "margin" can challenge and ultimately displace the "center".





CONCLUSION

After a time being all realizes life is fugal where journey started and stopped too and forced to say “ nothing happens “ just like Estragon said in ‘ Waiting for Godot ‘but if they realises that all life they just ‘ performed ‘ and their life had no contribution of their own .Will they be shocked? Although that’s truth, all are doing it consciously or unconsciously but some people like Jairaj is victim of that ‘practice ‘ as he failed in his performance as well as in his ‘ practice’. Hence he failed as ‘ man’ .But if in a society those man who are worse than animals can be called as ‘ man ‘then definitely it is good not to be called as man .Jairaj in his way right if wrong was anything then it was society and their fixed identity of “man “ .There in this circumstances failing as a man is indeed huge success as a human .

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Bio-Note

Sangita Saha is a professional author and aspiring academic researcher based in Falakata, Alipurduar, West Bengal. She holds a Master's degree in English and has achieved significant academic milestones, including qualifying for the National Eligibility Test (NET) under the PhD category and the 27th West Bengal State Eligibility Test (SET) in English. Her research interests center on the intersection of spirituality and humanity in literature, with a specialized focus on Feminism, Gender Studies, and Modernism. As an active creative writer, Sangita has authored published works such as the poetry collections River Goes Like You and Me, Still in Raindrop Every Part Remains, and Dry September Again Seeking the Truth, as well as the novel My Devotion to You. Beyond her writing, she is an





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RESEARCH ARTICLE

The Ecology of the Sacred: Ecospiritual Dimensions in Margaret Atwood's Selected Works

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ABSTRACT

The relationship between humans and the nature is one of the most important themes in literature. The 20th century literature explores the human consciousness towards environment. It also shows the connection between human spirituality and ecology. Margaret Atwood reflects upon these issues in her fiction as well as her poetical works. She goes beyond the physical connectedness and tries to show the co-existence between humans and nature as they are inseparable. She possesses spiritual vision and digs deeper the various layers of eco-spirituality. The present paper is a close reading of her selected works such as *Surfacing*, *Oryx and Crake*, *The Year of the Flood*, *MaddAddam*, and selected poems with reference to eco-spiritualism. In the age of posthumanism, man has become dependent on machine and going away from nature. The ecological imbalance is one of the major issues in the present time and Atwood gives a call to survive nature with collective efforts. She shows nature as a sacred space and discusses spiritual dimensions. Basically, this study tries to focus upon the ethical philosophy to save endangered nature.

Keywords: Ecospiritualism, Ecocriticism, Deep Ecology, Posthumanism. Ethics

INTRODUCTION

The ecological imagination in the works of Margaret Atwood is most powerfully articulated through her speculative dystopian narratives, particularly in *Oryx and Crake* (2003) [1] and its companion novels. Rather than presenting environmental collapse solely as a scientific catastrophe, Atwood frames it as a moral and civilizational failure rooted in unchecked technological ambition and anthropocentric arrogance. The devastated landscapes in her fiction reflect not merely ecological ruin but a deeper estrangement between humanity and the natural world.





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Although Atwood resists explicit religious categorization, her narratives can be interpreted through an eco-spiritual lens. Communities such as the God's Gardeners in *The Year of the Flood*[2] embody a quasi-spiritual ecological ethic that blends survival strategies with reverence for biodiversity. Their practices suggest that ecological awareness entails not only environmental responsibility but also an ethical transformation of human self-understanding. In this sense, Atwood's dystopian fiction invites readers to reconsider the assumption of human superiority and instead recognize interdependence as a condition of survival.

This study argues that Atwood's ecological vision functions as a secular form of spiritual reflection—one that does not rely on doctrinal religion but emerges through ethical consciousness, accountability, and moral awakening. Her dystopian worlds therefore operate simultaneously as ecological warnings and philosophical meditations on coexistence, responsibility, and the fragile continuity of life on the planet.

This paper investigates Eco spiritualism in selected works, focusing on:

- Spiritual reconnection with nature (*Surfacing* [3]).
- Environmental ethics and sacred ecology (*The Year of the Flood*).
- Posthuman ecological spirituality (*MaddAddam* [4] Trilogy).
- Apocalyptic ecological imagination in poetry.

Theoretical Framework: Ecospiritualism and Ecocriticism

Defining Ecospiritualism:

Ecospiritualism refers to the recognition of nature as sacred or spiritually significant, emphasizing ethical coexistence with the environment. It draws from deep ecology, ecofeminism, and indigenous ecological philosophies. Rather than treating nature as a resource, ecospiritual thought sees humans as participants within an interconnected web of life.

Ecocriticism and Ecofeminism:

Ecocriticism examines literature's representation of environmental relationships and ecological crises. [5, 6] Ecofeminism, meanwhile, connects the domination of nature with patriarchal oppression. [7, 8, 9, 10, 11]

Ecofeminist readings of Atwood highlight the symbolic connection between women and nature and the impact of industrial and patriarchal exploitation. Atwood's works frequently challenge anthropocentrism- the belief that human life is superior to all other forms. Scholars emphasize that *Oryx and Crake* critiques capitalist science and ecological utopianism alike, demonstrating the complexity of environmental discourse. [12]

Deep ecology and spiritual ethics:

Deep ecology argues that all living beings possess intrinsic value. [13] In *The Year of the Flood*, environmental ethics resembling deep ecological philosophy guide characters' survival and moral choices, reflecting a quasi-spiritual reverence for all life.

Ecospiritual Awakening in *Surfacing*

Wilderness as Sacred Space:

Surfacing represents one of Atwood's earliest explorations of ecological spirituality. The unnamed protagonist returns to the Canadian wilderness searching for her missing father, only to experience a profound psychological and spiritual transformation. Nature becomes both a refuge and a teacher, enabling self-discovery and healing. She rises her voice against the human cruelty. She compares the massacres of the animals with the Christ:

Anything that suffers and dies instead of us is Christ.... The animals die that we may live, they are substitute people, hunters in the fall killing the deer, that is Christ also....We are eaters of death, dead Christ - flesh resurrecting inside us, granting us life. Canned spam, canned Jesus, even the plants must be Christ. But we refuse to worship; the body worships with blood and muscle but the





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thing in the Knob head will not, wills not to, the head is greedy, it consumes but does not give thanks. (Surfacing 179)

Ecofeminist critics argue that the protagonist's journey symbolizes a return to primordial ecological consciousness. Her immersion in the wilderness dismantles modern alienation and reconnects her with instinctual and spiritual awareness.

Nature and Identity:

The protagonist's spiritual awakening occurs through encounters with animals, forests, and lakes. She gradually rejects technological modernity and embraces a more organic existence. Ecofeminist analysis suggests that the novel portrays nature as a living presence rather than a passive landscape, emphasizing its role in personal and communal identity formation.

Ecospiritual transformation:

Her transformation culminates in a symbolic merging with nature — a rejection of societal expectations and a rediscovery of primal identity. The wilderness becomes sacred ground where spiritual renewal occurs.

Ecospiritualism in the *MaddAddam Trilogy*

Environmental apocalypse and spiritual crisis:

The trilogy (*Oryx and Crake*, *The Year of the Flood*, *MaddAddam*) explores a world devastated by corporate greed, genetic engineering, and environmental collapse. Ecological disaster functions as both material catastrophe and spiritual crisis.

Scholars emphasize that Atwood's dystopian narratives examine ecological deterioration caused by capitalist science and social inequality, revealing how environmental destruction reflects deeper moral failures. [14]

God's Gardeners: a Spiritual Ecology

In *The Year of the Flood*, the eco-religious group God's Gardeners practices sustainable living and reverence for all species. Their rituals combine science, environmental ethics, and spiritual practices. Critics observe that the group's survival is grounded in environmental ethics resembling deep ecology, emphasizing intrinsic value of life.

Their hymns and sermons reflect ecological spirituality — blending ecological science with sacred narratives to foster ethical responsibility.

Posthuman Spirituality:

The genetically engineered "Crakers" represent a new form of ecological consciousness. Free from destructive human impulses, they embody a harmonious relationship with nature. Through them, Atwood explores whether spirituality might emerge in a posthuman ecological society.

Eco-spiritual Themes in *Oryx and Crake*

Critique of Anthropocentrism:

The novel critiques human exceptionalism and technological hubris. Characters treat animals as commodities and ecosystems as expendable resources. Atwood exposes the dangers of seeing humanity as separate from nature. She gives solution to the betterment of the planet:

Noon is the worst, with its glare and humidity. At about eleven o'clock Snowman retreats back into the forest, out of sight of the sea altogether, because the evil rays bounce off the water and get at him even if he is protected from the sky, and the he reddens and blisters. What he could really use is a tube of heavy-duty sunblock, supposing he could ever find one. (*Oryx and Crake* 37)

Environmental critics argue that the novel highlights complex debates between ecocentric and anthropocentric perspectives, demonstrating that even environmental ideologies can become flawed when rigid or extreme.



**Sunrima and Karthik Kumar****Spiritual absence and Ecological collapse:**

The dystopian world reflects a society devoid of ecological reverence. Corporate greed replaces spiritual connection, resulting in moral decay and environmental catastrophe.

Memory and nature:

A spiritual desire for nature is reflected in Snowman's sentimental recollections of extinct ecosystems. His narrative of survival turns into churning on how humans have lost touch with nature.

Ecospiritual Imagination in Atwood's Poetry

Many of Atwood's poems are about the end of the world and environmental destruction. Critics opine that her lyrical imagination shows environmental disaster while also looking at imaginative and spiritual ways to deal with ecological issues. Nature seems to be both preserver and destroyer. Atwood uses metaphors and symbols to show how the ecological catastrophe affects our spiritual lives.

DISCUSSION

Atwood's novels depict ecospiritualism as a new kind of ethical matter rather than an idealised portrayal of nature. The portrayal of her characters shows that being aware of the environment needs change one's conscious mind which means seeing how everything is in coexistence and being responsible for all living things. Her works imply that ecological sustainability relies on both technical advancement and moral and spiritual development. Atwood asks readers to ponder upon where humans fit into the cycle of life by showing environmental disasters next to spiritual awakenings.

Posthuman Eco-spirituality in MaddAddam**Beyond Human Exceptionalism**

Margaret Atwood, in the *MaddAddam* trilogy, introduces posthuman world not as technological revolution but as an ethical platform. In this trilogy, the characters Oryx and Crake design genetically engineered Crakers which bring positive revolution. These Crakers reduce hostility, hierarchy and environmental exploitation. It is very important invention as it provides the new ontology. Its important point is that it does not claim dominance over other creatures.

In the traditional world, humans have control over everything. There are also environmental issues and consumptions. While in the posthuman world, the Crakers exist without any kind of ecological limits. Their daily rituals, community songs, and myth-making practices show an emerging cosmology reflecting interdependence. There is no question of survival as each creature exists because others do. They all are in co-existence. This is the vision of eco-spirituality which unites all together rather than reserved for humanity only. The true meaning of spirituality gets reflected through Toby's speech in *MaddAddam*. During a situation where Crakers required explanation, she creates a story on ecological balance which shared ethical concern. The idea of story-telling is not only a part of plot here but it is a moral act. By converting it into story-telling, ecological responsibility has become a part of ritual. In this manner, Atwood suggests that spiritual awareness may arise not from institutionalized religion but from collective efforts of environmental vulnerability.

Ethical survival and Collective Responsibility:

Unlike dystopian narratives centered solely on survival, *MaddAddam* proposes ethical survival — a form of living grounded in mutual care and ecological respect. Characters such as Toby and Ren move beyond individual survival toward communal responsibility. Their spiritual growth occurs through caregiving, cooperation with nonhuman species, and participation in ecological restoration.





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This shift reflects a key principle of ecospiritualism: survival must be morally grounded and ecologically sustainable. The rebuilding of community after environmental collapse symbolizes a spiritual renewal rooted in humility and interdependence.

Myth-making as Ecological spiritual practice:

The myths Toby creates for the Crakers blend humor, survival history, and reverence for nature. These narratives emphasize that ecological spirituality is not fixed but evolving. Rather than promoting dogmatic religion, Atwood presents spirituality as an adaptive cultural practice shaped by environmental realities.

Ecofeminism and Ecospiritual Ethics

Gender, Nature, and Resistance

Ecofeminist philosophy is essential for comprehending Atwood's eco-spiritual vision. Women characters often endure persecution akin to ecological exploitation. But they also become people who help others learn about the environment and change their spiritual lives. In *Surfacing*, the main character's rejection of patriarchal conventions is similar to her reconnecting with nature. In the *MaddAddam* trilogy, women like Toby and Pilar represent ecological knowledge, which includes herbal medicine, sustainable practices, and spiritual rites that have to do with the environment. Pilar's respect for bees shows that she understands how different species relate to each other on a spiritual level. She doesn't see animals as resources; instead, she sees them as partners in a shared ecology. Her teachings emphasise the ethical aspect of ecological spirituality: reverence for nonhuman existence.

The body as Ecological site:

Ecofeminist readings emphasize that the female body becomes a site where ecological and spiritual conflicts intersect. In *The Year of the Flood*, the commodification of bodies parallels the exploitation of nature. The God's Gardeners' emphasis on vegetarianism and sustainable living symbolizes resistance against systems that treat both bodies and ecosystems as commodities.

Spiritual practices in the group emphasize bodily discipline — mindful eating, ecological rituals, and environmental stewardship — demonstrating how spirituality becomes embedded in daily ecological practices.

Spiritual leadership and Ecological knowledge:

Women in Atwood's narratives often function as spiritual leaders or guides. Pilar's teachings about bees and Toby's storytelling demonstrate alternative forms of authority rooted in ecological wisdom rather than hierarchical power. This redefinition of leadership aligns with ecofeminist values emphasizing care, community, and environmental stewardship.

Apocalyptic Ecospiritualism in Atwood's Poetry

Nature as witness and victim:

Atwood's poetry frequently depicts landscapes scarred by human activity — polluted rivers, deforested lands, and endangered species. These images function not only as environmental critiques but also as spiritual warnings. Nature appears as a silent witness to human moral failure. In poems such as "Progressive Insanities of a Pioneer," Atwood critiques colonial attitudes toward land. The pioneer's attempt to conquer the wilderness results in psychological fragmentation, symbolizing the spiritual cost of environmental domination. The poem's imagery emphasizes that the destruction of ecosystems leads to the erosion of human identity.

Mythic imagery and Ecological Consciousness:

Atwood's poetry often employs mythic imagery to frame ecological crises. Myth functions as a spiritual language capable of expressing environmental trauma beyond scientific discourse. Animals and natural forces become symbolic figures representing ecological balance or disruption. In many poems, animals appear as moral judges or spiritual messengers, reminding humanity of its interconnectedness with other species. Such imagery reinforces ecospiritual themes of humility and ethical responsibility.



**Sunrima and Karthik Kumar****Creative imagination as Ecological healing:**

Atwood's poetic voice suggests that creative imagination itself is a spiritual response to ecological crisis. Writing becomes an act of ecological witnessing – preserving memory, warning future generations, and fostering environmental awareness. Poetry thus functions as a form of ecological activism grounded in spiritual reflection.

Indigenous and Deep Ecological Influences**Interconnectedness and Sacred landscapes:**

Although Atwood does not directly appropriate specific indigenous spiritual systems, her works reflect broader concepts of interconnectedness often associated with indigenous ecological worldviews. Landscapes in her narratives possess agency, memory, and sacred significance. In *Surfacing*, the wilderness is not merely a backdrop but an active participant in the protagonist's spiritual transformation. The novel emphasizes that humans must learn to listen to the land – an idea resonating with indigenous ecological philosophies emphasizing reciprocal relationships with nature.

Deep ecology and Intrinsic value:

Deep ecological principles appear throughout the *MaddAddam* trilogy. The God's Gardeners teach that every species possesses intrinsic worth, independent of human utility. Their ecological hymns celebrate animals and plants as sacred beings deserving protection. The trilogy's critique of corporate science highlights how technological exploitation arises from the denial of intrinsic value in nature. By contrast, deep ecological spirituality emphasizes humility, simplicity, and ethical coexistence.

Ecospiritualism as Ethical Philosophy**Critique of Consumer Capitalism:**

Atwood's ecospiritual vision critiques consumer capitalism as a root cause of ecological destruction. Corporate culture in *Oryx and Crake* reduces life to commodities, erasing spiritual reverence for nature. Environmental collapse thus becomes a moral and spiritual crisis rather than merely a scientific problem.

Spiritual transformation through crisis:

Characters across Atwood's works undergo spiritual transformations triggered by ecological disasters. The apocalypse in the *MaddAddam* trilogy forces survivors to reevaluate their values and relationships with nature. Crisis becomes a catalyst for spiritual awakening.

The role of memory and storytelling:

In *Oryx and Crake*, Snowman's nostalgic ideas work more than memory; they re-open the past and the lost human connections. Hence, the story-telling works to preserve the culture and saves total ecological erasure. Likely in *MaddAddam*, Toby's narrative shows that Crakers understand its place within the natural order. The idea of improvising the society turns into shared cosmic world. By doing so, Atwood proves that stories are not meant for entertainment alone, but they work as moral guide for humanities. She removes some events and communities from the narrative as she wanted to guide the non-human world accordingly. Ecological consciousness therefore, is brought up not through scientific investigation but through narrative memory. In this sense, storytelling becomes a guiding force through which ecological values are internalized and sustained across many generations.

CONCLUSION

In her poems as well as short-stories, Atwood introduces the moral base for how people should deal and interact with nature. She does not directly introduce eco-spiritualism as an ideology but she dramatizes it by weaving it within the story. In *Surfacing*, the main character, who is not named, goes into the woods. His action shows the readers the transformation of the characters and their psychological and moral recognition. In later times, in *The Year of the Flood's* God's Gardeners society, ceremony, song, and environmental discipline are all connected together into a





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living environmental morality. Even the posthuman Crakers in *MaddAddam* possesses an inner faith that is not based on escapism but on biological harmony. What unites these representations is a sustained critique of anthropocentrism. Atwood's narratives repeatedly dismantle the assumption that humans occupy a privileged moral hierarchy. Animals, ecosystems, and genetically modified beings are not background elements; they participate in interconnected systems of survival. Her poetry, similarly, registers ecological grief and tentative healing through shifting metaphors and stark natural imagery, suggesting that environmental damage is both material and existential. Importantly, Atwood resists offering prescriptive solutions. Instead, her work compels readers to confront their ethical accountability. Environmental awareness emerges less as a policy directive and more as a transformation of perception—a recognition that coexistence requires restraint, humility, and communal responsibility. In this sense, eco-spiritual consciousness in Atwood's writing operates as an ethical orientation rather than a theological system. Atwood's ecospiritual farsightedness is vital in the present time when the world is in danger and the ecosystem is uncertain. Her works remind humans that it will be possible to save environment only when we change our attitude towards it. She uses legends, anecdotes, myths and her own narrative tales to help people remember where they fit into the web of life.

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RESEARCH ARTICLE

Ecological Multiplicity and Postcolonial Futures: Tidal Narratives, Climate Imagination, and Environmental Justice in Amitav Ghosh's *The Hungry Tide*

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ABSTRACT

This study examines Amitav Ghosh's *The Hungry Tide* as a seminal work of climate fiction that reimagines narrative form amid ecological precarity, postcolonial histories, and multispecies entanglements. Set in the tidal landscapes of the Sundarbans, the novel dramatizes environmental crisis not through apocalyptic spectacle but through polyphonic storytelling, tidal temporality, and epistemic plurality. Drawing upon postcolonial ecocriticism, the Anthropocene humanities, and concepts such as slow violence (Nixon) and tidalectics (DeLoughrey), the analysis foregrounds how Ghosh intertwines mythic cosmologies, scientific observation, subaltern knowledge, and political memory to cultivate an ethics of ecological attentiveness. By engaging Akhter and Islam's recent work on urban ecologies, the paper situates *The Hungry Tide* within a broader South Asian climate imaginary that spans rural deltas and metropolitan peripheries. The novel's refusal of narrative closure mirrors the open-endedness of climate futures themselves, inviting readers into imaginative solidarities across human and nonhuman worlds. Ultimately, the study argues that Ghosh transforms the realist novel into a site of environmental thought, one that resists mastery and embraces relationality, multiplicity, and ethical humility in the face of planetary uncertainty.

Keywords: Climate Fiction; Postcolonial Ecocriticism; Anthropocene Humanities; Tidalectics; Multispecies Ethics; Narrative Polyphony



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INTRODUCTION

In an age increasingly defined by environmental disorder, literature has assumed an essential role not merely as a record of loss, but as an instrument of ecological consciousness. Amitav Ghosh's *The Hungry Tide* (2004) emerges within this emergent climate imaginary not as an exaggerated allegory but as an embodied practice of environmental ethics. It reconfigures narrative form to think through the entwined vulnerability of human, geological, and multispecies lives. Set in the Sundarbans, the "beautiful forest" whose very name connotes both ecological abundance and vulnerability, functions as a narrative confluence where environmental precarity, political history, and nonhuman agency intersect. Ghosh offers a literary modality one might call eco-narratology, a mode of storytelling that enacts ecological impermanence, relationality, and justice through rhythms of voice, landscape, and narrative temporality. This study connects that narrative architecture to ask: how does Ghosh frame ecological precarity onto literary form, inviting readers into sustained ethical attentiveness? To engage these questions, this study is grounded in interconnected theoretical frameworks. Postcolonial ecocriticism (Huggan & Tiffin, 2006) alerts us to how colonial legacies, uneven modernities, and conservation agendas inform both ecological crisis and its representations. Rob Nixon's notion of slow violence (2011) sharpens our attention to the minutiae of ecological attrition that precede disaster. Anthropocene temporalities, as elaborated by Chakrabarty (2009; 2021), highlight the challenge of rendering the immense spans of geological time legible within human-scale narratives. Tidalectics (DeLoughrey, 2019) further invites us to think through more-than-linear narrative structures shaped by watery flux. To clarify how these theoretical lenses intersect, see Figure 1.

To position Ghosh's work within the broader discourse of South Asian environmental narratives, the study draws upon Akhter and Islam's study of urban ecocriticism through Jhumpa Lahiri's *The Lowland* (2024). Their work broadens the ecocritical gaze to include metropolitan spaces as sites of environmental violence and resilience by analysing Kolkata's metamorphosis "pollution, loss of green spaces, and the urban ecologies eclipsed by infrastructure". Although Ghosh's Sundarbans is ecologically and narratively removed from the urban corridors of Kolkata, the methodological synergy is striking: both writers mobilize literary attention to contest environmental injustice, whether in shifting islands or sprawling cities. These parallel invites a conceptual synthesis across rural and urban bioregions, gesturing toward a literary ecology that bridges tidal geographies and urban peripheries in the shared task of environmental remediation.

This study unfolds through four interlinked analytic movements. First, it examines tidal temporality and ecological precarity, showing how *The Hungry Tide* blurs human time, geological time, and historical trauma through narrative rhythm. Second, through narrative polyphony, it reveals how myth, science, vernacular, and environmental awareness converge into a plural epistemic architecture that resists monolithic knowledge. Third, in the section on postcolonial ecologies, the Sundarbans emerges as a contested terrain marked by political displacement, conservation regimes, and capitalist extraction. Fourth, the study turns to eco-narratology and climate imagination, considering how Ghosh's narrative reconstructs climate awareness not as abstraction but as part of embodied story, sensory ethics, and imaginative solidarity across species. Crucially, each section builds upon, rather than repeats from, its predecessors. This structure allows the analysis to remain dynamic, meandering with tidal logic, rather than linear or teleological.

At a broader disciplinary level, this paper seeks to enrich the conversations between climate fiction, postcolonial studies, and environmental humanities by demonstrating how *The Hungry Tide* illustrates the intimate, complex, and ethical potentialities of literature under planetary duress. In an era when literary forms are pressured to make sense of systemic collapse, *The Hungry Tide* offers neither apocalyptic catharsis nor utopian solution, but a sustained invitation to dwell with precarity, listen for multiple voices, and reimagine story as ecological praxis.





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Tidal Temporalities And Ecological Precarity In *The Hungry Tide*

Amitav Ghosh's *The Hungry Tide* (2004) unfolds as an incisive reflection on how ecologies in motion as embodied by the Sundarbans' tidal landscapes, demand narrative forms that are immersive, ethical, and sensitive to temporal distinction. To orient readers unfamiliar with the Sundarbans region, see Figure 2 for a map of the Sundarbans delta, showing river networks, mangrove extents, and protected zones, which provides spatial context for the novel's shifting geographies. In refusing spectacle or polemic, the novel invites readers into an ecology of attention, where the rhythms of human and nonhuman life merge in subtle and disquieting ways. Here, climate change is not a remote abstraction but a lived, sensory, and affective experience: the tides themselves perform temporality, insisting that we attend to precarious worlds that unfold beyond human time and control (Trexler, 2015).

The narrative begins with an apparently simple premise: Piya, an American cetologist of Indian descent, journeys to the Sundarbans to study the endangered Irrawaddy dolphins. She encounters Kanai, who has travelled from Delhi to retrieve his late uncle Nirmal's journals, and Fokir, a fisherman born of and shaped by the rhythms of tides. Beneath this triangulation lies an unfolding meditation on climate precarity: the tenuousness of biodiversity, the fragility of community, and the violence enacted upon both by social and environmental forces. The novel's cataclysmic cyclone—claiming Fokir's life—is not an end but a punctuation; it crystallizes the convergence of human histories and tidal histories and dramatizes what Chakrabarty (2009) names the “collapse of humanist temporalities” in the Anthropocene, where personal and planetary timescales collide in unpredictable and inseparable ways. What distinguishes Ghosh's narrative within climate fiction is its refusal to frame environmental change as catastrophe alone. Instead, the novel marshals observation: Moyna noting the disappearance of fish eggs entrapped by synthetic nets; Piya tasting a “metallic savor” in the water; Horen remarking that cyclones have started arriving “quicker”; Nirmal reflecting that “the wheel of time was spinning too fast to be seen” (Ghosh, 2004, p. 45). These moments enact what Nixon (2011) terms “slow violence”, : environmental harm that unfolds gradually, invisibly, yet devastatingly, often entwined with the operations of state power and global capital.

In this literary strategy, *The Hungry Tide* intertwines the experiential with the planetary. Nirmal's journals reflect on the Morichjhapī refugee settlement and its violent suppression in the 1970s, weaving together displacement, political injustice, and ecological fragility. His statement that “mangroves were Bengal's defense against the bay” (Ghosh, 2004, p. 271) acquires bitter irony as deforestation, sea-level rise, and repeated cyclones erode both literal and metaphorical defences. The drowned islands dramatize what Heise (2016) theorizes as the “disappearance of place” in an age where climate change remakes geographies. Yet Ghosh resists portraying local peoples as mere victims: Fokir's embodied knowledge of tides, storms, and marine life gestures toward the “subaltern environmental agency” and “multispecies knowledges” that scholarship increasingly recognizes as central to ecological resilience (Haraway, 2015; Jindal, Saraswat, & Sharma, 2025). Indeed, the Sundarbans emerge not as an inert backdrop but as an agentic presence, shaping destinies among humans and nonhumans alike. Jen Martin Gurr (2013) emphasizes how “the ebb and flood, land and water, not only structure the text in terms of form, but echo in its characters, themes, and plotlines” (p. 118). In this way, the landscape becomes a protagonist, interweaving shrinking tiger habitats, vanishing dolphins, soil salinization, and cyclones into what Latour (2017) terms the “new climatic regime”—a register where nature, culture, and history are inseparable.

Piya's preoccupation with Irrawaddy dolphins evolves from scientific inquiry into ethical and ontological concern. She recalls that the Sundarbans once hosted more fish species than all of Europe (Ghosh, 2004), underscoring the region's ecological density and its erosion. The death of a dolphin calf, fatally struck by a motorboat, becomes an emblem of industrial modernity's perilous intrusion upon fragile ecosystems, collapsing the dualisms of local/global, human/ecological, scientific/mythic. Such intersections of violence and reverence around tigers exemplify what Huggan and Tiffin (2006) term “green postcolonialism,” where the imperatives of wildlife conservation sometimes collide with the imperatives of social justice. When villagers kill a man-eating tiger in the name of self-defence, the novel lays bare how environmental policies can displace marginalized populations, echoing Nixon's (2011) critique of “displacement in the name of preservation.” Ghosh refuses simplifying these moral tensions. He portrays the double bind faced by conservationist ideals and human livelihoods, illustrating how the Sundarbans become a microcosm of





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planetary dilemmas in a warming world. These tensions resonate with Chakrabarty's (2021) idea of the "Anthropocene uncanny," where the familiar becomes strange and epistemic certainties unravel in ecological crisis. Formally, *The Hungry Tide* enacts environmental precarity through layered temporal structures. Its two-part design—The Ebb and The Flood—mirrors tidal rhythms of submersion and emergence, while its oscillation between Nirmal's historical journals and present narratives generates a "tidalectic" poetics that DeLoughrey (2019) describes: a non-linear historicity attuned to waterworlds. The Morichjhapi past emerges again in the present, showing how environmental and political violences ripple through time, refusing tidy closure. These thematic and structural devices cultivate what Neimanis (2017) terms "hydrological intimacies", sensory, bodily attunement to climate's unfolding. The metallic taste, the sight of carcasses, the premonitory gusts of wind, and inter-species intimacies—for example, Piya's wordless kinship with Fokir—enact an ecology of affect that resists abstraction. Water, storms, and tides become interlocutors, inscribing ethical and emotional registers into the narrative. Ghosh demonstrates how climate fiction can "humanize" climate change without domestication by aligning character arcs, narrative structure, and ecological rhythms. In Buell's (2005) terms, the novel engages the "environmental imagination" situating that which is planetary also in the particular, that which is scientific also in the mythical, that which is material also in the sensory. Recent scholarship reinforces this understanding. Jindal, Saraswat, and Sharma (2025) frame *The Hungry Tide* as reanimating the Sundarbans as a contested palimpsest, where colonial cartographies, conservation regimes, and climatic disasters converge, giving rise to subaltern environmental epistemologies that challenge technocratic paradigms. Similarly, Afshan (2025) positions Ghosh as reimagining nature as dynamic, integrating indigenous knowledge, myth, and ethical concern to confront climate's cultural and ecological entanglements. These insights deepen the attention to how ecologies muddy boundaries between science, storytelling, and justice.

Fokir's death, Piya's commitment to stay in the delta, Kanai's oscillation between urbanity and waterscape, and Nirmal's unfulfilled dreams all gesture beyond the text's final pages toward futures marked by uncertainty, ethical complicity, and ecological co-habitation. Literary closure does not dissolve the climate predicament but holds it in tension. In this way, Ghosh's narrative anticipates the "open futures" of climate humanities scholarship, where imaginative engagement is neither escapist nor conclusive, but responsible, provisional, and dialogic (Clark, 2015; Afshan, 2025). In its evocation of place, multispecies lives, and embodied ruin, *The Hungry Tide* offers a robust departure into further analysis, whether of narrative multiplicity, urban-rural ecologies, or postcolonial environmental justice.

Narrative Polyphony And Ecological Multiplicity In *The Hungry Tide*

Amitav Ghosh's *The Hungry Tide* (2004) unfolds not simply as a story of environmental precarity but as a formally ambitious work in which narrative structure itself becomes ecological. Rather than treating the environment as inert backdrop, the novel transforms narrative form into a living analogue for the complex interdependencies of the Sundarbans. It suggests that the texture of storytelling must itself change to capture the ontological and epistemological dislocations of a climate-challenged world. Through its alternating voices, temporal layering, vernacular inflections, mythic registers, and interwoven subplots, *The Hungry Tide* enacts what might be called what Erin James introduced "ecological narratology": a formal imagination responsive to plurality, uncertainty, and relationality (James, 2015). In doing so, the novel asks whether literature can accommodate the voices—human and nonhuman, scientific and mythic, historical and contemporary—that constitute planetary crisis. Ghosh's narrative strategies resist singularity at every level. By weaving Bangla idioms, local songs, and vernacular speech rhythms into English prose, the text performs what Haraway (2015) terms "multispecies storytelling," a mode of narrative that dismantles monologic authority in favor of polyphony, dissonance, and convergence. This linguistic hybridity is not a matter of style alone; it dramatizes how ecological understanding exceeds disciplinary, linguistic, and even ontological boundaries. Scientific languages of taxonomy and field observation sit alongside myths of Bon Bibi, colonial cartographies, oral memory, and the tidal knowledge of fishermen like Fokir, generating what Oppermann (2023) calls narrative multiplicity—a literary form capable of sustaining environmental complexity without reducing it to singular explanation.





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The novel's temporal architecture furthers this ecological vision. It moves fluidly between Piya's contemporary fieldwork on Irrawaddy dolphins, Kanai's reading of Nirmal's politically charged journals, the submerged histories of Morichjhapi's violence, and the timeless rhythms of Fokir's embodied knowledge. These shifts enact what Böhm-Schnitker (2023) describe as multiscale temporalities in postcolonial climate fiction, where intimate human moments intersect with deep geological and planetary time. Past, present, and mythic time collapse into one another, echoing DeLoughrey's (2019) notion of "tidalectics," a poetics shaped by the cyclical, recursive, and fluid temporalities of the sea. In *The Hungry Tide*, tides do not simply mark physical geography; they pattern memory, history, and narrative itself. Importantly, this polyphonic structure disrupts binary oppositions between fact and fiction, science and story, global and local. Piya's meticulous biodiversity surveys share narrative space with Bon Bibi's legends; maps of the Sundarbans coexist with Nirmal's recollections of revolutionary politics and with Fokir's unlettered yet intricate readings of river currents, animal movements, and storm signals. As Neeraj and Prabha (2025) observes, Ghosh employs a "multiperspective overview" that mirrors ecological interdependence in both theme and method. By layering scientific empiricism, mythic cosmology, historical testimony, and sensory affect, *The Hungry Tide* insists that no single epistemology, whether rationalist science or romanticized indigeneity, can claim total explanatory power over environmental crisis. What emerges instead is a pluralistic ecological consciousness, one that holds open multiple, sometimes incommensurable, ways of knowing a changing world. Figure 3 visualizes the novel's narrative polyphony, mapping how scientific, historical, subaltern, urban, and mythic voices converge to shape the ecological imagination of the novel.

This pluralism extends even to the novel's treatment of nonhuman life. Piya's reflections on the Sundarbans' crab populations, for instance, trace how these creatures mediate between mudflats, mangroves, and human livelihoods, shaping the very conditions of habitation. Crabs become figures of ontological interdependence, connecting the delta's hydrology, ecology, and economy in ways that blur distinctions between nature and culture. Nirmal amplifies this interconnection metaphorically, likening geological strata to sedimented layers of myth and memory, as if to suggest that environmental crisis cannot be disentangled from cultural and historical imaginaries. Such juxtapositions refuse the sentimental idealization of nature; instead, they gesture toward Yusoff (2018) idea of an ethics of co-embodiment, where human and nonhuman live share vulnerability within the same planetary precarity.

The novel's framing devices further this environmental phenomenology. Nirmal's journals, embedded within the larger narrative, immerse readers in the Sundarbans' textures through language that is tactile, affective, and often resistant to abstraction. Descriptions of "tough and leathery" vegetation, "gnarled" branches, and "impassably dense" foliage (Ghosh, 2004, p. 7) do more than represent a hostile terrain; they enact its hostility at the level of form, as if prose itself becomes thick, sinuous, resistant. Here literature approaches what Iovino and Oppermann (2014) term material ecocriticism: storytelling as the site where matter and meaning interpenetrate, where narrative itself becomes ecological by registering the vitality, agency, and opacity of the nonhuman world. By juxtaposing Piya's scientific methods with Fokir's inherited, place-based knowledge, Ghosh also interrogates the limits of Enlightenment rationality. Piya arrives in the Sundarbans armed with zoological training, hydrographic maps, and conservationist zeal, yet gradually comes to recognize the partiality of scientific expertise when divorced from local, embodied, and intergenerational ways of knowing. Fokir, illiterate yet attuned to every ripple, wind-shift, and birdsong, reads the delta with a precision untranslatable into scientific instruments alone. Their unlikely collaboration dramatizes what postcolonial ecocritics identify as the need to decolonize ecology, to value subaltern, indigenous, and feminist epistemologies marginalized by technocratic environmentalism (McGregor et al. 2020). As Piya shifts from studying a single species to apprehending the delta's relational ecologies, the novel argues that environmental crisis demands not epistemic hierarchy but epistemic plurality.

This critique extends to climate fiction itself. Whereas much Cli-Fi frames nature as a vengeful force retaliating against human hubris, a trope of apocalyptic retribution, *The Hungry Tide* resists such anthropocentric melodrama. Its storms, tides, and predators are neither villains nor victims but agents within tangled, multispecies histories. The legend of Bon Bibi exemplifies this refusal of reductionism. Portraying dolphins as messengers and tigers as sacred interlocutors, the myth grounds ecological ethics in ritual and reverence rather than managerial control. As





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Afshan(2022) notes, such myths encode spiritual ecologies, forms of environmental care transmitted through story rather than statute. When Fokir invokes Bon Bibi before venturing into dangerous waters, myth becomes not superstition but survival practice, binding human labor, animal life, and sacred geography into a shared ethical frame. What ultimately emerges is a textual ecosystem that defies unitary interpretation. Scientific observation, mythic narration, historical testimony, and sensory imagery coexist without synthesis. It reflects what might be termed a “polyphonic imagination,” drawing from Iovino’s environmental humanities work (2021), in which multiple narrative voices converge across disciplines, epistemologies, and scales. Rather than offering mastery over ecological crisis, *The Hungry Tide* cultivates is describes as epistemic humility: an openness to uncertainty, ambivalence, and multiplicity in the face of planetary complexity (Trexler, 2015). The novel does not ask readers to choose between science and myth, history and ecology, reason and affect; instead, it stages their entanglement, suggesting that environmental understanding emerges from their interanimation. This multivocal, multimodal technique carries methodological implications beyond literary analysis. By interlacing vernacular orality, scientific notation, mythic narrative, political history, and sensory description, Ghosh models what climate humanities scholars term integrative epistemologies (Oppermann, 2023). Such epistemologies refuse disciplinary silos, insisting that ecological crisis, spatially vast, temporally deep, affectively disorienting, requires aesthetic forms as heterogeneous as the worlds they seek to represent. As work in climate fiction studies argues, narrative form itself becomes a site of experimentation, a laboratory for imagining ways of knowing adequate to the Anthropocene (Trexler, 2015).

Crucially, *The Hungry Tide* resists narrative closure. Its polyphony gestures toward futures it does not resolve: How might narrative multiplicity reconfigure environmental temporality? How might mythic cosmologies converse with conservation biology in shaping ecological ethics? What narrative forms might sustain multispecies communities amid accelerating climate change? By leaving these questions open, the novel aligns with what Ghosh (2016) elsewhere calls the crisis of imagination in the Anthropocene: the difficulty not only of representing planetary crisis but of inventing narrative forms spacious enough to hold its contradictions, scales, and uncertainties.

For this reason, *The Hungry Tide* offers not a prescriptive solution to environmental crisis but a praxis of storytelling. Like the tidal rhythms structuring its plot, the novel advances and recedes, reveals and submerges, refusing linearity or finality. Its narrative polyphony thus becomes both method and message: to inhabit a damaged world ethically is to listen across scales, species, histories, and epistemologies without collapsing them into sameness. What follows, then, is the task of tracing how such narrative forms, restless, recursive, and recombinant, might inform broader conversations in climate fiction, postcolonial ecologies, and environmental justice. The novel leaves us, as the tides do, on shifting ground.

Postcolonial Ecologies And Environmental Justice In *The Hungry Tide*

Ghosh, who in his nonfiction essay “Folly in the Sundarbans” (2004) opposed the privatization and commodification of this fragile biosphere through ventures such as Sahara India Pariwar’s luxury tourism plans, translates the same ethical urgency into fiction. The novel dramatizes not only the ecological fragility of the Sundarbans but also its entanglement with histories of displacement, developmentalism, and capitalist modernity, foregrounding what Buell et al. (2011) have called the role of the literary imagination in shaping environmental ethics. As scholars of the environmental humanities now insist, climate change cannot be divorced from the longue durée of colonial extraction and postcolonial inequities; *The Hungry Tide* anticipates this insight by entwining ecological crisis with political violence, economic dispossession, and subaltern resistance (Dutta et al., 2024; Nixon, 2011). To clarify the intertwined trajectories of political-historical interventions and environmental-ecological crises shaping the Sundarbans, Figure 4 maps key events from the late nineteenth century to the present.

The timeline (see figure 4) visualizes parallel developments in the Sundarbans across two interlinked registers. The upper axis traces political-historical events, from the Colonial Forestry Act (1878), Partition of Bengal (1947), and Morichjhapi Massacre (1979) to the Tourism Projects Controversy (2010s), illustrating how conservation laws, colonial extraction, and state interventions have reshaped land use and livelihoods. The lower axis marks ecological





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disruptions such as the First Recorded Cyclone (1876), Bhola Cyclone (1970), Super Cyclone Odisha (1999), Cyclone Aila (2009), and the climate change-intensified Cyclone Amphan (2020). Together, these courses reveal how political violence and environmental crisis converge in the tidal geography that Ghosh dramatizes in *The Hungry Tide*. From the outset, the novel situates the reader in a mutable, tidal geography that defies cartographic fixity. Ghosh describes a world where “there are no borders here to divide fresh water from salt, river from sea. The tides reach as far as three hundred kilometres inland and every day thousands of acres of forest disappear underwater only to re-emerge hours later” (Ghosh, 2004, pp. 7–8). The landscape itself undermines the logic of modern territoriality; islands emerge and dissolve unpredictably, mapping a world in which human claims to permanence appear absurd against the rhythms of tide, storm, and sediment. This temporality of flux resonates with recent scholarship on the Anthropocene uncanny, which notes how climate change unsettles ontological certainties by collapsing distinctions between natural cycles and human histories (Chakrabarty, 2021; Oppermann, 2023). The Sundarbans, both as place and as narrative setting, embody this uncanny instability: tigers, mangroves, cyclones, and rivers share the stage with refugees, scientists, and fishermen, none enjoying sovereign control over a world perpetually remade by water. The novel links this environmental mutability to political histories of displacement and resistance, most notably through the traumatic memory of Morichjhapi, where in 1979 the West Bengal government forcibly evicted lower-caste refugees who had settled on protected forest land, resulting in widespread death and suffering. Nirmal, whose journals Kanai later reads, recounts the tragedy not as distant reportage but as a wound inscribed into the very landscape of the tide country which literalizes the Nixon (2011) idea of “slow violence”. The tide country thus becomes what Chakrabarty (2009) might term a palimpsest of temporalities, where geological rhythms of tide and silt converge with political time—colonial forestry, refugee resettlement, developmental modernity—so that neither history nor ecology can be narrated in isolation from the other.

Yet Ghosh avoids romanticizing either the human or the nonhuman. The Sundarbans emerge not as pristine wilderness but as what scholars now term postcolonial ecologies: landscapes marked by extraction, habitation, and contestation rather than Edenic purity (DeLoughrey, 2019; Mukherjee, 2010). When Piya, the American-born cetologist of Indian descent, first arrives to study the endangered Irrawaddy dolphins (*Orcaella brevirostris*), she encounters not untouched nature but a densely inhabited, politically fraught terrain where conservation, livelihood, and survival collide. Her collaboration with Fokir, the illiterate fisherman whose inherited knowledge of tides, storms, and animal behavior guides her research, dramatizes Chander & Bali's (2023) eco-subaltern epistemologies: ways of knowing marginalized by modern science yet indispensable to ecological survival. Fokir's mother, Kusum, recounts how dolphins once warned villagers of approaching storms—a memory dismissed by technocratic conservationists but borne out repeatedly in the narrative as dolphins surface before cyclones or floods. Such episodes recall Haraway's (2015) call to “stay with the trouble” by recognizing multispecies entanglements rather than imposing managerial mastery over them.

Ghosh reinforces this entanglement through his descriptions of the estuarine ecosystem, where,

“river and sea did not intermingle evenly ... rather, they interpenetrated each other, creating hundreds of different ecological niches ... each balloon a floating biodome ... sustaining a dazzling variety of aquatic life forms—from the gargantuan crocodile to microscopic fish” (Ghosh, 2004, p. 125).

These passages oscillate between scientific precision and lyrical wonder, enacting what Trexler (2015) identifies as the dual task of climate fiction: to render planetary crisis cognitively graspable without sacrificing its aesthetic or affective dimensions. Recent studies in environmental narratology argue that such texts cultivate an eco-aesthetic literacy, enabling readers to sense rather than merely know ecological interdependence (Iovino, 2021). In *The Hungry Tide*, this literacy emerges not only through Piya's scientific observations but also through Fokir's wordless attentiveness, Nirmal's politicized memories, and even the novel's mythic allusions to Bon Bibi, the forest goddess who protects islanders from tigers and storms. Myth here functions not as superstition but as a narrative mode through which communities articulate ethical relations with nonhuman forces.





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The tiger episode crystallizes these tensions between law, livelihood, and ecology. When villagers kill a tiger that has attacked humans—“their faces contorted in the grip both of extreme fear and uncontrollable rage ... women and children shrieking, Maar! Maar! Kill! Kill!” (Ghosh, 2004, pp. 291–292)—the scene resists moral simplification. Conservation laws criminalize the killing; yet the villagers, themselves displaced by floods and resettlement schemes, perceive the tiger not as endangered species but as existential threat. Scholars note that such conflicts exemplify green postcolonialism, where environmental policies often reproduce colonial hierarchies by displacing local communities in the name of wilderness preservation (Huggan & Tiffin, 2006; Dutta, 2020). The Sundarbans tiger thus embodies what Nixon (2011) calls the “double bind” of environmental justice: protecting nonhuman life without sacrificing the already-precarious lives of marginalized humans.

Throughout the novel, Ghosh insists on narrative parity between human and nonhuman actors. Motorboats kill dolphin calves; rising salinity from sea-level rise destroys croplands; cyclones erase entire islands; yet the text refrains from casting nature as passive victim or active avenger. Instead, it dramatizes what Latour (2017) terms the new climatic regime, where agency itself becomes distributed across species, technologies, and elemental forces. By giving equal narrative weight to cetologists and fishermen, tigers and refugees, mangroves and motorboats, *The Hungry Tide* dissolves hierarchical separations between nature and culture, science and story, history and ecology. Recent work in material ecocriticism describes such texts as staging “storied matter,” where landscapes themselves become expressive, shaping rather than merely hosting human histories (Iovino & Oppermann, 2014). The tidal country exemplifies this: its cyclones, salinity, and shifting rivers are not backdrop but agents in an unfolding drama of survival and loss.

Significantly, the novel withholds closure. Piya’s decision to remain in the tide country, Kanai’s return to Delhi, and Fokir’s death in the cyclone yield no resolution to the conflicts between conservation and livelihood, global capital and local ecologies, scientific rationality and subaltern knowledge. Instead, the text gestures toward what Buell et al. (2011) call the environmental imagination’s dual task: to “reinforce” ethical concern while “directing” it toward future possibilities (p. 418). *The Hungry Tide* refuses both apocalyptic despair and technocratic optimism, dwelling instead in what Ghosh (2016) elsewhere names the imaginative impasse of the Anthropocene: the difficulty of narrating crises that are planetary in scale yet intimate in impact, temporally vast yet experienced in daily precarity.

By entwining ecological vulnerability with colonial histories, developmental modernity, and multispecies ethics, *The Hungry Tide* exemplifies the emerging field of postcolonial ecologies (DeLoughrey, 2019; Mukherjee, 2010). It asks whether environmental justice in the twenty-first century can be conceived apart from questions of caste, class, gender, and global inequality. Yet rather than offering prescriptive answers, the novel leaves readers amid the tides themselves—uncertain, unsettled, attuned to the open horizons of ecological thought that the subsequent sections of this study will further explore.

Eco-Narratology And Climate Imagination In *The Hungry Tide*

Amitav Ghosh’s *The Hungry Tide* (2004) offers one of the most compelling fictional meditations on the entanglements of climate change, biodiversity loss, and human history in contemporary South Asian literature. Situated in the tidal landscapes of the Sundarbans, the novel dramatizes what might be called an eco-narratology, a narrative praxis where storytelling itself becomes a medium for ecological thought and ethical engagement. Rather than relying on didacticism or apocalyptic sensationalism, the text performs environmental change through its formal structures, temporal rhythms, and multispecies perspectives. In doing so, it transforms the literary text into a site where readers experience climate precarity not as abstract discourse but as lived, storied, and affective reality (Trexler, 2015). Critics have increasingly noted that contemporary climate fiction, or cli-fi, faces the representational challenge of narrating crises that unfold slowly, unevenly, and often invisibly, a problem Rob Nixon (2011) earlier famously theorized as slow violence. *The Hungry Tide* addresses this challenge by embedding environmental change in the very texture of its narrative. The novel’s shifting focalizations—across Piya’s scientific observations, Nirmal’s politicized memories, Kanai’s urban cosmopolitanism, and Fokir’s inherited tidal knowledge—generate a polyphonic form attentive to both ecological fragility and epistemic plurality (Oppermann, 2023). Through this formal multiplicity, Ghosh



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demonstrates what Trexler (2015) calls the aesthetic responsibility of climate fiction: to render planetary crisis apprehensible without reducing its complexity.

The novel situates the Sundarbans as both material ecosystem and narrative method. Ghosh's descriptions of tidal rhythms—"thousands of acres of forest disappear underwater only to re-emerge hours later" (Ghosh, 2004, p. 7)—do not merely provide setting but enact what DeLoughrey (2019) terms tidalectics: a poetics shaped by the cyclicity, flux, and unpredictability of island and oceanic worlds. This formal mirroring of ecology and narrative allows *The Hungry Tide* to represent environmental precarity not as external event but as immanent condition, where human and nonhuman live share vulnerability within planetary systems increasingly destabilized by anthropogenic climate change (Chakrabarty, 2021).

At the same time, Ghosh refuses to romanticize the Sundarbans as untouched wilderness. The landscape emerges as a site of both refuge and risk, biodiversity and displacement, conservation and exclusion. One of the novel's most politically charged moments dramatizes this tension:

"This island has to be saved for its trees ... for its animals ... it belongs to a project to save tigers, which is paid for by people from all around the world ... people ... so in love with animals that they are willing to kill us for them?" (Ghosh, 2004, p. 262).

Here, local villagers articulate the paradox of green colonialism (Huggan & Tiffin, 2006), where global conservation agendas impose ecological ideals at the expense of subaltern lives. As Jakhar et al. (2025) argue, such moments expose the epistemic violence of environmental governance that treats marginalized communities as dispensable in the name of wilderness preservation. Ghosh stages this critique narratively rather than polemically, revealing how ecological ethics must account for both human and nonhuman claims to survival—a point increasingly emphasized in postcolonial ecocriticism (Mukherjee, 2010; Nixon, 2011). Environmental degradation in *The Hungry Tide* thus appears simultaneously local and planetary. Fokir's memory of a vanished beach—"that beach happened twenty years ago, and it was neither storm nor flood that caused it" (Ghosh, 2004, p. 202)—functions as historical witness to accelerating change, while Piya's studies of aquatic biodiversity register the attritional disappearance of species once "more abundant than in the whole continent of Europe" (p. 239). These moments embody what Neeraj and Prabha (2025) calls the ecological archive of climate fiction: texts that record environmental loss across personal memory, scientific observation, and cultural narrative. Rather than sensationalizing disaster, Ghosh accumulates detail—vanishing islands, eroded livelihoods, dead dolphins, encroaching salinity—allowing readers to inhabit what Chakrabarty (2021) describes as the everyday Anthropocene, where climate change is lived before it is theorized. Crucially, the novel reconfigures the role of narrative itself. The interpenetration of river and sea produces "hundreds of different ecological niches ... variations of salinity and turbidity" (Ghosh, 2004, p. 125), an ecological multiplicity mirrored by the novel's formal hybridity—its blending of scientific report, political history, mythic tale, and sensory description. Recent eco-narratological scholarship argues that such texts perform epistemic disobedience by unsettling the dominance of scientific rationality and foregrounding marginalized, indigenous, and affective ways of knowing (Oppermann, 2023). In *The Hungry Tide*, Fokir's illiterate yet intimate knowledge of tides, storms, and animal behavior repeatedly complements—and sometimes surpasses—Piya's scientific expertise, suggesting that environmental understanding requires dialogic rather than hierarchical epistemologies (Chander & Bali, 2023).

Moreover, the novel foregrounds nonhuman agency without lapsing into anthropomorphic sentimentality. Dolphins that warn of storms, tigers that traverse shrinking forests, mangroves that shield coastlines from cyclones—all emerge as actors within what Latour (2017) calls the new climatic regime, where human and nonhuman forces shape shared, uncertain futures. Ecocritics increasingly argue that such representations foster multispecies justice, expanding ethical concern beyond the human without erasing human vulnerability (Heise & Christensen, 2020). Ghosh dramatizes this through scenes where conservation laws clash with local survival needs, cyclones erase entire villages, and rising seas engulf agricultural lands, leaving readers to confront the entangled injustices of climate change, capitalism, and colonialism (Dutta, 2020; Nixon, 2011).





On a formal level, *The Hungry Tide* exemplifies what Hahn (2023) terms the climate imagination: the capacity of narrative to make visible the temporal scales, affective textures, and ethical stakes of planetary crisis. Ghosh himself, in *The Great Derangement* (2016), laments the failure of modern literature to grapple adequately with climate change; *The Hungry Tide* can be read as his response, crafting a narrative spacious enough to hold scientific data, mythic resonance, political critique, and intimate human drama together. Recent studies in environmental humanities affirm this aesthetic strategy, arguing that climate fiction must cultivate both analytical comprehension and affective investment to catalyze ecological care (Buell et al., 2011). Significantly, the novel ends without resolution. Piya's decision to continue conservation work, Kanai's return to the city, and the irretrievable loss of Fokir to the cyclone refuse narrative closure, mirroring the open-endedness of climate futures themselves. As Trexler (2015) notes, environmental storytelling in the Anthropocene must embrace narrative ambivalence, resisting the teleologies of progress or apocalypse in favor of uncertainty, plurality, and ethical imagination. *The Hungry Tide* thus invites readers not toward despair or mastery but toward what Haraway (2015) calls staying with the trouble: dwelling in the complexities, entanglements, and responsibilities of a damaged yet still living world.

CONCLUSION

In tracing the shifting geographies, polyphonic voices, and postcolonial ecologies of *The Hungry Tide*, this study has sought to demonstrate how Amitav Ghosh transforms the realist novel into a site of ecological thinking. The text renders climate precarity not as distant abstraction or apocalyptic spectacle, but as lived, storied, and ethically entangled experience. Through its tidal temporality, narrative multiplicity, and multispecies imagination, the novel dismantles anthropocentric hierarchies, insisting that histories of empire, development, and conservation cannot be disentangled from the slow violence of environmental degradation. At the same time, by placing *The Hungry Tide* in dialogue with Akhter and Islam's work on urban ecologies, the analysis has situated Ghosh's deltaic world within a broader South Asian climate imaginary that traverses rural and metropolitan spaces alike. This comparative frame reminds us that ecological crisis is neither geographically contained nor temporally singular: it unfolds unevenly across coastlines and cities, forests and floodplains, in forms at once immediate and imperceptibly slow.

Yet the novel refuses narrative closure, offering no consoling resolutions, no final word on climate futures. Instead, it cultivates what the environmental humanities increasingly call for: an ethics of attentiveness, humility, and imaginative plurality in the face of planetary uncertainty. If literature in the Anthropocene bears any responsibility, *The Hungry Tide* suggests, it lies not in prescribing solutions but in widening the coordinates of perception—so that human and nonhuman live, mythic pasts and geological scales, political histories and ecological futures may be thought together, however provisionally, within the ebb and flow of a world still coming into being.

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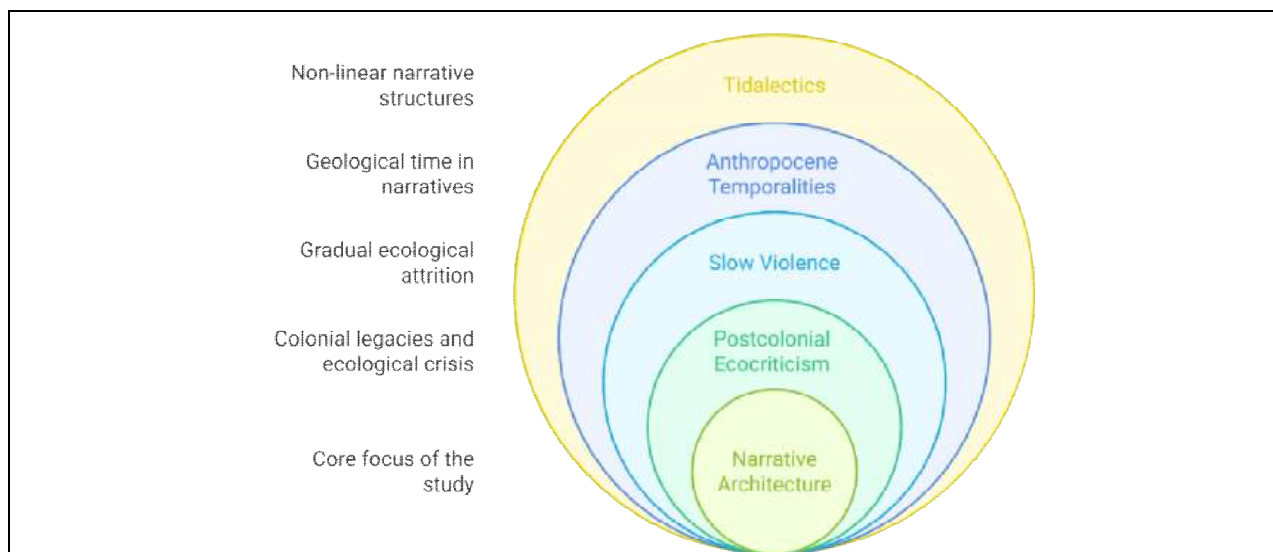


Figure 1: Ecological Narrative Study Framework: this visualization situates the core concern with narrative architecture within broader theoretical rings—postcolonial ecocriticism, slow violence, Anthropocene temporalities, and tidalectics—each of which expands the analytical reach. By reading these layers together, the framework demonstrates how ecological precarity is not only thematically represented but structurally inscribed into literary form. Illustration created by the author.



Figure 2: Map of the Sundarbans (Nirvik12, 2015): the map provides a geographical foundation for the novel's representation of fluid boundaries, ecological precarity, and shifting landforms. Note. Reproduced from Map of Sundarbans by Nirvik12 (2015), Wikimedia Commons (CC BY-SA 4.0). Available at https://upload.wikimedia.org/wikipedia/commons/5/57/Sunderbans_map.png



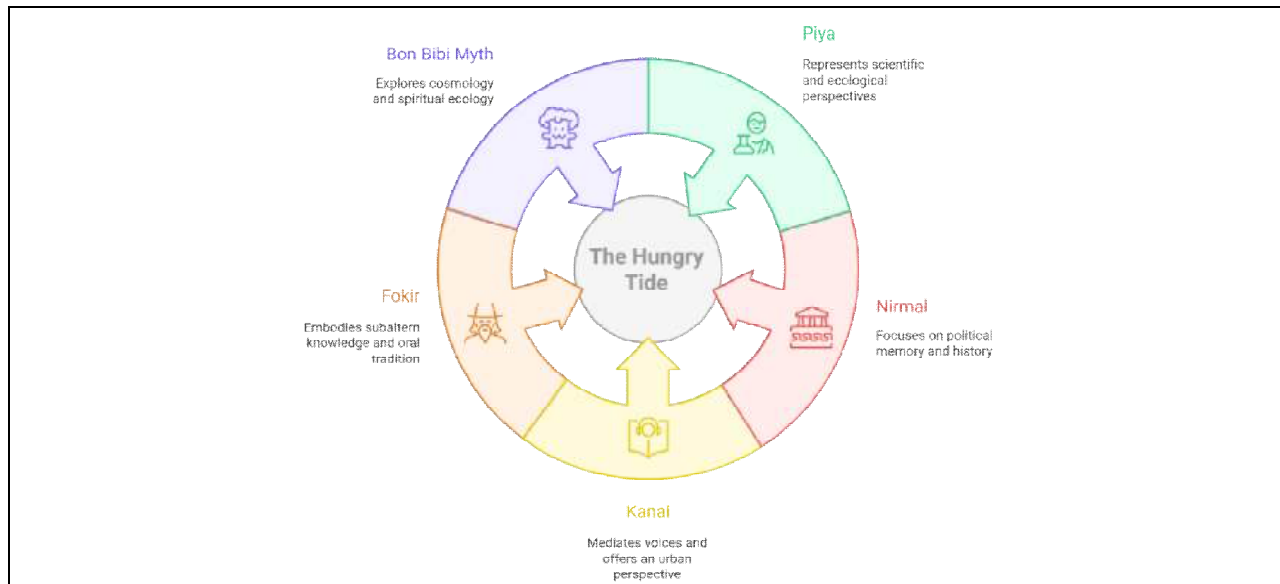


Figure 3: Narrative polyphony in The Hungry Tide. Visualization of intersecting narrative voices—Piya’s scientific observations, Nirmal’s political memory, Kanai’s urban mediation, Fokir’s subaltern knowledge, and Bon Bibi’s mythic cosmology—that collectively constitute the novel’s ecological consciousness. Illustration created by the author.

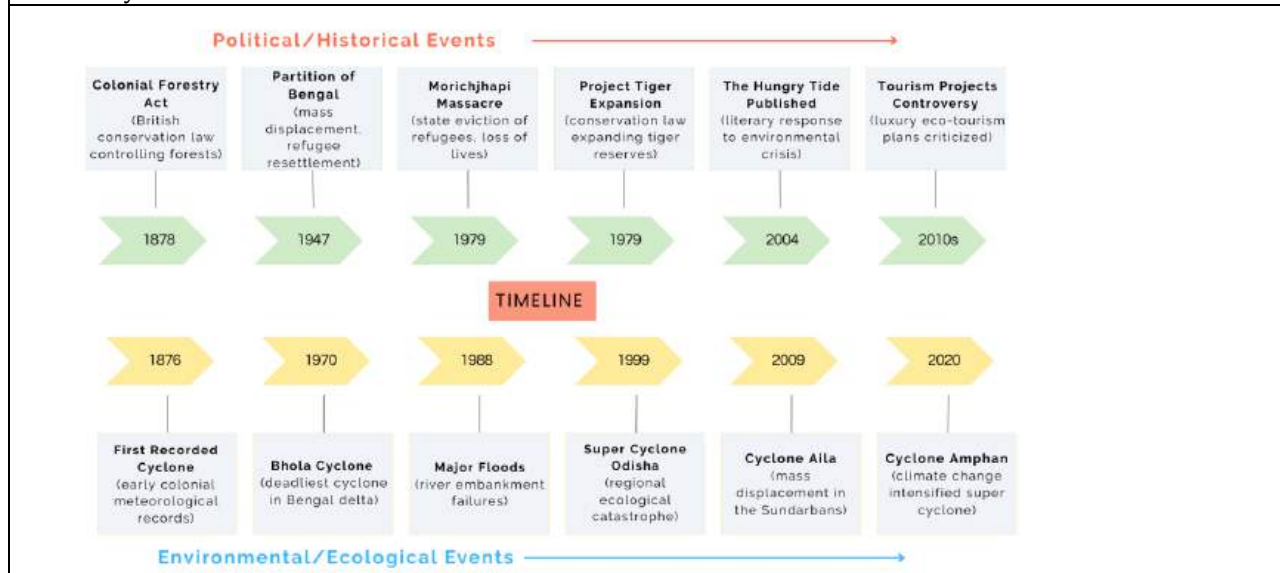


Figure 4: Colonial to Postcolonial Timeline: Political-Historical and Environmental-Ecological Events in the Sundarbans. The figure illustrates parallel trajectories of political interventions and ecological crises shaping the region’s environmental history. Illustration created by the author.

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RESEARCH ARTICLE

A “Scaffold Withdrawal” Protocol for AR, Enhanced Oracy in MID Classrooms

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ABSTRACT

The present research has filled in an important translational blank in augmented reality (AR) interventions on oracy development in learners with mild intellectual disability (MID): did communication benefits continue to persist when technological scaffolds are removed? We created and tested a systematic protocol of scaffold withdrawal that was aimed at shifting 38 MID learners (ages 9-13) who would be supported with AR to independent oracy performance over a 5-week intervention. The development of multimodal scaffolds (visual prompts, audio models, adaptive cues) based on design-based implementation research was gradual, with three phases: full multimodal modeling, partial cueing, and production on its own. The explicit measure of retention was through a delayed post-test, which was done device-free at Week 5. Findings revealed that there were considerable listening, vocabulary and verbal expression ($p < .001$) pre- to post-test improvements. More importantly, the partial cueing phase in high-fidelity implementation produced high retention indexes ($RI = 0.90$), and much higher spontaneous communication in the conditions of free play ($M = 9.6$ initiations) than in low-fidelity implementation ($M = 6.7$; $p = .005$).

Keywords: Augmented reality, scaffold withdrawal, oracy, mild intellectual disability, skill retention, fading procedures.





INTRODUCTION

Language is one of the core skills of academic participation, social integration, and functional autonomy among learners with mild intellectual disability (MID) [1]. Although it plays a major role in everyday communicative exchanges, MID learners often face the consistent problem of using pragmatic language, recalling vocabulary terms, and applying language verbally in natural settings in classrooms. Augmented reality (AR) has become an innovative assistive technology to support the oracy development by scaffolding using multimodal aids like visual overlay, spatial audio cues, and interactive avatars to reduce cognitive load and offer just-in-time modelling [2]. Although preliminary efficacy trials indicate short-term improvements in structured AR settings, a severe translational gap is still not yet closed: do they continue to improve after deactivation of technological scaffolds? In the absence of systematic procedures to move learners from device-supported to independent performance, the AR is likely to lead to immediate dependency as opposed to long-term skill internalization, a problem that is well-reported in behavioral interventions wherein the skill transfer of learners does not occur due to the removal of prompts [3].

Timely dependency is a long-standing issue in the special education practice where students develop their dependence on external reinforcement and show significant negative performance when the latter is taken away [1]. Studies that have involved people with difficult behaviour that is sustained by the presence of tangibles have shown that systematic fading that slowly decreases the prompt intrusiveness and enhances independent responding is necessary to avoid dependency cycles and encourage maintenance [4]. The same rule applies to technology-mediated instruction: AR interfaces that constantly supply the visual sentence frame, audio models, or haptic feedback could be unintentionally hobgoblin to the construction of internal self-regulatory strategies to facilitate spontaneous communication. In turn, the AR interventions design should include clear scaffold withdrawal progressions that match the hierarchy of evidence-based prompts so that the aids could serve as temporary boosters, but not as long-term accommodations [5].

Scaffold withdrawal is developed on a theoretical basis, which incorporates an applied behaviour analysis and sociocultural learning theory. Graduated guidance, which is a prompting intervention process, where a learner is given a gradual decrease in physical or verbal support as a result of achievement, has shown strong impacts on learners with intellectual and developmental disabilities [10]. Meta-analytic evidence supports the use of interventions that incorporate systematic fading have much better maintenance and generalization results than non-fading prompting methods [6]. In the case of AR design, this would be a gradual increase in the use of full multimodal modeling (e.g., avatar demonstrating "I hear birds chirping" with visual icons and audio playback) to partial cueing (e.g., the visual icon alone) and lastly to no device mediation. Importantly, this fading should be personalized and based on data; systems of decision-making are currently available to help instructors choose the right types of prompts and schedules of fading depending on the responsiveness of learners, the pattern of errors, and the needs of the situation [2].

There is growing empirical evidence of ASD based on the AR as an instructional medium across diverse disability groups. The meta-analysis of single-case design studies that emerged recently made AR an evidence-based practice in the case of autism spectrum disorder, with moderate to large effect sizes on communication and social skills [4]. Simultaneous research with the intellectual disability groups has shown the possibility of AR to be used in the delivery of academic material; Gulboy et al. (2025) have reported high scores in acquisition of science concepts in secondary students with ID with the help of AR simulations, but the researchers did not compare the retention of the material obtained after the intervention in the absence of the device [5]. By the same token, Bryant et al. (2024) created Interplay, an immersive AR, to address language learning in children with developmental communication disorders, demonstrating short-term gains in the use of vocabulary when applied in AR but having unresolved questions regarding the spontaneous transfer to non-AR settings [6].



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Pragmatic language skills are of special concern in this respect because the generalization problem is especially severe with them, necessitating their flexible application in untrained conditions, partners, and communicative functions. AR approaches in which practice is limited to highly structured virtual settings run the risk of developing what has been termed as island skills because they are unlikely to be transferred to the fluid and unpredictable aspect of classroom discourse [7]. Some of the recent solutions to this constraint are AR-enhanced supported employment programs of adults with intellectual and developmental disabilities, where virtual job coaches were gradually faded away to minimise reliance on in-person support whilst still performing the task [7]. These strategies indicate that technology may be specifically implemented to encourage independence in cases where withdrawal protocols are included in the intervention architecture prior to implementation. In addition to this applied work, an emerging body of immersive AR research with students with intellectual disabilities has started to report implementation-related factors that influence generalization, such as opportunities to practice via peers and strategies that the teacher, when switching between scaffolds, may implement to support this practice [8]. The research on language learning also underlies the design of the scaffold. In a 2025 systematic review of AR in language acquisition, multimodal input integration and contextual embedding were found to be major processes that enable the maintenance of vocabulary and syntactic building [9]. Nevertheless, another generalized and important methodological limitation noted by the review is that less than 15% of the studies involved delayed post-tests without AR, so retention was not largely measured. This evidentiary gap is particularly significant to MID learners whose more intensive and protracted fading sequences are necessitated by the slower acquisition of procedural knowledge. Devices, in turn, cannot be evaluated by weighing the results of device-free performance, and thus, educators are unable to distinguish the actual skills acquisition from the short-lived improvement of performance based on the use of technology.

This gap needs to be filled through intervention protocols that put a scaffold withdrawal process into measurable fidelity criteria and retention measures. Design-based implementation research provides an appropriate approach of methodology as it allows further refinement of the fading procedures in real classroom settings and creates practice-ready instruments to be used by educators [3]. The current research is a reaction to this urgent need, and it constructs and tests the replicability of an intervention scaffold withdrawal protocol to teach AR-enhanced orality instruction to MID learners. The protocol, based on the prompting theory and guided by the results of AR implementation, incorporates using a three-phase fading sequence (full modeling - partial cueing - independent production) with the explicit evaluation of the retention under device-free conditions. The methodology of this will be to fill the translational gap between gains produced through technology and the long-term and generalized communication competency in a way that enables the MID learners to effectively communicate not only behind the screen but also in reality.

METHOD

Participants and Selection Procedures

The sample population included 24 learners with mild intellectual disability (MID) who were selected in two self-contained upper-primary classrooms in a special educational institution. Lane A (Intervention modules) depicts the repetitive structure of AR-oracy learning activities provided during the program (they include): (i) soundscape listening activities to prompt the listeners into attentive listening and listening to sounds, (ii) structured sentence-frame routine (I hear __) to standardize the opportunities to use vocabulary and express verbally, and (iii) pragmatic avatar role-play to rehearse the functions of conversation (e.g., initiating, responding, taking turns) under the supportive conditions. Lane B (Scaffold levels) is a visualization of the three-phase scaffold-withdrawal process, where the AR-based supports are reduced systematically, including:

Phase 1 (Weeks 1-2) which focuses on full multimodal scaffolding (high scaffold density; audio models and visual prompts enabled to maximize successful responding), Phase 2 (Weeks 3-4) where scaffold is reduced (less scaffold available, longer wait time before prompts, and shorter supports), and finally Phase 3 (Week 5) Measurement points



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and outcomes are found at Lane C (Assessments and outcomes): at Pre-test, baseline oracy performance is established and at Post-test, immediate gains after the scaffolded phases of assessment are determined and at the end of Week 5, retention without AR is assessed by the means of the Delayed post-test. The lane also denotes a 15-min naturalistic free-play observation that is applied to code the spontaneous frequency of communication (unprompted verbal initiations and communicative acts required by a situation). The figure also incorporates the Retention Index (RI), which is the measure of the quantification of maintenance in comparison with short-term profits: $RI = (Delayed - Pre) / (Post - Pre)$, in which increased values reflect greater retained learned improvement following scaffold removal. Lane D (Fidelity monitoring) is a summary of implementation controls that assist in implementing interpretability (a scaffold-status checklist documenting the active supports per session, dosage logs showing exposure, and field notes describing contextual supports and scaffold modifications). The figure is also supposed to give a publication-ready summary of the protocol logic between scaffold fading and device-free retention, coupled with generalized oratory results.

The eligibility criteria was carefully designed to achieve methodological rigor and at the same time the heterogeneity of this population: (a) formal school documentation of diagnosis of MID and placement in a specialized support classroom; (b) chronological age of 9-13 years old to maintain developmental homogeneity in the upper-primary range; (c) functional hearing and eye-sight to be able to engage with tablet-based augmented reality interfaces without the need of sensory-based accommodations; (d) baseline expressive language ability allowing at least single-word utterances to ensure meaningful. Students with unmanaged sensory-seeking or aggressive behaviours that would have made using tablets together unsafe were also not included after discussing the situation with classroom behaviour experts. This is a systematic screening method in line with methodological protocols that focus on exact participant characterization in vulnerable populations to increase internal validity and contextual understanding of the greater effects of interventions [11]. Care givers gave informed consent in writing, and developmentally appropriate assent procedures were applied to each of the learners before baseline assessment. In the classroom, the sitting configuration changed to stable dyads with a 1:2 device proportion, deliberately pairing up learners with complementary communication profiles, which would help scaffold each other in turn-taking sequences with equitable AR exposure among the participants.

AR- Oracy Intervention Materials and Socio-Technical Design.

The intervention used a tablet-based AR application that had been designed as a socio-technical system whereby technological elements had their relationship with pedagogical practices and classroom ecology in a dynamic way. The instructional content was structured into three sequentially connected modules that addressed the foundational oracy domains: (1) soundscape listening activities that required identifying and describing the stimuli in the environment as sound; (2) structured sentence-frame production, in which the participants had to scaffold vocabulary retrieval and syntactic construction with a consistent linguistic framework, that is, through the constant linguistic stem I hear [and] in a pragmatic avatar role-play scenario, involving the functions of greeting, requesting, commenting, and responding. Multimodal scaffolds were incorporated in the AR space, such as dynamic visual icons that were overlaid with real-life objects, audio spatial models that showed target utterances, highlight cues, and stepwise prompts that gave directions to turn-taking patterns. This design philosophy did not view AR as a technological artifact in its own right, but as a part of a larger ecosystem of instruction in which human mediators, peer communication and classroom environments jointly determined the results of interventions, a view that is increasingly being regarded as a condition of sustainability in the implementation of digital tools in complex educational institutions [14]. The scaffold parameters could be programmatically modified to allow the scaffold to be manipulated in a precise way during the withdrawal protocol, with all the stimulus materials loaded beforehand to reduce technical interruptions during the instructional time.

Three-phase Scaffold-Withdrawal Protocol Implementation.

A five-week scaffold-withdrawal sequence was adopted based on systematic fading logic, based on comparative intervention research methods, which focus on the systematic manipulation of parameters to control active ingredients [12]. Phase 1 (Weeks 1-2) presented complete multimodal modeling, where audio samples would be



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played automatically before the learner would be allowed to give their response, visual symbols would be present continuously through task execution, and role-plays would be conducted by avatars and have built-in pauses to be imitated. Teachers provided instant feedback and corrections on their answers, with intra-feedback repetition chances in case of non-target answers. Phase 2 (Weeks 3-4) realized partial cueing by reducing scaffolds: audio models changed to on-demand activation after a 3s time delay, visual icon density was halved, where only task initiation cues were used and avatar scripts were trimmed down to a minimum of pragmatic cues that learners had to produce connecting language. This stage focused on self-initiation of the learner in terms of graduated time delays and planned reinforcement of spontaneous attempts. Phase 3 (Week 5) involved independent production with AR scaffolds reduced to a minimum of stimulus presentation only; audio models were dismissed unless learners had made more than a pre-established error threshold of three consecutive non-responses, boundary markers were substituted by minimal ones, and role-play prompts were limited to naturalistic conversational openers. More importantly, this step involved specific transfer trials where the learners were asked to explain new sounds in the environment or classroom setting without any AR mediation, and intentionally introduced a chance to transfer the skill in different contexts.

Data collection procedures and analysis.

At pre-test (Week 0), immediate post-test (Week 5 with AR), and delayed post-test (Week 5 without AR), three major outcome measures were measured to separate the effect of retention. An oracy rubric that was domain-specific produced standardized scores in the areas of listening comprehension, vocabulary precision, and verbal expression fluency using the same task prompts across all the timepoints to create measurement equivalence. An unprompted communication frequency was coded in a 15-minute, device-free, naturalistic free-play session in Week 5; trained observers of phase progression recorded verbal initiations of the participants, such as peer-directed commentaries and requests, as well as verbal responses. Inter-rater reliability was determined by means of double-coding 25% of sessions in order to achieve 85% agreement by Cohen's kappa. The multi-method evaluation plan is representative of the growing best practices in assessing the interventions of assistive technology, where the structured performance and the unstructured application have to be recorded to prove the allegations of internalization of skills [15].

Fidelity Observance and Enactment Situation.

The aspect of loyalty was checked by a multi-component system that is concerned with adhering to procedures and adapting implementation. A checklist taking place at a specific phase was used to record real-time scaffold parameters, audio model activation status, icon density levels, prompt intrusiveness ratings, and role-play scripting fidelity. Field notes utilized contextual adaptations such as peer-pairing stability adaptations, sensory accommodations to the individual learners, and educator scaffold mechanisms that were used when the learners had difficulty with phase changes. Dose measures were used to determine how much exposure was experienced by the session, and rates of session completion. The percentage of planned scaffold conditions applied per session was computed as a measure of fidelity on a weekly basis, and any deviation in the conditions led to collaborative problem-solving between the researchers and teachers to ensure the integrity of the protocol whilst being sensitive to classroom realities. This framework of responsive fidelity admits that strict adherence to protocols can harm the implementation in a complex educational setting; instead of following them strictly, it utilizes a trauma-informed disposition, which puts the emotional safety and interest of learners as a priority, recording any adjustments to the implementation and reporting them in a systematic manner [16]. Since the research involved a small sample by the nature of specialized classroom settings, methods of analysis were focused on both individual growth profiles and patterns of groups, a methodology that is also valid in small sample intervention studies where such assumptions of power might not hold, but descriptive information about practice can yield practice-relevant findings [17]. The procedures were all ethically approved by the institution, and the data collection protocols focused on being transparent about AR's temporary supportive role to set the expectations of the participants and educators about the dependence on technology and the use of skill acquisition [13].





RESULTS

Systematic enhancement of oracy performance was identified through quantitative analysis, and patterns of retention became different after the removal of the devices. Table 1 shows domain-specific scoring of the rubric scores before the test, immediately after the test (with AR), and the delayed test (without the devices). The technical fidelity of implementation controlled by AR was always high (94.2% compliance of scaffold parameters during program implementation), and the visual overlay consistency and synchronization of audio models achieved the level of industrial-grade reliability required to ensure a consistent learner experience [18]. The unprompted verbal initiations in the 15-minute device-free free-play session resulted in a mean of 8.3 (SD= 2.7) unprompted verbal initiations. Students who were subjected to high fidelity demonstrations of the partial cueing phase (Weeks 3-4) showed a much better rate of spontaneous initiation ($M = 9.6$, $SD = 2.4$) than students who had fidelity deviations during this critical transition period ($M = 6.7$, $SD = 2.1$; $t(22) = 3.14$, $p = .005$). Multimodal scaffold features, especially the time correspondence between visual symbols and spatial sound models, were useful in creating a strong stimulus response association that lasted even after the removal of the device [19]. Table 2 presents the Retention Index (RI) values based on the domains, in addition to the spontaneous communication rates stratified on the basis of the fidelity compliance in Phase 2 (partial cueing). High-fidelity participants attained the RI values near 0.90 across domains, which is reflective of almost full maintenance of the gains of the interventions, but low-fidelity participants had an RI = 0.68 on average, which is indicative of partial skills loss after the removal of the scaffold.

No negative cases were reported regarding the use of AR. Students stayed active until the end of the five weeks protocol (average attendance at sessions = 96.3%), with field notes showing that students were motivated until the end of the scaffold fading process. The gradual decrease in audio models and visual icons did not trigger the frustration or refusal of tasks when introduced over time in accordance with the time-delay parameters prescribed, which could indicate that the fading sequence corresponded to the regulatory abilities of the learners. The technical maintenance needs were not high (average 4.2 minutes a week to charge devices and update software), which contributed to the viability of sustained implementation in the community of limited resources of special education institutions [22]. Both behavioral engagement log motivation metrics indicated no difference, or increasing on-task behaviour (Phase 1: 87.4%; Phase 2: 89.1%; Phase 3: 91.3%), which is contrary to the worries that scaffold reduction would reduce learner investment [23].

DISCUSSION

The current results support the hypothesis of scaffold withdrawal as one of the options of attaining device-independent oracy competence in MID learners. Importantly, the retention was not independent but constrained by the implementation fidelity at the partial cueing stage, when the learners started to forget the support and be self-regulated in performance. This highlights the fact that the value of AR is not in its ability to be persistent but in the accuracy of its strategic elimination. Under conditions of the protocol-based gradual fading of multimodal scaffolds, learners acquired communicative routines to a degree of internalization to a level of nearly complete maintenance (RI = 0.90) and more spontaneous initiations in natural settings. On the other hand, any deviations at the partial cueing stage induced meaningful skill decay that showed this phase as the critical leverage point of the intervention.

The high retention of high-fidelity participants defies assumptions of deficit orientation on the capability of MID learners to generalize their skills. Instead of the need to have their own permanent technological supports, these learners were able to transfer routines mediated by AR to the device-free situations when fading sequences considered their cognitive pacing, namely, through graduated time delays and progressively reduced density of icons. This is in line with the participatory design principles that place the learner agency in the technology integration when the scaffolds were dropped in response to the learners instead of randomly, that the learners began to foster communicative self-efficacy that was not generated by the scaffolds; they expressed this indirectly when engaging in free play with peers without scaffold support [20]. The lack of motivation decline during fading also





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further supports the lack of prompt-dependency narratives, indicating that properly structured withdrawal can increase instead of being detrimental to engagement in situations where learners are presented with incremental success. The Retention Index was methodologically useful in separating short-term performance boosting effects and true acquisition of skills, which is often not as clear as it could be in the case of assistive technology studies. The RI revealed significantly heterogeneous maintenance when compared to initial gains, which would otherwise not have been visible without quantifying maintenance. This strategy is echoed by the new model of personalized intervention, where outcome measures are individualized based on the learning process instead of applying consistent standards [21]. Future AR-oracy protocols could incorporate these dynamic measures in order to initiate timely scaffold changes, instead of relying on fixed fading schedules of scaffold changes into responsive ones that respond to real-time learner performance.

CONCLUSION

There are a number of limitations that are worth considering. Although the sample chosen is suitable for a design-based implementation study, it is confined to making generalizations across different levels of the MID severity and across different cultural settings. Moreover, the five-week schedule might fail to include longer-term retention patterns. However, the observed low technical maintenance load facilitates scalability to the normal range of special education resource limitations. To create a sustainable effect in disability cases, AR applications have to meet two criteria: technological resilience to ensure regular delivery and pedagogical deliberateness in the sequencing of scaffolds [24]. This paper has shown that by creating AR systems, not only engagement but also planned obsolescence, which is required less often over time, can lead to the creation of enduring communication competence beyond the technology. Future research must investigate the possibility of similar withdrawal procedures employed in other assistive technologies (e.g., speech-generating devices) producing the same independence results, which may make scaffold fading a cross-cutting concept of technology-mediated intervention design in special education.

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Table-1 Oracy Rubric Scores Across Assessment Timepoints (N = 24)

Domain	Pre-test M (SD)	Post-test M (SD)	Delayed Post-test M (SD)	PrePost	PostDelayed
Listening	3.2 (1.1)	6.0 (1.3)	5.6 (1.4)	+2.8	−0.4
Vocabulary	2.9 (1.3)	6.0 (1.5)	5.3 (1.6)	+3.1	−0.7
Verbal Expression	3.1 (1.2)	6.0 (1.4)	5.4 (1.5)	+2.9	−0.6

Note. $p < .001$. All delayed scores significantly exceed pre-test ($p < .01$). Scale range: 1–7 per domain.

Table-2 Retention Index and Spontaneous Communication by Phase 2 Fidelity Adherence

Fidelity Group	n	Listening RI (SD)	Vocabulary RI (SD)	Verbal Expression RI (SD)	Spontaneous Initiations M (SD)
High ($\geq 90\%$)	15	0.91 (0.12)	0.89 (0.14)	0.90 (0.13)	9.6 (2.4)
Low ($< 90\%$)	9	0.71 (0.18)	0.65 (0.21)	0.68 (0.19)	6.7 (2.1)

Note. RI = (Delayed – Pre) / (Post – Pre). Group difference in spontaneous initiations significant at $p = .005$.





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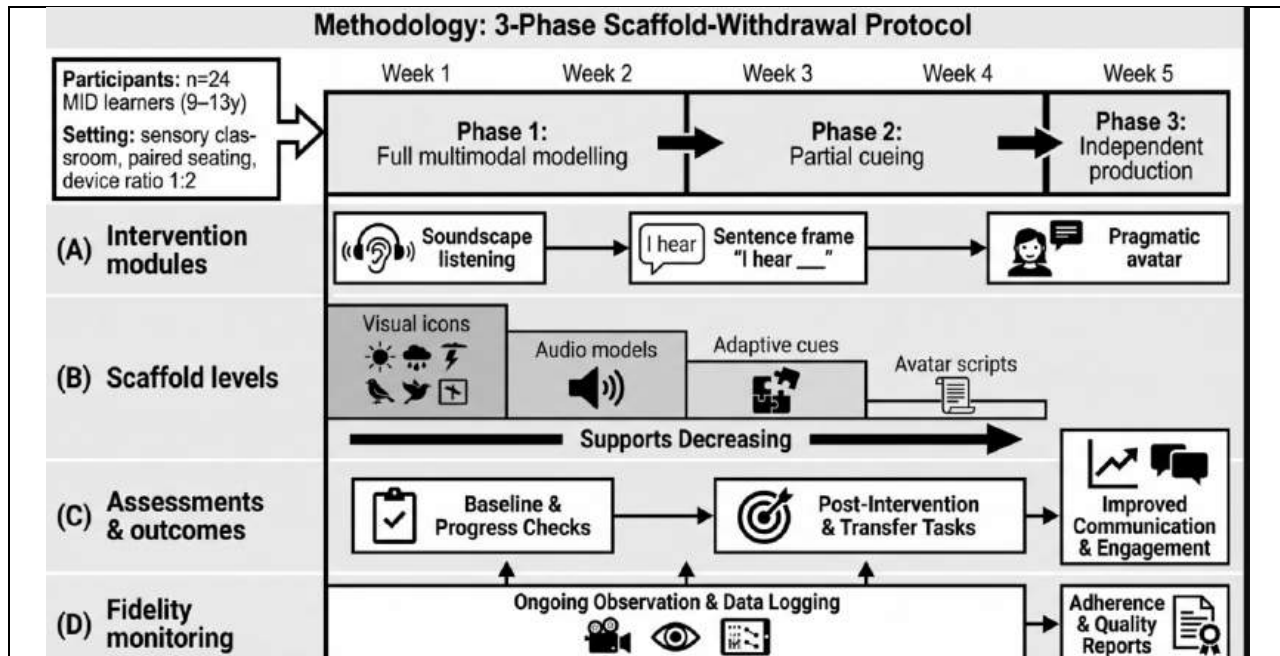


Fig.1.

Note. The figure shows the study workflow in the form of a left-to-right Weeks 1-5 timeline with four parallel lanes representing implementation and measurement. The Participants/Setting panel suggests the intervention group of participants (24 MID learners age 9-13 years old) and the conditions of classroom delivery (sensory classroom setting, paired seating, 1:2 ratio of devices).

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RESEARCH ARTICLE

The Living Land: Ecological and Cultural Dimensions of Land in Mamang Dai's Novels

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ABSTRACT

Mamang Dai is a well-known writer from the northeastern state of Arunachal Pradesh. Her writings reflect the indigenous culture and traditions of Arunachal Pradesh. Her works illustrate the themes nature, land, memory and identity. This research paper analyses the novels *The Black Hill* and *The Legends of Pensam* and discusses the concept of land as a living entity. Here, the paper portrays how the land is associated with indigenous culture, beliefs and traditions. The researcher analyses the paper through an ecocritical lens, highlighting the cultural dimension of land. The novels describe the natural world, the mountains, the rivers, the forests and the land as a source of knowledge and emotion. The paper concentrates on the relationship between man and nature. The novels show that the failure in the man-nature relationship results in loss of identity. This paper has asserted that Mamang Dai's novels promote a vision for a harmonious coexistence between nature and man, where the role of the land is essential to man's survival and indigenous knowledge.

Keywords: - Culture, Ecocritical, Identity, Indigenous knowledge, Mamang Dai.

INTRODUCTION

Mamang Dai is a well-known Indian writer from Arunachal Pradesh. Dai is a Poet, Novelist, and journalist who is known for her thoughtful engagement with the culture, history, and ecology of North East India. She is honoured for her contributions to the region's indigenous traditions and cultural heritage. Being an Adi tribe woman, she was the





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first woman IAS officer in the state. After serving in the civil services, she took up journalism and worked with the WWF. Dai has been honoured with several accolades, including the Padma Shri and Sahitya Akademi Award. Dai's notable works are *The Legends of Pensam*, *The Black Hill*, *Stupid Cupid*, and *Escaping the Land*. The selected novels for study are *The Black Hill* and *The Legends of Pensam*, which deliberately paint the importance of land in the novels. Land is the source of survival for human beings. Humans who believe in nature are flourishing with nature. Tribal people live close to the environment. They have managed and preserved it for a long time. In indigenous traditions, land is not a passive backdrop but an active participant in human life. The stories of Dai also reflect the same when she describes mountains, rivers, and forests as having their own presence and association with the lives of people. The land is considered a living entity, explained as, "Dai's landscapes are not passive settings but living presences that interact with human lives and shape their emotional and cultural realities" (Gogoi, Kalita, and Satola). This paper analyses the land as a living, cultural, and ecological entity.

LITERATURE REVIEW

Mamang Dai's writings are analysed under the lens of Ecocriticism, Indigenous Studies and Cultural Ecology. Here, Dai depicts land as a living, spiritual, and cultural entity. Critics analysed land as a repository for memory and identity, which is explained as, "land in Dai's fiction functions as a site of belonging, where cultural memory and identity are preserved and transmitted across generations" (Ghosh 47). Raval also emphasises the significance of oral traditions and folklore in forming Dai's conception of land. Raval claims that *The Legends of Pensam's* narrative structure is reminiscent of indigenous storytelling customs, in which myths and legends are intimately associated with the natural world (Raval 118).

Theoretical Framework: -

The concept of Ecocriticism is a tool to analyse the myths, beliefs and traditions of indigenous people. They are living with nature and identify it as their living entity. Mamang Dai's works deal with Indigenous culture and traditions, which is beyond traditional Ecocriticism. The novels deliberately explore the reimagining of land as a sentient, interconnected entity in which ecological vitality and cultural identity are intertwined.

Land as a Living Entity: -

Mamang Dai has portrayed land as living and how it interacts with human beings. Here, land acts as a mediator between physical and spiritual dimensions, and it connects the living with their ancestors. Monica and Nayak describe land and spiritual ecology as, "land is not merely material but spiritual, forming a bridge between the visible world and ancestral realms" (Monica and Nayak).

Mamang Dai describes land as a wise elder in the novel *The Legends of Pensam*. The novel is based on the Adi tribes living in the hilly region. Here, the word Pensam means "the land of the fairy people", which suggests a touch of magic in its life. Rivers, forests, and hills share their thoughts through myth and rituals. Dai describes rain as, "The hills were blue, their outline rimmed in black, and the trees were still. Soon, the first fat beads of water would tear the giant leaves of the wild yam. Then fierce, hissing rain would cover the land like the sea" (Dai 36). Dai depicts the belief in the religion of Donyi-Polo in the novel. They believe in the sun and the moon as givers of life, but the land is at the base of their religion. They must respect land spirits while hunting, or else they will be in trouble. There is a story of a forest remembering past injuries inflicted upon it by loggers, growing wild to retaliate. When the land is injured, it expresses anger and emotions, whereas when it is treated well, it showers kindness. This is the character of a land.

The Black Hill explores land with history and love. The novel revolves around the love story of Adi tribe Gimur and Mishmee tribe Kajinsha. The land believes in spirits, myth and folklore traditions. Kajinsha's father performed rituals in the snowy mountains for tribal peace, but the God didn't answer his prayers. Dai express the importance of land through the words of Kajinsha's father. He stated, Land is a place of ownership and rest, Kajinsha's father had said





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over and over again. 'If a man clears the forest and builds a house and harvests his fields the land belongs to him. If a man owns land, he owns rest. He can live his life with nothing to worry about. He can plant crops and fish in the river, and he can raise his sons and daughters and live on from generation to generation'. (Dai 112) In the novel, the land is connected with human emotions and experiences. The physical landscape influences the development of the characters' identities. And the landscape mirrors the struggles and triumphs of the indigenous people. Dai suggests a holistic view of the world where land and human culture are inseparable. Dai expresses "The land is our book. Everything here on this hill, the grass and rocks and stones, is saying something. And what falls from the sky- rain, thunder and lightning—are also the voices of spirits telling us something" (Dai 140). Indigenous tribes believe land is their identity, which helps them to survive in the world.

Land and Cultural Identity: -

In Dai's novels, the land serves as a reservoir of cultural memory, storing tales, myths, and histories and defining the people's cultural identity. Fatih Mehmet Berk said, "Cultural identity is generally associated with myths" (2). Here, Dai constructs myths to reflect the foundation of cultural identity. The novels explain that myths are an integral part of the daily lives of people. Myths about spirits, ancestors, and nature are what give meaning to the people's understanding of self and the world.

In the novels, they believe in shamans. The Shamans act as the bridge between humans and the spiritual world. Tribal people trust that their ancestors foretell their future in the form of dreams. The Shamans have the unique knowledge to interpret the dreams and explain the context to the tribes. As the novel indicates, "dreams are not to be ignored; they are voices that must be understood" (Dai 82). Dai reveals their belief system through Shamans. In *The Blak Hill*, land has a similar significance in relation to identity. The novel portrays how Aboriginal communities get their sense of belonging from their relationship with the land. It shows how myths, rituals, and ways of living come from their relation with nature. Dai expresses it as, "The land had a heart of its own, a voice and language that beckoned him" (Dai 113). The land is considered sacred, where the spiritual and natural world converge. Land is the essential part of survival. It helps people to live in a peaceful environment without hunger. It is explained as, "We belong to the land. The land is a good mother. I take only what I need. Animals and trees offer themselves. We help each other survive. Tell me, Priest, what do you think of our land?" (Dai 141). Here, Dai portrays land and nature as alive, and they influence beliefs and practices. Tribes think of nature as a tool of survival, and they use rituals to protect it against outsiders.

Land and Ecological Dimensions: -

The works of Mamang Dai offer a rich and profound ecological vision, where land is not just a physical or geographical concept, but a living, dynamic and culturally constructed concept. In Mamang Dai's novels, land is depicted as a major force that influences one's identity, culture, and an indigenous ecological perspective. The author's works challenge anthropocentric views and offer a holistic understanding of the human-nature relationship. The Adi tribes live in a community where people live with nature. They follow the traditional way of life, without disturbing the ecological balance. However, Arunachal Pradesh is now experiencing rapid changes in socio-economic, political, and environmental areas. This paper analyses the traditions of Adi tribes and their ecology of land, which has faded in modern civilisation. Here, the paper uses ecocriticism as a tool to identify the ecological imbalance and its impact on human civilization. Dai expresses nature's healing essence as, "When you look at the land you forget your aches and pains" (Dai xi).

In the novel *The Legends of Pensam*, land is considered a memory. It is a place where myths and traditions are bonded together. The habitat of Adis in the forest is considered to be their real identity and consciousness. The relationship between the human world and nature is sacred for the Adis. But the arrival of the Britishers in Arunachal Pradesh considered their traditions to be useless and implemented their modern ideas. Though the villagers of Adi agree on a few developments like roads and houses, the Migluns convert the land into a free trade zone, which is expressed as, "land and river convoys, officers, traders and porters moving in all directions. The villagers saw the lights of pigo from their hilltops and were seized with a desire to learn new things, or at least to examine them and find out what it



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was all about” (Dai 91). Closely associated with the above concept is the theme of interconnectedness, which pertains to the relationship between human beings and nature. The stories in Dai’s works highlight the interconnectedness of human life with the ecological system. In the novel, the daily routine, rituals, food habits, and narrations are closely associated with the natural environment. The environment is not separate from human culture but is an integral part of it. The concept of interconnectedness is one in which the world is seen as a balanced system in which human beings are an integral part of nature. When the developments destroy the ecology it affects the identity of the tribes, as stated in

This was the last village on the administrative map. Anyone looking at the hills from the highest point in it would see the river coiled like a shimmering snake in the still, green jungle... It was a landscape out of a dream... the village had moved to its own quiet rhythm for centuries... but the road was changing all that... The red gash turned in great loops and bends and plunged into the heart of the far mountains, trying to reach the scattered villages buried deep in the land of mist and wild chestnut. (Dai 148).

Along with colonialism, Dai also examines the problems associated with modernity and cultural change. The paper analyses how the gradual encroachment of modern ways of living results in a decline in traditional ecological ways. When the younger generation loses knowledge of cultural heritage, they lose their own identity. They forget about the sacredness of land and its importance for survival. Mamang Dai expresses it in her work as, “Land was being stolen. Forests were being cut and logs floated away down the river. New fences marked old territory and it seemed a curtain had fallen over the old villages. What was once sacred, the old sense of joy, was being lost” (Dai 163).

Dai’s novels also show a clear ecological ethic in action, one in which the indigenous people live in harmony with nature, only taking from the earth what they need, in a balance of use and preservation. Colonial intrusion and environmental disturbance are evident in the novel *The Black Hill*. The novel discusses the effects of colonial intrusion and how it affects the ecology and culture. The outsiders bring their own system to destroy the sacredness of the native land. The developments of infrastructure and the activities of missionaries are used to symbolise the intrusion of alien ideas. It is expressed as, “The arrival of the priest had changed the landscape. How could he have climbed these mountains? He had legs the colour of ivory, she had seen them once he was crossing a stream and he had pulled up his robe” (Dai 180).

In reading both novels, the researcher understands that land is a sacred and living entity of indigenous tribes. The novels discussed the importance of myths, beliefs, and spiritual elements to understand the culture of the tribes. Here, their culture is deeply rooted in the environment. Without their land, they can’t survive. Because it is their land provides them with identity.

CONCLUSION

The research paper offers a nuanced and multifaceted exploration of the idea of land and ecology. By depicting the land as a living and sacred being with knowledge and wisdom, the author challenges the dominant anthropocentric and colonial discourses on the idea of land and ecology. Here, Mamang Dai not only seeks to preserve the traditions of the indigenous people but also contributes to the contemporary discourse on ecology and the environment.

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RESEARCH ARTICLE

Evaluating the Role of AI in Enhancing Academic Performance: A Study of Undergraduate Students in Tamil Nadu

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ABSTRACT

Artificial Intelligence (AI) has rapidly transformed various aspects of our lives, including the field of education. Undergraduate education, being a critical stage in a student's academic journey, has witnessed significant changes due to the integration of AI technologies. This abstract provides an overview of the dynamic and multifaceted landscape of artificial intelligence (AI) usage in the educational realm. The study explores the patterns of AI usage, its impact on learning, and the underlying reasons for undergraduate students' engagement with AI-driven chatbots. Utilizing a mixed-methods research approach, combining surveys and interviews, the investigation unveils distinct usage patterns among students, showcasing the multifaceted roles of AI in their academic journeys. The investigation dissects the influence of AI tools on students' comprehension, problem-solving skills, and its potential impact on independent thinking. The study also confronts challenges and concerns associated with AI utilization, including ethical considerations and worries regarding academic integrity. This study contributes to the growing body of knowledge on the integration of AI in education and serves as a foundation for informed discussions, policy considerations, and recommendations to harness the potential of AI tools in enhancing undergraduate learning experiences.

Keywords: Artificial Intelligence (AI), AI-driven chatbots, undergraduate education, students, usage pattern, challenges and concerns.





INTRODUCTION

Background of AI in Education

Education, like virtually any other industry, is indeed undergoing very radical changes and developments through AI. The use of AI tools within learning environments has dramatically changed the practice of student access to content, instructors, and each other. From the use of adaptive learning platforms to AI-driven tutoring systems, artificial intelligence in education has spread extremely fast and therefore offered personalized and flexible learning experiences. Such systems can trace student learning, predict learning needs, and offer individualized recommendations to those promoting learning individualization, as well as increase access to education for diverse learners (Shawar & Atwell, 2007). Especially for that reason, it has been very helpful for students who have unique learning styles, learn at their own time, and get instant feedback.

For facilitating HCI in education, AI tools such as chatbots are essentials. These chatbots, as human-like conversations, are simulation tools that can help students in real time by answering their questions, clearing things up, providing other resources or readings. AI-based systems further help to smoothen the processes required administratively in such a way that several numbers of students could be handled without trying to offer individualized support. For instance, AI-tutoring systems can adjust the difficulty level of the task to fit the ability level of the student in such a way that there is a challenge presented with support for the learner in terms of growth and development (Baidoo-Anu & Owusu Ansah, 2023).

However, despite these promising features, an intensive use of AI in education has a number of challenges facing it, some of which major and generic concerns include: The reliability and trustworthiness of the AI system regarding its interaction with different students. With this, AI tools, specifically the ones applied in language learning or content generation may sometimes fail to recognize specific dialects or accents or cultural context. For example, some AI-based voice recognition software is not fluent in all languages; this can be exploited against the interest of non-English speaking countries' students or people with a strong regional accent (Rudolph et al., 2023). This is quite relevant to the concepts that require critical thinking rather than relying on answers produced by AI; this can degrade the skill development of students in concern to analysis and innovative skills.

There are also some ethical issues when AI is used in teaching. AI needs to collect data, which raises privacy and security concerns over data and what happens to all the collected information with personal data. The institution should ensure that the student's data will be kept safe and also provide how the data utilised comes into view. Moreover, some biased algorithms have powered applications of AI; these reflected societal or cultural prejudices that further pushed certain student groups into marginalized roles. Appropriately safeguarding students from such risks must be correlated with accessing the benefits AI can deliver to students for greater effectiveness in learning (van Dis et al., 2023).

There are some challenges to implementing AI in education, including its risks and the complexity of usage. Nevertheless, AI in education presents some undisputable transformative potential: it can assist in developing a curriculum, supporting students with disabilities, and even assist the instructor in grading assignments, recognizing or identifying areas in which students require additional support. AI systems are increasingly adopted within higher education institutions to help in predictive analytics about the identification of students who are lagging and providing timely interventions to aid a student's journey through an institution. Till date, the impact made by AI in this regard is more relevant in a globalized world wherein universities and colleges will have students belonging to different cultural and linguistic backgrounds and hence would like to keep abreast of students belonging to diverse cultures, for AI does seem to bridge the gap with the delivery of tailor-made education.



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Although it is well understood that the transformation AI made in education has been highly transformative, it raises a complex bundle of challenges that institutions need to travel through. AI is well integrated in the education process concerning the way it has its benefits counterweighing potential risks such that all students will be there to enjoy the benefits that AI offers in a non-marginalized way due to the limiting constraining limitations. Such a delicate balance in attaining a totally inclusive, progressive, and an evolving education system can easily ensure that it meets the requirements of the 21st century (Frieder et al., 2023).

Importance of AI in Undergraduate Learning

The integration of AI tools into undergraduate education provides an excellent learning experience through real-time and personalized facilitation to help the students master complex information and develop critical thinking. AI systems include intelligent tutoring platforms and adaptive learning technologies, therefore addressing various styles of individual learning, as well as paces, thereby making the process more efficient and engaging (Liu et al., 2021). It aids students in getting deeper insights into subject matter and develops their ability to independently solve problems. With AI, therefore, there is a greater opportunity for interaction that would enable the student to engage thoroughly with the content and apply what they know in different academic and real-life settings. This will prepare them for professional challenges and further studies because of intellectual autonomy and technical skills. Undergraduate education will be more exciting, student-centered, and focusing on aspects related to continuous improvement and critical thinking through these AI-enhanced methods.

Rationale for the Study

Its application and impacts about undergraduate education in Tamil Nadu remain relatively under-explored despite its vast uses in various industries. While educational institutes in the region only begin to include AI-driven tools in the pursuit of improving results, relatively little empirical work has been conducted to investigate the way in which such technologies are being used by students. Important areas of concern to both educators and policymakers relate to the interactions of students with AI platforms and the motivations of using such applications, their impact on academic performance and experience. Understanding these dimensions would be important in developing tailored applications for specific needs of students and in improving quality in education generally. Given the concentration of higher education in Tamil Nadu, in such a context, the findings of such a study could be useful both at the institutional and policy levels toward embedding AI into education both in effective and equitable ways. A specific need identified with the existing body of literature is this gap for consideration of these particular issues with AI integration into education in this region.

Research Objectives

The present study will attempt to:

- Record the usage patterns of AI among undergraduate students in Tamil Nadu
- Identify the motivations and causes for engagement with the usage of AI-driven educational tools among students
- Examine the impact of AI tools on the academic performance, problem-solving abilities, as well as independent thinking of students
- Examine ethical issues arising from the use of AI in performing academic tasks; there comes the question of plagiarism and originality in it.
- Suggestive input on responsible inclusion of AI in undergraduate learning.

LITERATURE REVIEW

AI in education is fast catching up worldwide since it offers new vistas for re-vision of teaching-learning methodologies. According to Liu et al. (2021), "AI tools in education improve student engagement, reduce learning gaps, and allow for personalized instruction." Supplemental to teaching in classrooms, developed countries can use Coursera, EdX, and other platforms. Chatbots are the devices in AI which make possible a human-to-human-like conversation. In academics, chatbots like ChatGPT will be of great use in furnishing speedy responses, teaching the



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students, and helping them with homework. "AI-driven chatbots can provide students with on-demand access to academic support, which could benefit students seeking to require flexibility in their learning schedule, says Clark & Lee, 2020. The literature incriminates that AI tools are going to result in positive learning outcomes through adaptive learning experiences attuned to each learner's specific needs. According to Park et al. (2019), one student "who had used an AI-based platform reported the following: "Such a tool helped them to channel their efforts toward problem areas, with immediate feedback provided." AI in education raises ethical concerns on academic integrity from the student's side and even their own personal data. Indeed, Anderson, 2022 discussed that "many students unwittingly engage in plagiarism while using AI tools to complete their assignments." This is aggravated by the issues that the students misuse AI-completed written content without working out the information.

Many works have already been undertaken on the general global impact of AI in education, but few were region-specific, such as in the case of Tamil Nadu State, where educational institutions are embracing new technologies at rates never before known. "As the need to explore local factors influencing cultural attitudes toward technology and education increases, which might influence how students use AI tools, these investigators took a more direct approach, they say," says Liu et al. This paper fills such lacunas by focusing on the experiences of undergraduate students attending universities within Tamil Nadu.

Research Design

This paper uses a survey method to collect data from undergraduate students from different institutions in Tamil Nadu. The questionnaire will be structured to gather details relating to the variety of aspects, and as aspects deal with specific varieties of scales over frequency at which AI tools are used, types of AI platforms they use, and what impact these tools make upon their results. The questionnaire designed had equal combinations of closed-ended and Likert-scale questions to allow for successive statistical analyses of the responses. This entire sample size was carried out through stratified random sampling which further brought about diversified academic disciplines. This made generalization possible to the findings of the **research** towards other populations of students. These data were then subjected to both descriptive and inferential statistics, with the interrelation between the trends regarding the applications of AI and scholarship determined. This quantitative methodology allowed us to have a wide scope view of AI integration into the undergraduate level while informing a qualitative later phase of this research. There were 84 students in undergraduate studies. As indicated above questionnaire link was circulated to the students ensuring random sampling method, inviting them to complete the anonymous electronic survey to help us with the study.

FINDINGS AND DISCUSSIONS**Demographic particulars of the respondents/ Students.**

The table below in Figure 1 depicts the demographic characteristics of the respondents in the study. Statistics of the data indicate that the sample population comprises equal males and females with a total number of 84 undergraduate engineering students who were surveyed. 63% of the students are, respectively between the age group of 18-20 years, 32% within the age group of 15-17, and only 2.38% within the age group of 21-23 years. There are no students of 24-26 years of age. All participants are enrolled in engineering. Arts, science, or medical not represented. This group assists in bringing a concentrated knowledge of the background of students who are engineers for further statistical analysis.

Awareness and Familiarity with AI Tools:

Figure 2 According to survey results, more students found out about the AI-based chatbots from the social media and online forums (40 responses), followed by educational institutions (20 responses) and recommendations from peers or educators (12 responses). Majority of the students have directly used the AI-based educational tools in the learning process, 26 have not, and 11 are not sure. Only 27 students are aware of the specific institutional guidelines on AI use, while 34 report no policies and 23 are not sure. This means that there is a call for more effective plagiarism awareness as well as clearer institutional policies about AI usage for academic purposes.



**Mythili and Mayildurai****Usage of Chatbots and AI in Academics:**

Further when we asked about chatbots, the statistics show that the students increasingly apply them, as well as AI for different purposes, that is, mostly for homework assignments at 57 responses, research articles at 41, and exam preparation at 40. Most of the students (23) also apply chatbots for essay writing purposes. While 45 students reported to often use chatbots in order to perform the assignments or coursework, 15 use them very frequently, and only 1 student relies on them immensely. More importantly, among the reasons the students used chatbots was to generate ideas or insights, improving the quality of writing, doing research, and saving time with their assignments. Although students increasingly rely on these tools, levels of use are uneven, and 23 reported rarely or never using chatbots for their coursework.

Looking ahead, 41 students plan to continue using chatbots for academic work, while 8 do not, and 35 are undecided. This suggests that while chatbots are valuable for tasks like idea generation and research, there is still caution among some students regarding their role in academic work. The data emphasizes the need for students to develop a balanced approach to using chatbots, ensuring that these tools are used ethically and in accordance with academic integrity policies.

Impact on Learning and Academic Performance:

The data in the figure illustrates that the impact that chatbots had on the understanding of course materials by students has been moderate. Indeed, 51 reported that chatbots had moderately enhanced their comprehension, whereas 9 reported a significant improvement, while only 1 reported an extreme benefit. However, a smaller portion of students felt that there was no improvement at all, accounting for 6 students. Academic performance wise, 38 mentioned that their grades improved since being part of the chatbot program, 3 of whom said they greatly improved. On the other hand, 37 said that there were no improvements in their grades, and some experienced a slight decline in grades at 6. When asked if AI enhances education, 39 say yes, based on personalization, and 10 think that it is true indeed that AI would help in letting them free the administrative burden. However, 19 believe that AI would eventually replace the human ingredient that is needed in education, and 16 are uncertain of any response. Overall, the data shows that AI tools such as chatbots improve learning and enhanced grade score for some learners; however, others believed AI had a minimal role to play in the overall community. Most of the participants felt that this advantage of personalized learning was one they found favored, whereas loss of human interaction with education remains one of the most important concerns that have existed to date.

Ethical and Privacy Concerns:

Figure examines that a significant number of students express complaints over issues of ethics and privacy in the course of applying AI in school. Of the respondents, 44 are worried about data privacy and security, 25 are not sure, while only 15 indicate that they are not worried at all. This brings a state of increased awareness of the risks that accompany AI application but uncertainty is rife.

From the ethical points of view, 29 know what could be at play, to mention just academic integrity and fairness, 26 do not, and 29 are not sure. Similarly, about unintentional plagiarism, 27 are concerned, 28 dismiss it, and 29 are unsure. These numbers suggest that although some students become aware of what is at risk in misusing AI most of the students do not understand what there is in terms of all related ethical implications. What is apparently more significant is that out of the students, 37 have never been taught how to use AI responsibly in their academics and 24 are unsure whether they have or not. This indicates the need for establishing clearer policies and education on the ethics of using AI appropriately in academic settings. Because AI becomes increasingly part of all education, these issues will be talked about through proper guidelines and training for maintaining academic integrity and protecting student privacy.

Challenges and Limitations:

The following table shows the results on percentages of students who have suffered during their learning career with AI-powered assistants. Of the total respondents, 32 complain that they have had problems, 29 reported no issues,



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while 23 do not know whether or not they have had any. It could be mainly because of the flaws and errors that exist on the AI-generated work that 55 of the students have knowledge about. However, there are 17 students who do not know about these flaws while 12 were uncertain. In most instances, where AI sources like ChatGPT are not in use or would fail to apply, the student will opt for alternative means. The frequency at which students use other techniques can be ascertained by the following: textbooks stand atop with 49 followed by peer discussion or study group at 38. Personal research and reading ranks third at 30, while consultation with professors or instructors occurs at 28. Other method styles include traditional library research at 32, online academic platforms like Coursera or edX at 25, among others. In this regard, as indicated by the data analysis, there are many students who still maintain reliance on traditional methods even though AI tools are used most frequently in the education sector, which may indicate that AI cannot fully substitute for human contact and interaction, personalized guidance, or trusted academic resources. The results, therefore, show that although the advantages of AI exist, the limitation resides, and there is an indication that only when technology and traditional practices of learning exist in equilibrium can success in academics be holistic.

Future of AI in Education:

Students have mixed opinions with respect to how AI will unfold in education. It is because 25 believe that efficient teaching will be served and even replaced with AI, while 50 believe that human relations cannot be replaced. This means that it would amount to students valuing connection and help from educators a lot, which might be hard to deliver with AI. Considering the impact of AI tools like ChatGPT on the traditional classroom education, 27 students believe it to be an enhancement where learning is provided by instant information access and personalized support. Meanwhile, there are 26 students who believe AI will shift the role of educators towards mentoring inculcating thoughtful and reflective skills. Some of the students feel AI might reduce the need for old ways of teaching to a considerable extent whereas others are concerned about possible ethical and academic integrity issues. The data also shows that policy regulation is over AI usage. By considering this, 2 of 20 require clarity in guidelines. General point of view, AI is not to replace the human educators but should supplement them.

CONCLUSION

AI in education is considered as a step into promising advancement but one that gives concern to students. While some students feel that AI can provide effective instruction, most highlight the indispensable role that human interaction has in learning. AI tools such as ChatGPT have recently come to be seen as useful supplements to the traditional classroom form of education, providing a person-to-person approach, maximizing the access to information, and forcing educators to reinvent their new roles. However, most ethical issues, cases of academic dishonesty, and the appropriateness of getting over reliant on AI tools rise.

RECOMMENDATIONS

1. **Balanced Approach:** The institutions should embrace a balanced approach in which AI is used to complement the real teaching, but at the same time ensures the human element which enables meaning contact and mentoring as well as critical thinking.
2. **Guidance and Policies:** There has to be clear policies and guidelines regarding the adoption of AI tools in academic environments that do address issues of ethical use, privacy, as well as the issue of academic integrity.
3. **Teacher Role:** Educators should be inspired and guided to work on AI as a supporting tool and nurture more strategic thinking, problem-solving, and mentorship rather than mere knowledge distribution.
4. **Training Workshops/Seminars:** The ethical implications and constraints of AI should be taught to the students during regular workshops or seminars so that they properly use it while doing their formal assignments.
5. **Incorporation of AI Literacy:** As more AI tools are incorporated, educational institutions ought to include AI literacy in curricula, thereby giving students an added experience to better effectively and responsibly apply these technologies.





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		Frequency	Percentage
Gender	Male	42	50.00%
	Female	42	50.00%
Age	15-17	27	32%
	18-20	55	65.47%
	21-23	2	2.38%
	24-26	0	0.00%
UG	Engineering	84	100.00%
	Arts	0	0.00%
	Science	0	0.00%
	Medical/Para-medical	0	0.00%
	TOTAL		100%

Figure 1 - Demographic particulars of the respondents/ Students





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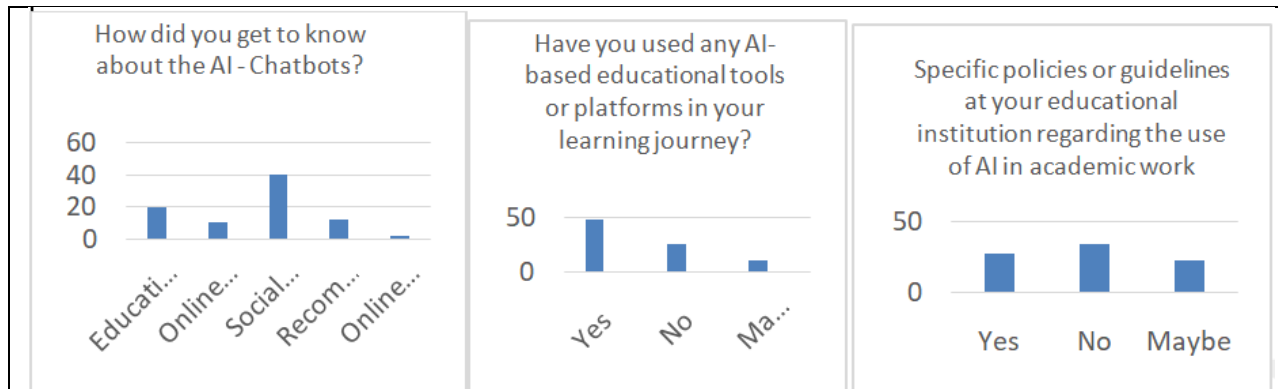


Figure 2:

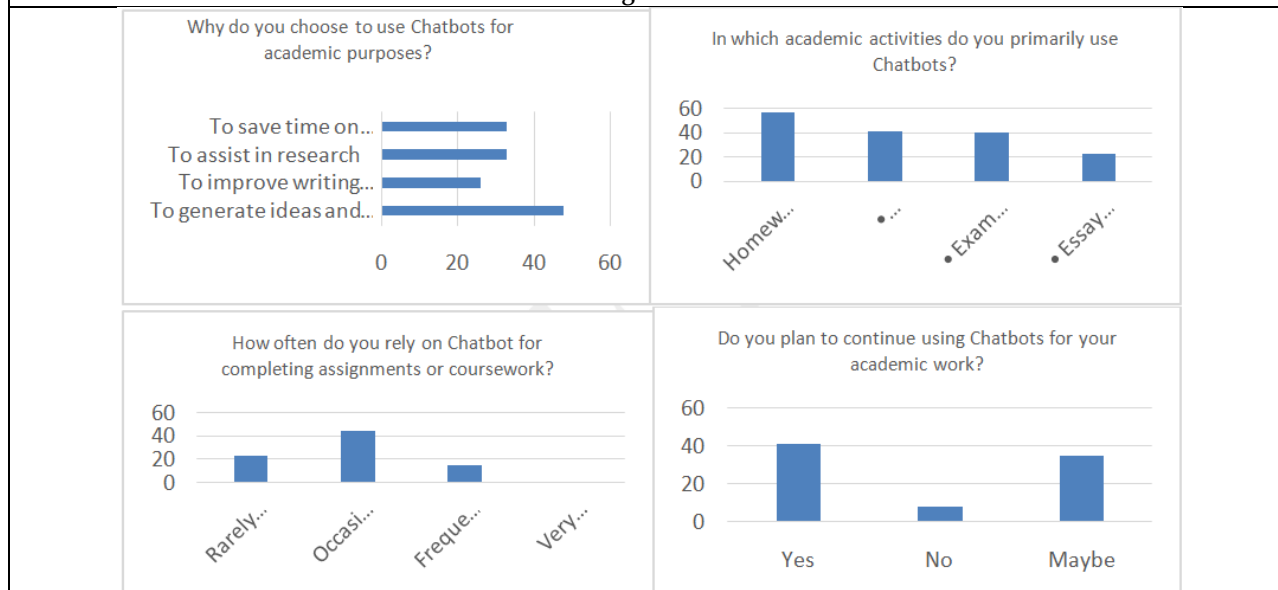
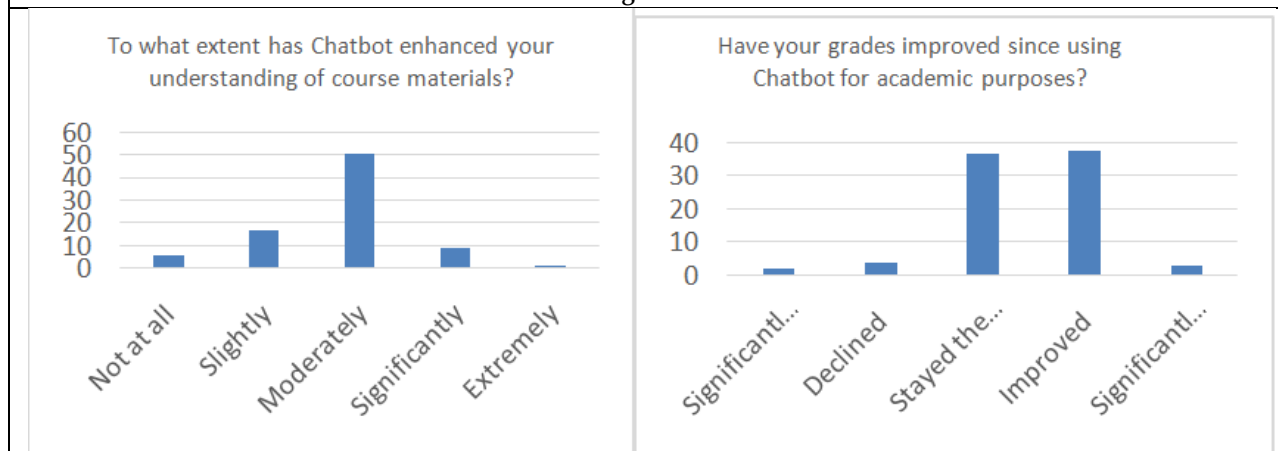


Figure 3.





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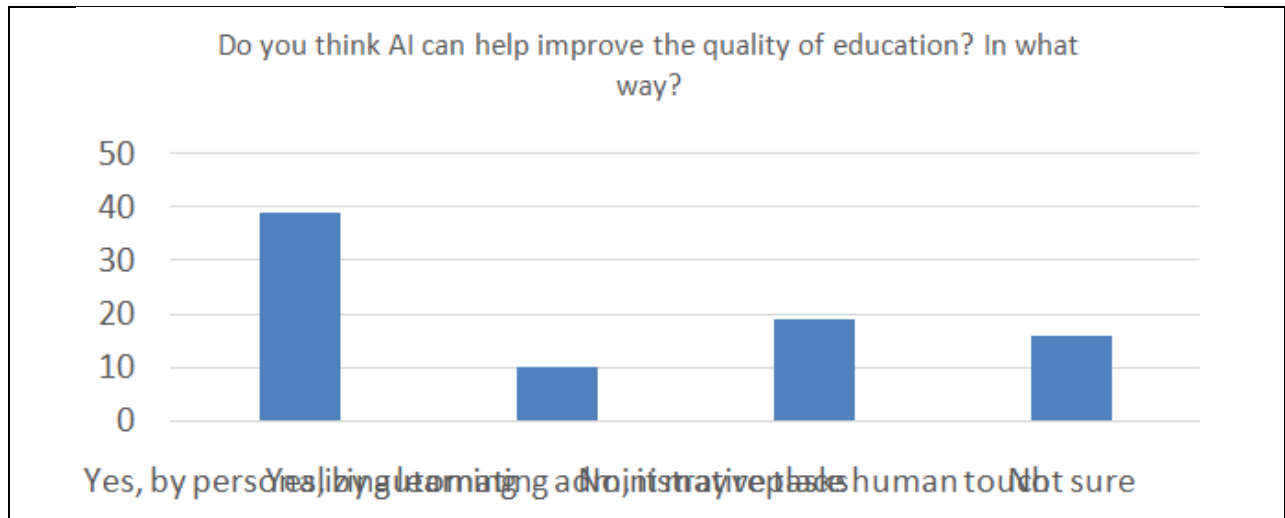


Figure 4:

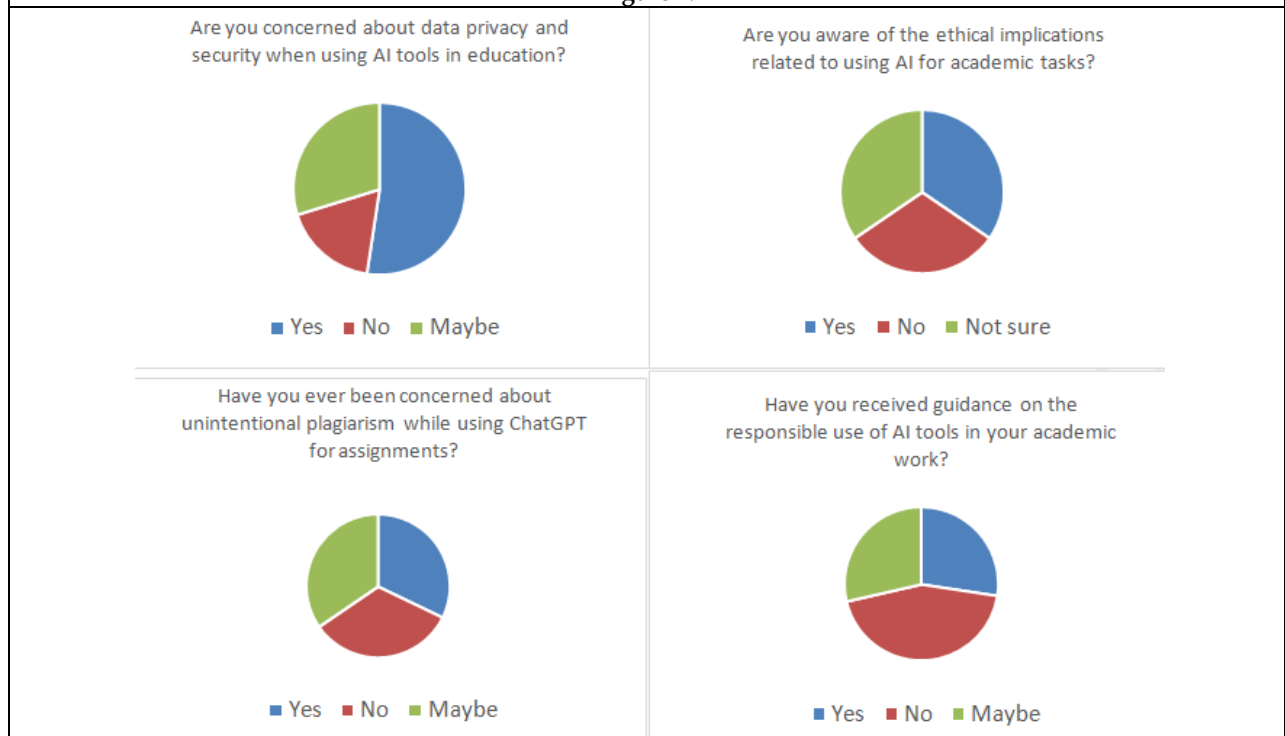


Figure 5:





Mythili and Mayildurai

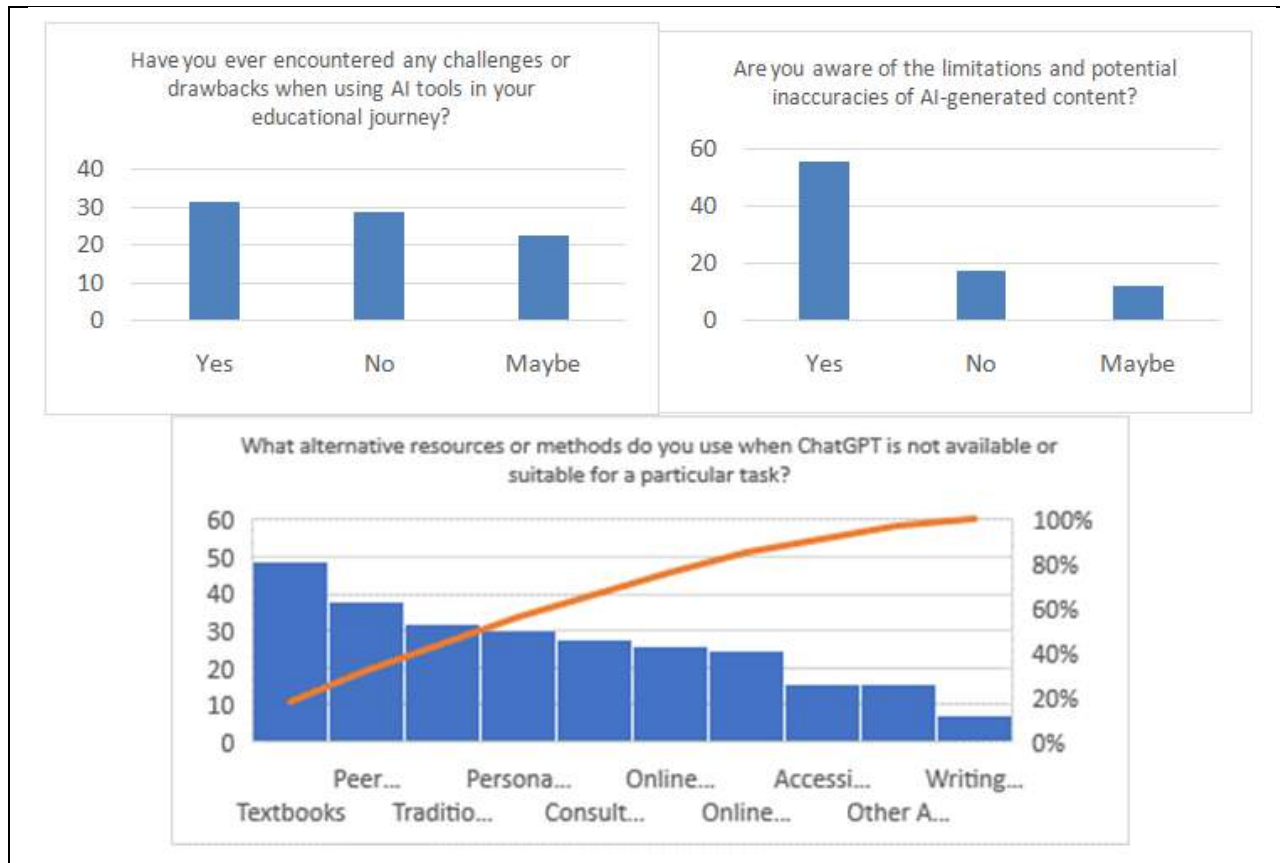


Figure 6:

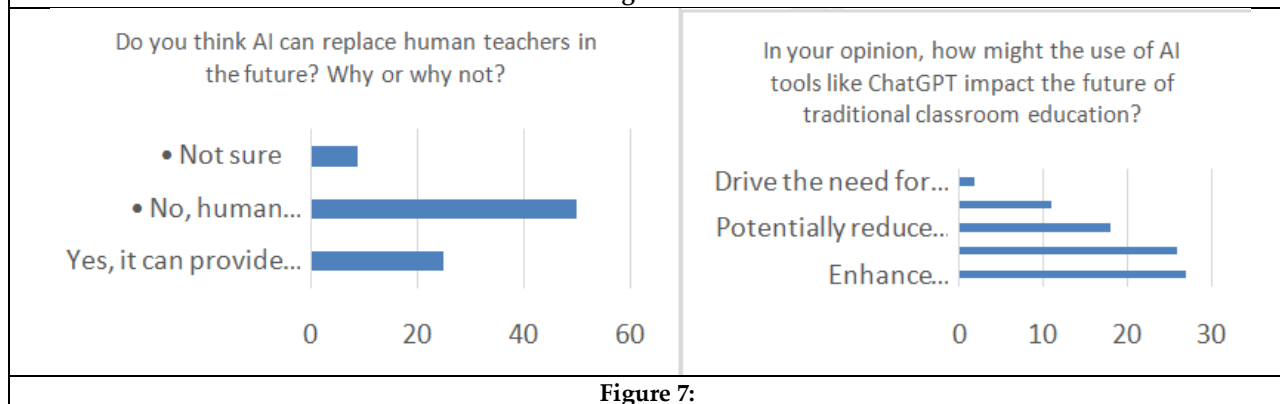


Figure 7:

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RESEARCH ARTICLE

The Eloquence of Words: A Stylistic Analysis of Language in Advertising

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ABSTRACT

Advertising language plays a crucial role in shaping consumer perception and influencing purchasing behavior. The effectiveness of advertisements often depends on the strategic use of language that captures attention, evokes emotions, and persuades audiences. This study examines the stylistic features employed in advertising language and explores how these linguistic strategies contribute to persuasive communication. By focusing on various stylistic devices such as metaphor, hyperbole, alliteration, rhyme, and repetition, the research highlights the creative and rhetorical techniques that advertisers use to construct memorable and impactful messages. The study adopts a stylistic approach to analyze selected advertising digital media. Through qualitative analysis, the research identifies recurring patterns of language use and investigates how stylistic elements enhance clarity, emotional appeal, and brand identity. Particular attention is given to the ways in which advertisers manipulate vocabulary, sentence structure, and sound patterns to create concise yet powerful messages that resonate with target audiences. The findings suggest that stylistic devices play a significant role in making advertisements more engaging, memorable, and effective in communicating brand values. The research also emphasizes the importance of linguistic creativity in modern advertising, where competition for audience attention is increasingly intense. Ultimately, this study contributes to the broader understanding of how stylistic analysis can reveal the underlying mechanisms of persuasion in advertising language and highlights the relationship between linguistic form and communicative function in media discourse.

Keywords: Stylistics, Advertising Language, Persuasion, Figurative Language, Media Discourse, Rhetorical Devices





INTRODUCTION

Language is a powerful tool in shaping human perception, behavior, and decision-making. In contemporary society, advertising has become one of the most influential domains where language is strategically employed to persuade and influence audiences. With the rise of digital media platforms, advertisements have evolved from simple informational messages to highly sophisticated communicative constructs that rely on linguistic creativity and stylistic innovation. Advertising language is not merely descriptive; it is inherently persuasive. It aims to attract attention, generate interest, create desire, and ultimately drive action. The success of an advertisement often depends on how effectively language is used to connect with the target audience. In this context, stylistics—the study of linguistic style—provides a valuable framework for analyzing how language functions in advertising. This research focuses on the stylistic features of advertising language in digital media. It examines how rhetorical and linguistic devices such as metaphor, hyperbole, alliteration, rhyme, and repetition contribute to persuasive communication. By analyzing selected advertisements, the study aims to uncover patterns in language use and demonstrate how stylistic strategies enhance the effectiveness of advertising messages.

Background of the Study

The evolution of advertising from print to digital media has significantly transformed the nature of communication between brands and consumers. Traditional advertisements relied on lengthy descriptions and detailed explanations, whereas modern digital advertisements emphasize brevity, creativity, and immediate engagement. With the proliferation of social media platforms, consumers are constantly exposed to a vast number of advertisements competing for attention. This shift has made language a crucial tool for differentiation. Advertisers now employ stylistic and rhetorical strategies to create impactful messages that stand out in a crowded media landscape. Stylistics, as a discipline, provides insights into how language functions in specific contexts. In advertising, stylistic analysis helps uncover how linguistic features such as metaphor, sound patterns, and syntactic structures contribute to persuasion. Understanding these features is essential for analyzing the effectiveness of modern advertising practices.

Statement of the Problem

Despite the growing importance of digital advertising, there is limited systematic analysis of how stylistic features function in contemporary advertising language. While previous studies have explored persuasion in advertising, many have focused on psychological or marketing perspectives rather than linguistic analysis. Moreover, the rapid evolution of digital media has introduced new forms of communication that require updated analytical approaches. There is a need to examine how traditional stylistic devices are adapted and utilized in digital contexts to influence consumer perception. This study addresses this gap by analyzing the stylistic features of advertising language and exploring how these features contribute to persuasive communication in digital media.

Research Questions

This study is guided by the following research questions:

1. How do stylistic devices such as metaphor, hyperbole, alliteration, rhyme, and repetition contribute to persuasion?
2. In what ways do linguistic choices enhance emotional appeal and audience engagement?
3. How does advertising language construct and reinforce brand identity?
4. What patterns of language use can be identified across different types of digital advertisements?

Objectives of the Study

The main objectives of this research are:

- To identify and analyze stylistic features in digital advertising language.



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- To examine the role of figurative language in persuasive communication.
- To investigate the relationship between language and brand identity.
- To contribute to the understanding of stylistic analysis in media discourse.

Theoretical Framework

This study is based on stylistic and rhetorical theories, including:

- Foregrounding Theory (Leech)
- Rhetorical Figures (McQuarrie & Mick)
- Discourse Analysis (Fairclough)

These frameworks help analyze how linguistic features function in persuasive communication.

Foregrounding Theory (Geoffrey Leech)

Foregrounding Theory, proposed by Geoffrey Leech (1966), is a central concept in stylistics that explains how certain linguistic elements are made prominent in a text to capture the reader's or viewer's attention. The theory suggests that language in literary and non-literary texts often deviates from ordinary usage to create a striking effect.

Foregrounding operates through two primary mechanisms:

Deviation: This involves a departure from standard linguistic norms, such as unusual vocabulary, unexpected metaphors, or creative syntax. In advertising, deviation is used to surprise the audience and make the message more noticeable.

Example: "Think different." (grammatically unconventional but impactful)

Parallelism: This refers to the repetition of similar structures, sounds, or patterns. Parallelism creates rhythm and emphasis, making the message more memorable.

Example: "Buy more. Save more. Live more."

In advertising language, foregrounding helps highlight key aspects of a product or brand, ensuring that the message stands out in a highly competitive media environment.

Rhetorical Figures (McQuarrie & Mick)

The concept of Rhetorical Figures, developed by McQuarrie and Mick (1996), focuses on the use of figurative and stylistic devices to enhance persuasion in advertising. Rhetorical figures are creative deviations in language that produce aesthetic pleasure and cognitive engagement.

These figures are broadly categorized into:

Schemes: These involve patterns of repetition or arrangement of words, such as alliteration, rhyme, and parallelism.

Example: "Fresh, fast, fabulous."

Tropes: These involve a shift in meaning, such as metaphor, irony, pun, and hyperbole.

Example: "Time is money" (metaphor)

According to McQuarrie and Mick, rhetorical figures increase the effectiveness of advertisements by:

Capturing attention

Enhancing memorability

Encouraging deeper processing of the message

Creating emotional and aesthetic appeal

In digital advertising, rhetorical figures are particularly valuable because they allow messages to be both concise and impactful.



**Discourse Analysis (Norman Fairclough)**

Discourse Analysis, as developed by Norman Fairclough (1995), examines how language functions within social and cultural contexts. It views language as a form of social practice that both reflects and shapes power relations, ideologies, and identities.

Fairclough's model of discourse analysis includes three dimensions:

Textual Analysis: Focuses on linguistic features such as vocabulary, grammar, and structure.

Discursive Practice: Examines how texts are produced, distributed, and consumed.

Social Practice: Explores the broader social and cultural context influencing the text.

In advertising, discourse analysis helps reveal:

How language constructs consumer identities

How brands position themselves in the market

How ideologies (e.g., beauty, success, lifestyle) are promoted

For example, advertisements often associate products with success, happiness, or luxury, thereby shaping consumer desires and perceptions.

REVIEW OF LITERATURE

The study of advertising language has been an important area of research within linguistics, media studies, and marketing, particularly in understanding how language functions as a persuasive tool. Scholars have examined the interplay between linguistic features, stylistic devices, and consumer behavior, highlighting the role of creativity and rhetoric in advertising discourse. One of the foundational works in this field is by Geoffrey Leech (1966), who, in *English in Advertising*, emphasized that advertising language is characterized by deviation from standard linguistic norms. According to Leech, advertisers deliberately manipulate language through stylistic innovation to attract attention and enhance memorability. His concept of foregrounding—achieved through deviation and parallelism—remains central to stylistic analysis in advertising. Building on this, Guy Cook (2001) in *The Discourse of Advertising* explored the relationship between language, context, and interpretation. Cook argued that advertisements cannot be understood in isolation, as they rely on cultural references, visual elements, and audience interpretation. He highlighted that advertising discourse is inherently interactive, engaging consumers through both textual and contextual cues.

Angela Goddard (2002) further examined how advertising language creates meaning through linguistic choices in *The Language of Advertising*. She pointed out that advertisers use a combination of verbal and visual signs to construct persuasive messages. Goddard emphasized the importance of audience positioning, suggesting that advertisements often address consumers directly to create a sense of personal engagement. The role of rhetorical devices in advertising was systematically analyzed by McQuarrie and Mick (1996), who introduced a framework for understanding rhetorical figures in marketing communication. They categorized figures into schemes and tropes and argued that such devices enhance persuasion by increasing attention, processing effort, and aesthetic appeal. Their study demonstrated that rhetorical figures are not merely decorative but function as powerful tools for influencing consumer perception. From a stylistic perspective, Paul Simpson (2004) provided a comprehensive framework for analyzing language through stylistics in *Stylistics: A Resource Book for Students*. Simpson emphasized the role of linguistic patterns, sound devices, and figurative language in shaping meaning. His work is particularly relevant in analyzing how stylistic features contribute to the effectiveness of advertising messages.

The socio-cultural dimension of advertising language is explored in Norman Fairclough's (1995) work on discourse analysis. Fairclough viewed language as a form of social practice and argued that discourse both reflects and shapes societal values and ideologies. In advertising, this perspective is crucial for understanding how language constructs consumer identities and reinforces cultural norms such as beauty, success, and lifestyle aspirations. Tanaka (1994) adopted a pragmatic approach in *Advertising Language: A Pragmatic Approach to Advertisements in Britain and*



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Japan, highlighting how advertisers rely on implicit communication and shared knowledge. She argued that meaning in advertising is often indirect, requiring consumers to infer messages, which enhances engagement and persuasion. More recent studies have focused on the impact of digital media on advertising language. Crystal (2003) noted that digital communication has led to the emergence of new linguistic styles characterized by brevity, hybridity, and creativity. Similarly, contemporary research indicates that online advertisements rely heavily on concise and impactful language due to reduced attention spans (Danesi, 2017).

In the context of stylistics and persuasion, Forceville (2008) examined the role of multimodal metaphors in advertising, demonstrating how visual and verbal elements interact to create meaning. His work highlights the importance of integrating linguistic analysis with visual semiotics in digital advertising. Furthermore, Cook (2012) and later studies have emphasized the increasing importance of emotional appeal in advertising. Emotional language, combined with stylistic devices such as repetition and metaphor, plays a significant role in influencing consumer attitudes and decision-making.

Summary of Literature Gap

While existing literature provides valuable insights into advertising language, there is a noticeable gap in the systematic stylistic analysis of digital advertisements, particularly in integrating rhetorical, stylistic, and discourse-based approaches. This study addresses this gap by examining how stylistic features function in contemporary digital media to enhance persuasion and engagement.

METHODOLOGY

This study adopts a qualitative research approach, focusing on the stylistic analysis of selected digital advertisements. The data consists of advertisements collected from social media platforms, websites, and online campaigns.

Data Collection

A sample of advertisements from various industries—such as food, technology, fashion, and healthcare—was selected. The advertisements were chosen based on their linguistic richness and use of stylistic devices.

Analytical Approach

The analysis focuses on identifying and interpreting stylistic features, including:

Lexical choices

Sentence structure

Figurative language

Sound patterns

Each advertisement was examined to determine how these features contribute to persuasion and audience engagement.

ANALYSIS AND DISCUSSION

Use of Metaphor

Metaphors are widely used in advertising to create vivid and imaginative associations. By linking products to desirable qualities, metaphors enhance the appeal of advertisements.

For example, a smartphone may be described as a “powerhouse,” suggesting strength and efficiency. Such metaphors simplify complex ideas and make them more accessible to consumers.

Metaphors also contribute to emotional engagement. By appealing to the imagination, they create a deeper connection between the product and the audience.

Advertisement 1 (Technology Product):



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"Unleash the beast in your hands."

Analysis:

The smartphone is metaphorically described as a "beast," suggesting power, speed, and dominance. This metaphor simplifies technical features into an emotional appeal.

Advertisement 2 (Energy Drink):

"Fuel your fire."

The metaphor of "fire" represents energy, ambition, and passion, appealing to young consumers.

Hyperbole and Exaggeration

Hyperbole is another common stylistic device in advertising. It involves deliberate exaggeration to emphasize product benefits.

Phrases like "the best coffee in the world" or "unmatched performance" are typical examples of hyperbole. While consumers may recognize the exaggeration, it still influences their perception by creating a sense of superiority.

Hyperbole is particularly effective in competitive markets, where brands seek to differentiate themselves.

Advertisement 3 (Food Brand):

"The world's most irresistible chocolate."

Analysis:

The claim is exaggerated but creates a perception of superiority.

Advertisement 4 (Skincare Product):

"Flawless skin in just one wash!"

This exaggeration appeals to consumer desires for quick results.

Alliteration and Sound Patterns

Sound devices such as alliteration play a crucial role in making advertisements memorable. Repetition of initial consonant sounds creates rhythm and musicality.

Examples like "fresh, fast, and flavorful" demonstrate how alliteration enhances recall. These patterns make slogans more engaging and easier to remember.

In digital media, where attention spans are short, such devices are especially valuable.

Advertisement 5 (Fast Food):

"Crispy, crunchy, crave-worthy."

The repetition of the /cr/ sound creates rhythm and makes the slogan catchy.

Advertisement 6 (Retail Brand):

"Style. Shine. Sophistication."

The repetition of the /s/ sound adds elegance and appeal.

Rhyme and Rhythm

Rhyme is another stylistic feature that contributes to memorability. Rhyming slogans are catchy and often remain in the audience's mind long after exposure.

For instance, phrases like "fit and lit" or "snack smart, live smart" use rhyme to create a pleasing auditory effect.

Rhythm also plays a role in structuring advertisements. Balanced and rhythmic sentences are more appealing and easier to process.

Advertisement 7 (Health Drink):

"Sip smart, stay sharp."

Analysis:

The rhyme between "smart" and "sharp" enhances memorability.

Sample Advertisement 8 (E-commerce):

"Click quick, shop slick."

The rhythmic pattern encourages quick action.



**Repetition**

Repetition is used to reinforce key messages and ensure that they are remembered. It can occur at the level of words, phrases, or structures.

For example, repeating a brand name or slogan increases brand recognition. Repetition also creates emphasis, highlighting important aspects of the product.

In digital advertising, repetition is often combined with visual elements to maximize impact.

Advertisement 9 (Sports Brand):

"Run more. Do more. Be more."

Analysis:

The repetition of "more" emphasizes improvement and motivation.

Advertisement 10 (Mobile Network):

"More speed. More power. More you."

Repetition strengthens brand positioning.

Lexical Choices and Wordplay

Advertisers carefully select words to create specific impressions. Positive adjectives, action verbs, and emotionally charged language are commonly used.

Wordplay, including puns and double meanings, adds creativity and humor to advertisements. This not only captures attention but also enhances engagement.

Advertisement 11 (Coffee Brand):

"Espresso yourself."

Analysis:

A pun on "express yourself," making the message humorous and memorable.

Sample Advertisement 12 (Travel Agency):

"Don't just travel. Time travel."

Suggests immersive experiences through metaphorical wordplay.

Sentence Structure and Conciseness

Digital advertisements often use short and simple sentences. This ensures clarity and quick comprehension.

Imperative sentences such as "Buy now" or "Try it today" create a sense of urgency and encourage immediate action.

Elliptical structures, where certain elements are omitted, are also common. These structures make messages more concise and impactful.

Advertisement 13 (Online Sale):

"Buy now. Save big."

Direct command encourages immediate action.

Sample Advertisement 14 (Fitness App):

"Start today. Transform tomorrow."

Parallel structure enhances rhythm and persuasion.

Emotional Appeal

Stylistic features contribute to emotional appeal by creating connections with the audience. Advertisements often evoke feelings such as happiness, nostalgia, or aspiration.

By appealing to emotions, advertisers can influence consumer attitudes and behavior more effectively than through logical arguments alone.

Advertisement 15 (Insurance):

"Because your family deserves forever."

Appeals to love and security.

Advertisement 16 (NGO Campaign):

"One act of kindness can change a life."

Appeals to empathy and moral responsibility.



**Chamundeshwari et al.,****Brand Identity and Language**

Language plays a key role in shaping brand identity. Consistent use of stylistic features helps create a distinct voice and personality for the brand.

For example, a luxury brand may use sophisticated and elegant language, while a youth-oriented brand may adopt a casual and playful style.

Language helps create a consistent brand voice.

Luxury brands use formal, elegant language:

"Crafted for excellence."

Youth brands use informal tone:

"Level up your vibe."

FINDINGS

The analysis reveals several key findings:

Stylistic devices enhance memorability: Features such as rhyme, alliteration, and repetition make advertisements more memorable.

Figurative language increases engagement: Metaphors and hyperbole create vivid and appealing messages.

Conciseness is crucial in digital media: Short and impactful messages are more effective in capturing attention.

Emotional appeal drives persuasion: Advertisements that evoke emotions are more likely to influence consumer behavior.

Language shapes brand identity: Consistent stylistic choices contribute to a recognizable brand voice.

Implications

The findings have important implications for both researchers and practitioners:

For linguists: The study demonstrates the value of stylistic analysis in understanding media discourse.

For advertisers: It highlights the importance of linguistic creativity in designing effective campaigns.

For educators: The research can be used to teach students about the role of language in persuasion.

CONCLUSION

Advertising language is a dynamic and powerful form of communication that relies heavily on stylistic features to achieve its persuasive goals. This study has shown that devices such as metaphor, hyperbole, alliteration, rhyme, and repetition play a crucial role in shaping consumer perception and enhancing the effectiveness of advertisements. In the context of digital media, where competition for attention is intense, the strategic use of language becomes even more important. Advertisers must create messages that are not only informative but also engaging, memorable, and emotionally appealing. By applying stylistic analysis, this research provides insights into the mechanisms of persuasion in advertising language. It highlights the relationship between linguistic form and communicative function, contributing to a deeper understanding of media discourse. Future research can expand this study by incorporating quantitative methods or exploring cross-cultural variations in advertising language.

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RESEARCH ARTICLE

Project - Driven Language Development for Engineers: Transforming English Communication in Technical Education

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ABSTRACT

Project-Based Language Learning (PBLL) addresses the challenges of effective student engagement during English classes by integrating language acquisition with real-world authentic situations. The model helps to hone the professional skills of the engineering students perpetually with its ability to make them work in real-life situations. This research work presents a case study of implementing PBLL for first year engineering students in Kumaraguru College of Technology, Coimbatore, India. The students were assigned authentic projects in the form of podcast production, preparing brochures, videos, content, and mobile application. A qualitative analysis of their performance was carried out to determine the outcomes. It was evident that the PBLL model stands as a unique and powerful tool to promote communication skills, creativity and peer learning. The outcomes of this mode of learning were phenomenal compared to the conventional learning strategies. The learners were found to significantly develop their communication skills along with other life skills such as teamwork, problem solving, creativity and digital literacy. This research work discusses the impact of implementing project-based learning in language classes and recommends strategies for effective engagement of the learners. The findings of this work advocate that this model is scalable, and PBLL stands as an effective method in preparing engineering students for their professional life as per the industry requirements.

Keywords: Engineering education, learner engagement, project-based language learning, collaborative learning.



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INTRODUCTION

Engineering education plays a major role in the higher education sector in India. English proficiency is considered as one of the required skills for an engineering student in the context of globalization of industries. It helps students to complete their daily tasks like assignments and to take up internships and placements. It is witnessed that the students entering higher education institutions possess varied levels of English proficiency. This mandates higher educational institutions to provide personalised mode of learning as per the proficiency levels of the learners. Many learners who have pursued their mode of study through their vernacular languages find it difficult to cope up with the learners from English medium schools. In such a scenario, traditional teaching approaches like grammar-based instruction and regular classroom lectures hub fail to address the issue. Therefore, in Kumaraguru College of Technology, Coimbatore, Tamil Nadu, India, it is attempted to segregate the learners into 3 different categories as per their English language proficiency and each group was provided with a different mode of learning to provide effective learning experiences.

Advanced learners possessing good English language proficiency are bound to often find their English classes boring and uninteresting. Therefore, in order to break their monotony and provide a personalised learning experience, these learners were offered with language related projects as a part of their English course. This was offered with a view to enhance their communication and soft skills in order to make them industry-ready engineers. Project-Based Language Learning (PBLL) has been adopted as a tool to enhance their involvement in language learning and to foster peer learning for effective engagement.

The benefits of this mode of learning includes providing authentic learning experience to the candidates, development of lateral thinking, opportunity to explore new technologies, and promoting soft skills in the form of collaborative skills, creativity, and critical thinking. This methodology also enables the students to take ownership in their activities and provide a rich learning outcome. The peer review mechanism involved in this methodology helps students to hone their language skills and professional behaviour. The longstanding challenges that prevailed in addressing the language proficiency of engineering students get addressed through this methodology in a meaningful way by providing real life exposure to use their English language skills in professional settings.

LITERATURE REVIEW

The review of literature yields better results for applying this learning method for engineering students. A research study by Wang proposes that PBLL serves as a student-centred and authentic way of language learning. It substantiates that real-world communication tasks make the learners involve themselves into the activities (Wang, 2020). Farouck (2016) project-based language learning enhances the motivation and confidence of the learners. Musa et. al., (2011) substantiate that this model improves the professional competencies of learners. It also fosters holistic development of the learners and helps them in developing resilience and interpersonal skills (Ghosheh et al., 2021). Kato et. al. (2023) demonstrated how projects help learners to enhance their English language proficiency and how it can be implemented in distance learning. Stoller and Myers (2019) provided a five-stage framework for implementing PBL in English classrooms.

AIM AND OBJECTIVES

This research study aims to investigate the effectiveness of project-based language learning (PBLL) as an indispensable tool to enhance English language proficiency and behavioural skills of engineering students. The objectives of the study are as follows:



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1. To evaluate the effectiveness of PBL on enhancing Language Proficiency
2. To analyse the level of student engagement in PBL
3. To explore the extent of peer learning
4. To investigate the skills learnt by the students through this mode

METHODOLOGY

A diagnostic test inclusive of all English language skills like Listening, Speaking, Reading and Writing (LSRW) was conducted for all the first-year engineering students (1585 students) across all engineering programs and they were categorised into 3 different categories in alignment with the Common European Framework of Reference (CEFR) levels based upon their performance as Basic (A2), Intermediate (B1) and Advanced (B2) level of learners. A course titled *Fluency Through Practice* was designed, curated and offered to the advanced learners. It was integrated into the regular class timetable and offered for a total of 60 hours throughout the academic semester (15 weeks). The course was offered for the Computer Science branches inclusive of Computer Science and Engineering, Information Technology, and Artificial Intelligence and Data Science in Semester I and for all other branches of engineering in Semester II. The course was offered in a blended mode where the students had face-to-face sessions, teamwork and independent project work apart from regular class hours.

There were 64 students in Semester I and 98 students in Semester II amounting to a cumulative of 162 students taking up this course. Among these students, 83 students were found to complete their higher secondary education from CBSE and ICSE schools, 58 students were found to complete their higher secondary education from Matriculation and State Board English medium schools, and 21 students were from Tamil medium and other vernacular language medium schools. There were 58% of girls and 42% of boys in the group selected. The urban and semi-urban population contributed to 72% and the rural population amounted to 38%. This demographic diversity contributed to a charged and motivating environment paving way for an enthusiastic group dynamics and peer-to-peer engagement.

The selected students were oriented on the principles of PBL and how it enhances the language and professional skills. They were also insisted on taking up authentic and meaningful tasks as projects for yielding better outcomes. Project basics such as project timelines, assessment rubrics, teamwork and the expected quality of the projects were outlined. The learners were advised to document their progress consistently through daily journaling. A structured ideation workshop was conducted to brainstorm project ideas and various themes like media production, content generation, research and peer learning were introduced to the learners to facilitate them to finalize their project ideas. The learners were introduced to the existing similar ideas like available podcast series, videos and brochures, and they were instructed to form project groups of 4 to 5 members organically as per their interests. After forming the group, they were encouraged to select the specific project / problem statements and check the real-world relevance and the purpose of the projects. Then, the student groups were oriented on taking up outcome-driven projects in order to emphasise the accountability of their work during the project reviews.

A project charter containing the details like project title, purpose, intended audience / user of the project, tasks allocated for individual team members, skills focused, and expected outcomes was prepared and shared with the learners. A project review was conducted to validate the project ideas, meaningful language use, check the feasibility and timeline with faculty members, senior students having project-making experience and industry experts. There were 36 project groups across Semester I and Semester II, and they undertook projects related to podcast production, creating English language-oriented videos, producing short stories in animated format, audio books, generating department brochures, books on a specific theme, technical vocabulary for engineers, aptitude practice modules, videos on interview tips, organizing events, and mobile application for English language learning.



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The projects were analysed at different levels qualitatively and quantitatively. Feedback and reflection on teamwork and project progress were collected continuously to ensure smooth conduction of the process. Three project reviews were conducted to monitor the progress of the project, and a final project review was conducted upon the completion of the project. A project report was prepared by each team and submitted for evaluation along with necessary proofs during the final project review. Peer evaluation and reflection helped the learners to continuously hone their English language proficiency.

RESULTS AND DISCUSSION

The course Fluency Through Practice turned out to be a breakthrough in English language teaching for engineering students. This increased the level of engagement of the students tremendously and served to be a successful model. It was observed that the students who struggled to present their findings during preliminary project reviews were able to present confidently and boldly during their final project review. The documented evidence in the form of classroom observations, self-reflections, peer evaluation and project review depicted consistent improvement of English language proficiency and soft skills of the learners. The key indicators of transformation were the increased spontaneity of the language, clarity of presentation, effective use of English language during formal and informal discussions, effective teamwork, clear feedback and self-reflection, and the project outcomes in the form of research paper publications, video stories, training content, printed communication, paper presentations, book publications, podcast series, and mobile applications.

The following list served as the indicators of growth for the participants: The learners exhibited improved confidence levels during their communication. More number of students started volunteering for carrying out various activities during the project phase. Improved teamwork was witnessed and adaptability to various situations increased as a result of group presentations and team project. The learners explored many new technologies and implemented the concepts in their projects, which is quite unusual for an English class. The 21st century skills like problem solving and creativity became a part of their learning process and the professional readiness of the candidates was visible with their preparedness to face real-world audiences.

All these indicators demonstrated the effectiveness of PBL model compared to the conventional English language teaching approaches. The level of engagement was apparently high with strong student participation during the contact hours, project reviews, group activities and individual presentations. Development of life skills during the process becomes an added advantage of the model and the learners developed confidence to face real-life situations. Peer learning and collaboration helped the candidates to identify their strengths and weaknesses thereby creating a supportive environment. It was noted that a few students exhibited leadership skills by mentoring the fellow students to complete tasks and assignments, which boosted the confidence of learners.

The flexibility of the framework to choose the project of their interest and organic formation of project teams supported creativity and autonomy. The genuine communication situations in different contexts like preparing brochures, presenting the findings, seeking information, and organizing events served as nexus between academia and practical experience. The entire process changed the perception of English language learning and promoted a meaningful learning. Consistent feedback mechanism ensured iteration and refining the execution process. Self-reflection helped the students to set personal goals and march towards the same. There were many challenges encountered during the execution of PBL. One of the significant issue was balancing the team members and the complexity of the tasks. A few teams found it difficult to manage teamwork in completing the assigned tasks. Specific tasks were assigned to individual members by the facilitators considering their strengths. A few students struggled to manage time for carrying out projects beyond the regular class hours, and skipping the timeline created last minute pressures. Limited knowledge about latest technology and limited access too posed challenges in completing the projects on time.





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CONCLUSION

The Fluency Through Practice course offered through project-based learning model demonstrated a significant improvement in the level of engagement of English classes. The tasks and projects undertaken during the course were found to be purposeful and authentic way of communication. It was witnessed that the students transformed from restricted participation to confident presentation. The outcomes of the projects reflected real-world relevance, use of technology in language learning, collaboration and problem solving. The autonomy to select the project statements motivated the learners and created ownership. It was observed that significant improvement in English communication skills was accompanied by the requisite 21st century skills.

This successful intervention opens up the possibilities to embed PBL in language acquisition. Embedding of multidisciplinary communication tasks and real-world scenarios in the course leverages peer learning and collaboration. Multimodal communication in the form of digital media creates awareness about existing technology. This instruction model serves as a viable option to instil English language to engineering graduates in an impactful manner, transforming them from successful communicators to collaborative professionals.

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Table 1 – Area Of Projects Assigned And Skills Developed By The Learners

S. No	Project Type	English Proficiency & Communication	Creativity	Collaboration	Problem Solving	Digital Literacy	Real-World Relevance	Peer Evaluation & Self-Reflection
1.	Podcasts	✓	✓	✓	✓	✓	✓	✓
2.	Creating Videos	✓	✓	✓	✓	✓	✓	✓
3.	Brochures	✓	✓	✓	✓	✓	✓	✓
4.	Digital Content	✓	✓	✓	✓	✓	✓	✓
5.	Creative Writing	✓	✓	✓	✓	X	✓	✓
6.	Mobile Application	✓	✓	✓	✓	✓	✓	✓

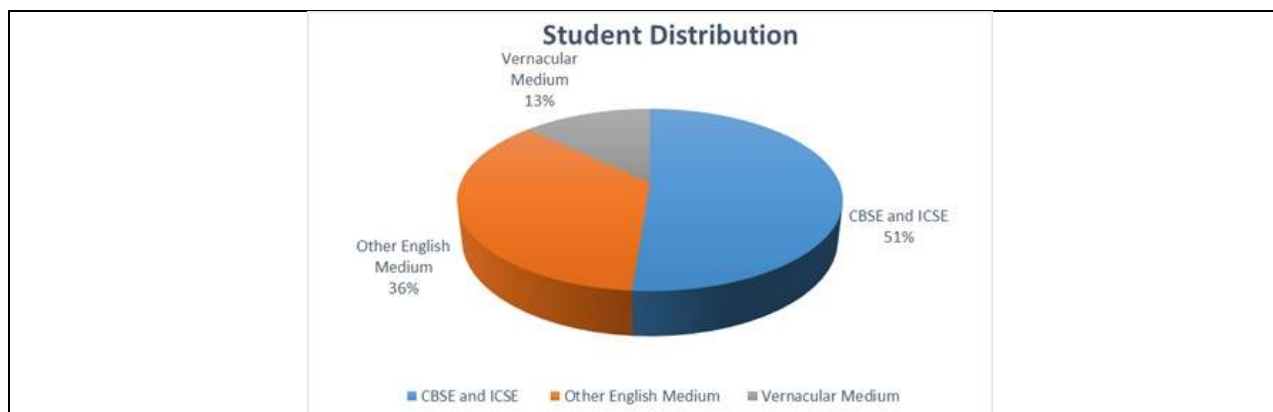


Fig. 1 –Distribution of students based on their medium of learning in their higher secondary education

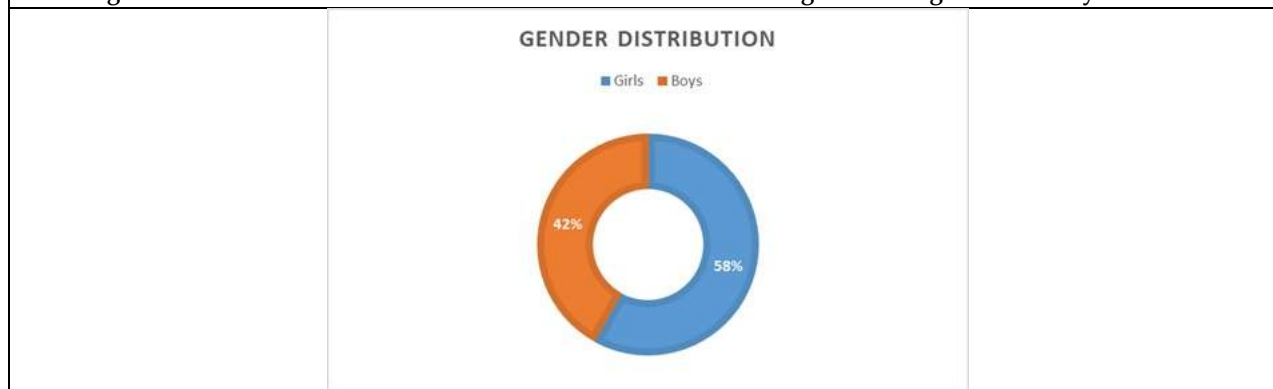


Fig. 2 – Distribution of students based on their gender





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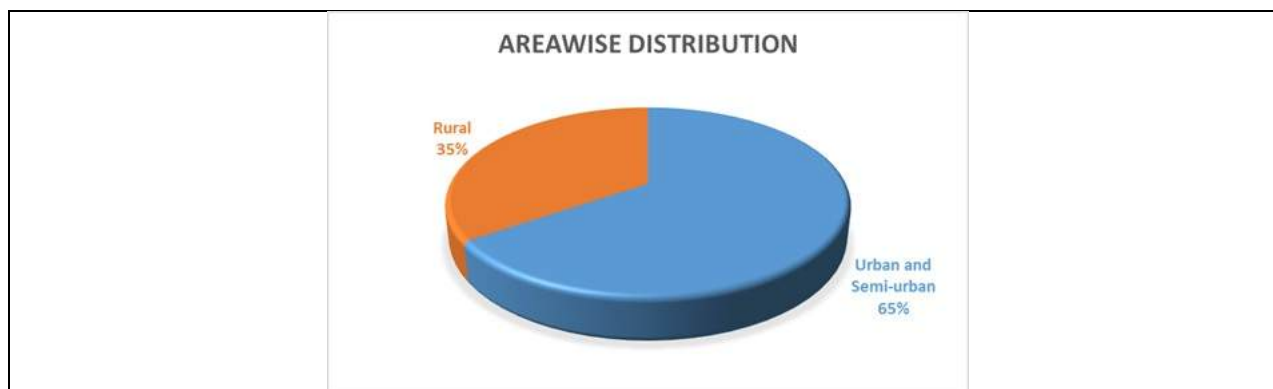


Fig. 3 – Distribution of students based on the location of their school

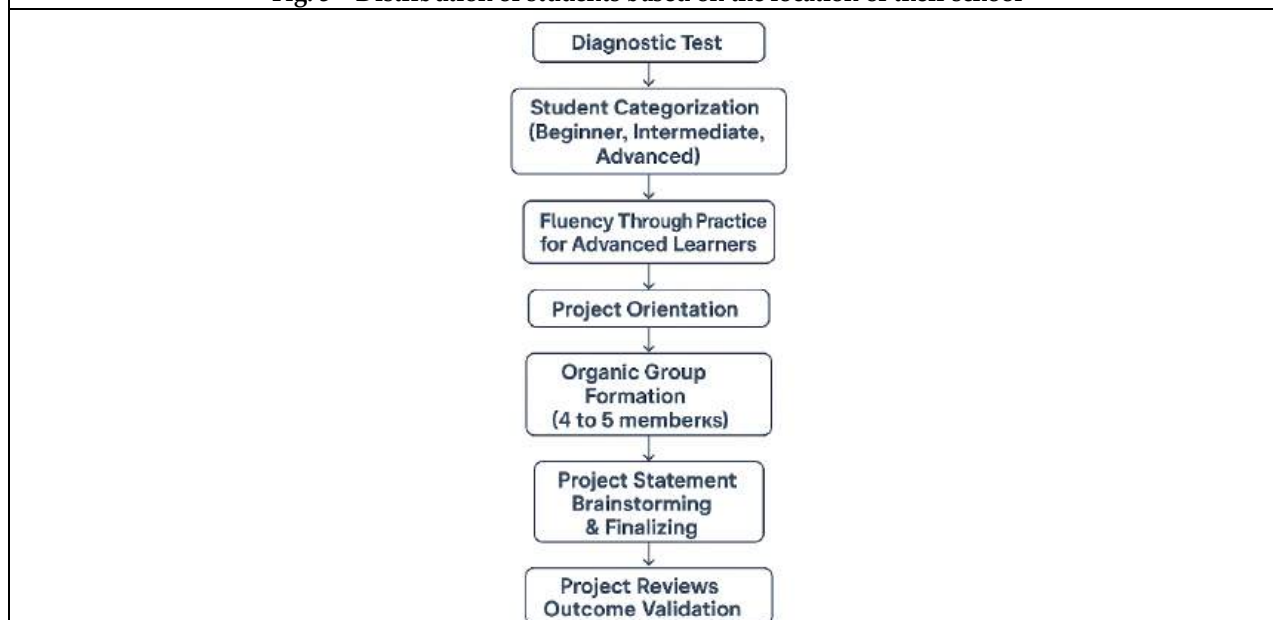


Fig. 4 – Process of Project-Based Language Learning implemented in the institution

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RESEARCH ARTICLE

Exploring the Educational Impact of Animated Storytelling on Children's Learning

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ABSTRACT

Animated storytelling has emerged as an effective educational tool that combines visual elements, sound, and narrative to enhance children's learning experiences. This study examines the educational impact of animated storytelling on children aged 5–10 years, focusing on aspects such as vocabulary development, imagination, academic performance, critical thinking, empathy, and moral values. The research was conducted through a survey involving 42 parents to observe behavioural and learning changes in their children. Primary data was collected using a structured questionnaire distributed through Google Forms, while secondary data from previous studies and reports supported the theoretical framework of the research. The findings reveal that animated storytelling positively influences several areas of children's development. A large majority of parents reported improvements in vocabulary (83.3%) and imagination (81%), indicating that animated narratives effectively enhance language learning and creativity. Many parents also observed moderate improvements in academic performance, critical thinking, and reading interest. Additionally, over half of the respondents agreed that animated content helps children understand moral values and develop empathy through engaging characters and storylines. The study concludes that animated storytelling is a valuable supportive learning tool, but it should be integrated with traditional teaching methods and parental guidance to achieve balanced educational development.

Keywords: development, learning, teaching, educational, guidance



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INTRODUCTION

Animated storytelling is the art of conveying narratives, emotions, and ideas through moving images, combining character development, audio, and visual techniques to bring stories to life. Animation has expanded beyond entertainment and has become an important tool in education. Storytelling has always played a significant role in memory retention, acquiring moral values and knowledge and cultural traditions across generations. Animated Storytelling helps children mainly with deeper understanding of concepts. Animated stories not only support language development but also help children learn ethical understanding through meaningful narratives and emotional connections with characters. Traditional learning methods often lack engagement, struggling to maintain attention whereas animation captures attention through dynamic visuals. It engages memory-sensory stimulation, increasing retention of memory. It allows for self-paced learning unlike traditional one to all approach. Animated story telling caters to diverse learners appealing to visual, auditory and kinesthetic learners. This approach stimulates real world scenario, improving practical application of knowledge and problem solving a much better alternative to passive learning methods.

History of Animation

One can trace the history of animation back to the 1800s with the invention of the Phenakistoscope, which laid the foundation for modern-day animation. It was a simple device consisting of images drawn in sequence around a disc with evenly spaced slits; when spun rapidly, it created the illusion of motion. It worked on the principle of persistence of vision to produce this effect. This marked the beginning of a new era in visual entertainment, and soon more inventions followed. Zoetrope was built upon the same principle, but it allowed multiple people to view the animation at once and was easier to mass-produce. Flipbooks also emerged, in which images were drawn on successive pages; when flipped quickly, they mimicked motion and soon became especially popular among children. The first ever animated film, *Fantasmagorie*, paved the way for many more animations, by bringing pictures to life. Walt Disney remains an iconic figure in animation, well known for his works like *Snow White and the Seven Dwarves* and *Mickey Mouse*. They incorporated audio with visuals providing a cohesive experience for the viewer, shaping the future of modern animation. Creations like *Toy Story* and *Jurassic Park* had a long-lasting impact on the audience, making it possible to believe in the magic of bringing inanimate images to life. Storytelling always served as a medium to share knowledge and values and it has undergone tremendous transformation in the contemporary world. Modern-day animation has also evolved to provide education, helping in simplifying complex concepts and ideas through visual imagery. This shift from traditional methods has certainly impacted on a child's learning experience.

LITERATURE REVIEW

Animated stories telling helps children to build a strong foundation of language. It increases their fluency, confidence and public speaking. It has a positive approach on children's communication skills; thus animated storytelling is considered as a significant pedagogical tool in language education for children. It also reduces anxiety and creates an interactive learning environment. Retention of vocabulary and patterns of sentences helps students in enhancing their language. Lacking meaningful speaking practice leads to decreased confidence and engagement in students. Engaging narratives through animation results in active participation of students and meaningful communication can be promoted by incorporating storytelling in language. Compared to books, interactive elements like animation, sound effects and background music keep children engaging for a longer time by which they can improve their comprehension skills. Primary school children are benefited by this animated storytelling which helps them for early literacy development.

For deeper understanding image should integrate video, charts, photos and animation. Rather than passive information, animated storytelling provides active knowledge construction. Children can easily learn things from



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combination of words and pictures rather than words alone. Well-structured animation can improve problem solving skills, language fluency, vocabulary, grammar and it can also inculcate moral values in children. Animated storytelling supports children learning by improving their understanding and memory. Logical reasoning is alone not enough for learning. Experiences are organized as stories, and this meaningful way of learning enhances children's understanding in a better way. Complicated things can easily be explained in a simple way by replacing them with relatable animations, photos and videos. Thereby it helps children to understand concepts clearly and increase their engagement.

Animated storytelling plays a significant role in shaping ethical understanding in children through content, well-structured narratives, relatable situations, and meaningful emotional conflicts that explain moral lessons such as perseverance, kindness, honesty, empathy, responsibility, hard work, and respect. This helps children to distinguish goods and bads, rights and wrongs and positives and negatives in a correct way. It helps children develop personality and moral understanding. Reflective thinking leads children to engage and boosts their ethical understanding in a better way. Students are inculcated with deeper moral reasoning and critical thinking, which boosts their real-world understanding. Thus, animated storytelling is a powerful way to improve language, moral values, and decision-making skills. These insights strongly support the idea that animated storytelling promotes value-based learning in children.

Memory retention, recalling contents, and even neuron growth is achieved by animated storytelling methods. The music, sounds, pictures, and motion help strengthen our neural connections. This helps in the development of our brain. When children are being connected to animated storytelling, they can experience the feelings and challenges of the characters. Hence, the children are being emotionally and socially benefited from this animated storytelling. As soon as they understand the characters' feelings, they start creating their own world of imagination with their own characters and scenarios. This is where their creativity is being boosted.

RESEARCH METHODOLOGY

1. The study was conducted among parents of children aged 5–10 years to examine the educational impact of animated storytelling. A total of 42 parents participated in the present study.
2. This age group was chosen because the early years are important for thinking skills, creativity, and values. Parents were selected instead of children as they observe their child's behaviour and learn every day and can better notice any changes.
3. Secondary data was collected from various research articles, reports, and studies related to animation in education and child development to support the theoretical framework of the study.
4. Primary data was collected with the help of a structured questionnaire prepared through Google Forms. The questionnaire was shared with parents, and responses were recorded.
5. Information regarding the child's vocabulary development, imagination, critical thinking ability, academic performance, empathy, moral values, problem-solving skills, and daily duration of watching animated stories was collected.
6. Parental observations regarding behavioural changes and overall development of their children after exposure to animated storytelling were also assessed.
7. The collected data was analysed using percentage distribution and presented through appropriate graphical representations for clearer interpretation of results.

Data Analysis and Results

Table 1 shows the information on animation watching habits of children. In the present study, it was found that most respondents, 24 (57.1%), reported that their children watch animation for less than one hour per day. Further, 17 respondents (41.5%) stated that their children spend between one to three hours per day watching animation. Only 1 respondent (1.4%) reported that their child watches animated content for more than three hours daily.



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Table 2 shows parents' opinions on how animated content influences children's cognitive and moral development. When asked about the problem-solving skills, 59.5% of the parents felt that their child's ability to solve problems has improved after watching animated content, while 40.5% did not notice any significant change. In terms of moral values, 66.7% agreed that children gain moral lessons through animation, whereas 33.3% disagreed. This indicates that a majority of parents believed animated content can positively shape moral understanding. Similarly, 64.3% (27 respondents) observed improvement in empathy among their children, while 35.7% (15 respondents) did not observe such development. Overall, the results suggest that most parents perceive animation as having a positive influence on children's thinking skills and moral growth, though opinions are not entirely unanimous.

Figure 3 presents the responses of the parents regarding the improvement in their child's imagination. The majority, 34 parents (81%), agreed that imagination has improved significantly, whereas 8 parents (19%) disagreed. This shows that most parents have clearly noticed a positive change in their child's creative abilities. The findings suggest that animated storytelling may help children think more creatively and express their ideas more freely. The figure presents parental responses regarding the impact of animated storytelling on children's development. A majority of parents (83.3%) observed an improvement in their child's vocabulary, while only 16.7% did not notice such change. Similarly, 66.7% agreed that children gained moral values from watching animated content. More than half of the parents reported positive changes in academics (54.8%) and improvement in critical thinking skills (57.1%). An equal percentage (57.1%) also observed increased interest in reading books. However, a comparatively higher percentage of parents did not observe academic improvement (45.2%) and critical thinking growth (42.9%), indicating that these areas show moderate rather than overwhelming improvement. Overall, the findings suggest that animated storytelling has a notably positive impact on vocabulary development, moral values, reading interest, and cognitive skills among children.

DISCUSSION

When I look at the responses from the survey, the first thing that stands out is how strongly parents feel that animation helps with vocabulary and imagination. More than four out of five agreed that their child's vocabulary has improved, and a similar number felt their imagination had grown. That makes sense — animated stories are colorful, engaging, and full of new words tied to visuals, which makes them easier to remember. It's not surprising that children pick up language faster when they're immersed in such lively storytelling. But when I shift my focus to academics, the picture becomes more complicated. Just under half of the parents noticed positive changes in school performance, while slightly more said they hadn't. This tells me that while animation sparks creativity and language, it doesn't automatically translate into better grades or stronger academic skills. The same pattern shows up with critical thinking and problem-solving: fewer than half of the parents felt these areas had improved. That suggests animation alone isn't enough to build those higher-order skills — children need guidance, discussion, and practice beyond just watching.

Engagement, however, is where animation shines. Some parents reported that their children had started showing interest in reading books, which is a big step forward. Animation often acts as a gateway — kids fall in love with characters and stories on screen, and then they want to explore them in books. Compared to traditional methods, animation clearly has an edge in sparking curiosity. Still, when it comes to moral values and empathy, the results are mixed. Only about a third of parents agreed that animation helped in those areas. That tells me the content of the stories matters a lot. If the animation is designed with strong moral lessons, it can work, but if it's just entertainment, the impact is limited. Putting all this together, I see a general pattern: animation is excellent for imagination, vocabulary, and engagement, but weaker when it comes to academics, critical thinking, and social values. This matches what many studies in education say — visuals and storytelling boost memory and creativity, but deeper skills require active learning and reflection. In other words, animation is a powerful tool, but it works best when combined with traditional teaching and parental involvement.





CONCLUSION

The objective of the study was to see whether animated storytelling benefits children, and the answer is yes, but only partly. It clearly helps with language and creativity, and it makes learning more engaging. At the same time, it doesn't automatically build problem solving or empathy. That means animation should be seen as a complement, not a replacement, for other methods. Used thoughtfully, it can bridge the gap between entertainment and education, making learning fun while laying the foundation for deeper skills.

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Table 1: Information on hours of animation watched

Information on animation watching	Frequency	Percentage (%)
<1 hr./day	24	57.1%
1-3 hrs./day	17	41.5
>3 hours	1	1.4

Table 2: Perceived Cognitive and Moral Impact of Animated Content

Variable	Response	No. of Respondents	Percentage (%)
Improvement in problem-solving skills	Agree	25	59.5%
	Disagree	17	40.5%
Acquisition of moral values through animation	Agree	28	66.7%
	Disagree	14	33.3%
Development of empathy	Agree	27	64.3%
	Disagree	15	35.7%

Table 3

Question	Agree (%)	Disagree (%)
Has your child's vocabulary improved?	83.3%	16.7%
Have you observed positive changes in academics?	54.8%	45.2%
Has their critical thinking improved?	57.1%	42.9%
Have they started showing interest in reading books?	57.1%	42.9%
Do they gain moral values from watching such animations?	66.7%	33.3%





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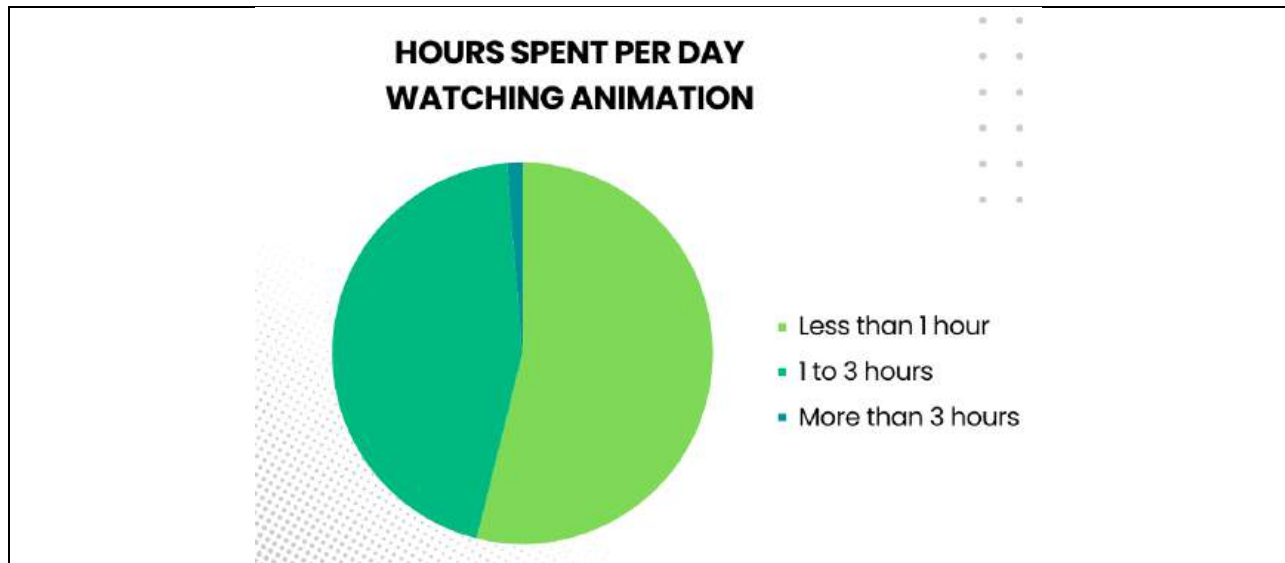


Figure 1: Information on hour of animation watched

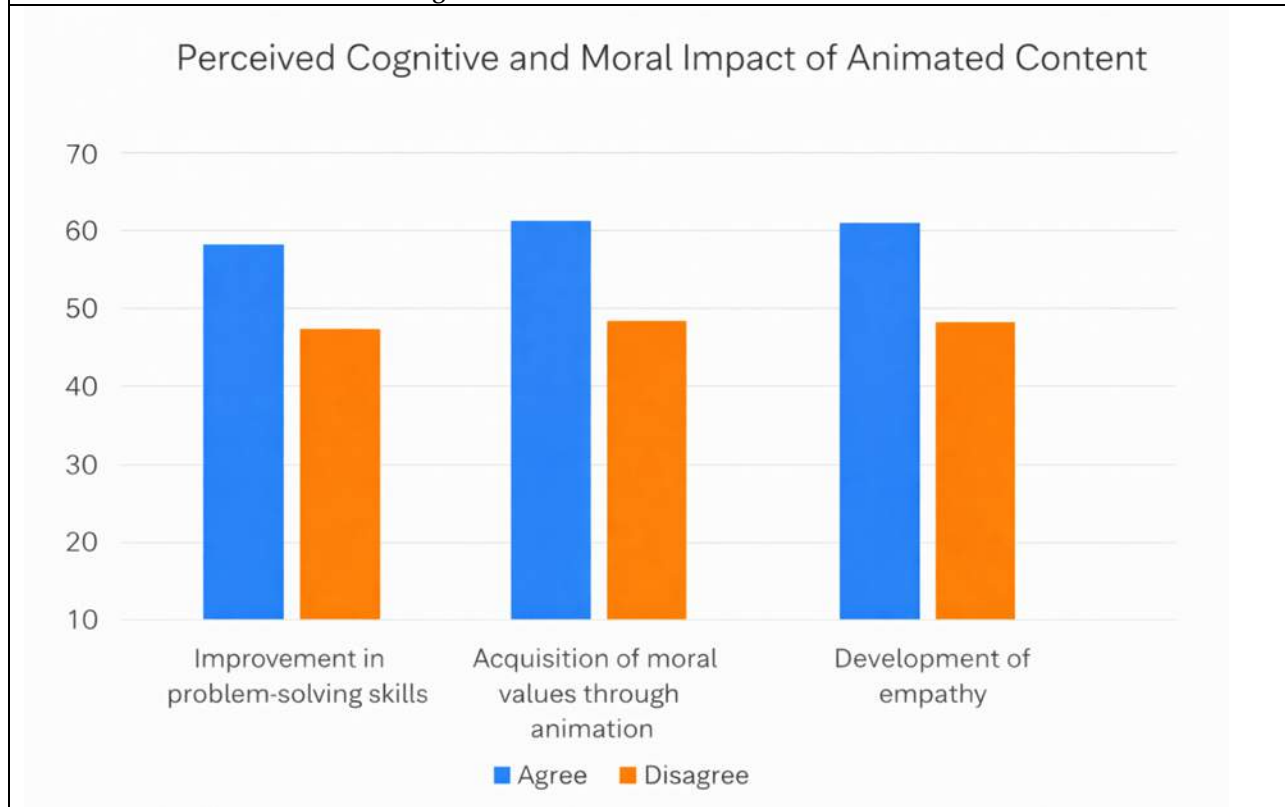


Figure 2: Perceived Cognitive and Moral Impact of Animated Content





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INFORMATION ON IMAGINATION GROWTH

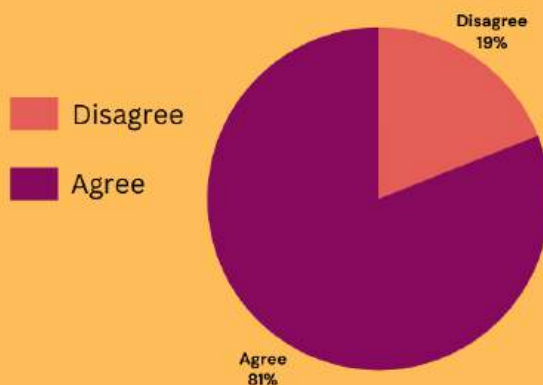


Fig 3 : Information on Imagination Growth

Parental Responses on Impact of Animated Storytelling

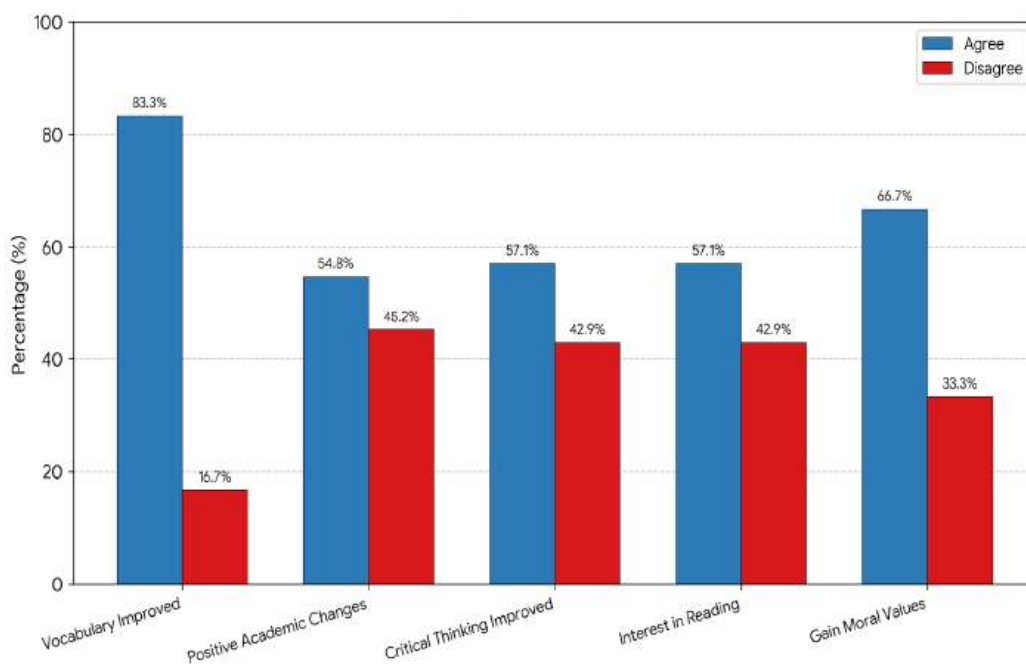


Figure 4: Impact on Animated Storytelling

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RESEARCH ARTICLE

Decoding the Embedded Plant Awareness in Folklore Among the Indigenous Naga Community

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ABSTRACT

In the modern world, plants have slowly receded into the background of human life. As everyday contact with nature declines, what scholars call Plant Blindness, later reframed as Plant Awareness Disparity has become increasingly visible. This condition reflects a gap in attention, knowledge, and value, where plants are often overlooked or treated as less important than animals. This study asks whether such a disparity is universal, or shaped by modern, human-centred ways of thinking. Focusing on the Naga communities, the study adopts a qualitative, interpretive methodology based on close reading of selected folklore, ethnographic writings, and archival texts. It explores how plant awareness is embedded in folklore, rituals, beliefs, and material culture. Drawing on Shalom H. Schwartz's framework, it shows that values such as Universalism and Benevolence extend beyond humans to include plants, while Tradition and Security sustain ecological balance through taboos and practices.

The findings show that in the Naga worldview, plants are not passive resources but living, relational beings. They appear as spiritual presences, prophetic symbols, and material anchors of social life. Dreams, omens, and sacred practices reveal a deep attentiveness where the condition of plants reflects the condition of the community. From the head-tree to the log drum, plant materials shape memory, identity,



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and communication. The study concludes that plant awareness in Naga life is holistic and lived. It challenges the idea that plant awareness disparity is universal, showing instead that cultural memory and practice can sustain a respectful, interdependent relationship with the natural world.

Keywords: Environmental Generational Amnesia, Indigenous Naga Community, Folklore, Human-Plant Intersection, Plant Awareness Disparity, Northeast India.

INTRODUCTION

Plants used to be everywhere around us, regardless of region, place, and time, until the modernization of villages and cities gradually marginalized them due to the spread of human occupation and activities, limiting the interaction between plants and humans, impacting detrimentally on the human's awareness of plants (Gaoue et al., 2017), and the correlation drawn between trees and human civilization by Pogue Harrison states that evolution from huts, villages, and cities to cosmopolitan marks civic expansionism (Harrison, 2009), leading to a condition, known as 'plant blindness' which is defined as an "inability to see or notice the plants in one's own environment leading to; (i) the inability to recognize the importance of plants in the biosphere, and in human affairs; (ii) the inability to appreciate the aesthetic and unique biological features of the life forms belonging to the Plant Kingdom; and (iii) the misguided, anthropocentric ranking of plants as inferior to animals, leading to the erroneous conclusion that they are unworthy of human consideration" (Wandersee and Schussler, 1999, 2001) later Parsley (2020) redefines the concept of plant blindness as Plant Awareness Disparity (PAD) to make the study more accessible in plant discourses beyond botanical knowledge.

The rebranding of plant blindness as plant awareness disparity has fascinated studies seeking to empirically understand the disparity across diverse populations in the categories of attention, attitudes, knowledge, and relative interest (Parsley, 2020). As Balas and Momsen states, people pay no attention to plants around them in their everyday lives because of a deference in the visual attention of the cognitive feature that gives less attention to plants (Balas and Momsen, 2014), and sometimes do not even consider that plants as living beings due to their lack of immediate and observable physical motion (Yorek et al., 2009). And this lack of attention towards plants by people deprives the plants of their biological individuality and phenomenologically pushes them into a whole large green backdrop (Wandersee and Schussler, 2001). This cognitive faculty of deprived attention towards plants is also said to arise from the missing visual cues that distinguish objects, whereas the green mass of plants does not exhibit much distinction, as identified in the shape and movement of animals (Feldman, 2003), causing disparity in the awareness of plants due to less attention given to plants for their appearance, lack of motion and other characteristics.

In addition to the cognitive aspect of attention in plant disparity, people's attitudes towards plants and the environment are also important factors contributing to plant awareness disparity. Public attitude in their preferences in choosing and investing their interest in animal studies for a career, and a decline in emphasis on plants in academia has reduced the opportunity for involving and investing in plant knowledge (Fančovičová and Prokop, 2011), which relates to attitude towards plant matters in discussing plant awareness disparity. And to increase attention towards plants, one has to develop a positive attitude towards them. Thus, attention and attitude are directly linked in the context of PAD. (Strgar, 2007; Mrkva et al., 2019; Lindemann-Matthies, 2005). And plant knowledge is also a vital aspect highlighted among the factors leading to the plant disparity. If not all the knowledge of plants, at least specific knowledge, such as the role and importance of plants to humans and the biosphere, is essential beyond the categories of students, teachers, and scientists in the discipline of plant study (Hershey, 1993; Frisch et al., 2010). Lastly, as the scholars dealing with the plant awareness disparity have identified 'relative interest', that is, people do not find plants as interesting as other living organisms, and often only consider the discipline of biology as a study of animals, is a popular delusion (Nichols, 1919). This relative lack of interest in



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plants contributes to the plant awareness disparity because this component is a determinant of attitude and knowledge (Pany et al., 2019). Is this plant awareness disparity, or the plant blindness identified by the scholars and environmentalists, an anthropocentric worldview rooted in humanist philosophy, or is it a persistent phenomenon across human civilization? Is the disparity in plant awareness historically tenacious in the culture of indigenous communities? These two questions are essential for identifying how it was addressed in pro-environmental indigenous spaces, if at all; plant awareness disparity is a persistent phenomenon in humankind is the interesting to discuss, since indigenous communities maintained a symbiotic relationship with nature, and in their animistic religion, saw no difference between humans and natural entities, including plants, animals, landscapes, and celestial bodies (Rodgers, 2025). If the animate and inanimate are seen and perceived with abilities to communicate, reflect, and act intentionally similar to those of humans, in addition to having a spirit in spiritual essence, (Van Eyghen, 2023), the question still remains unanswered whether plant blindness or plant awareness disparity was present in the indigenous communities, despite their eco-friendly social and cultural practices that are acclaimed as indigenous sustainable knowledge (Nakashima and Roue, 2002). So, this research aims to uncover the encoded plant awareness embedded in the folklore of the Naga indigenous communities and to analyze the disparity.

The Indigenous Naga community is one of the major tribes in the Northeast region of the modern-day state of Nagaland, India. "Naga is a generic word known to a particular tribe who live mostly in the North Eastern part of India. They are Indo-Mongoloid race speaking the Tibeto-Burman language. It has more than 50 sub-tribes, they are collectively known as the Nagas" (Horam, 2019). The Naga community comprises many clans and ethnic groups, including Angami, Aos, Sema, Lotha, Rengma, Chakheang, Sangtam, Ronyak, Phom, and Chang (Rama Shankar, 2012). "Those tribes known generally as Nagas, inhabit mountainous districts on the upper part of the valley of Assam, and southward of the Bramahpootra, not extending higher north than to a tributary of that great river, known as the Boree Deehing, in a latitude of about 17° 15'" (Owen, 1844), and the major Naga tribes include Angami, Ao, Chakhesang, Chang, Dimasa Kachari, Khiamniungan, Konyak, Lotha, Phom, Pochury, Rengma, Sangtam, Sema, Sumi, Yimchungru, Zeliang (Kire, 2019, pp. 12-26). Like any indigenous community, the Nagas have historically interwoven their life and culture with the environment around them. And their association with animals and plants is exclusively shaped by their dependence on them for survival. The close proximity of their lives to their surroundings has sustained an awareness of plants that, in turn, reciprocates the community's anti-generational environmental amnesia (Luikham & Bhattacharyya, 2024, pp-848-863). In this research, a select set of folklore and folktales readily available in archives and print forms is considered to encode plant awareness and sustainable practices that overcome generational environmental amnesia (Walshe et al., 2025, pp. 856–871), because many indigenous communities hold a values, beliefs and cultural practices that "treat plants as fundamentally autonomous, volitional, communicative, relational beings. The notions of plant personhood and human-plant kinship are expressed in stories, poems, and myths (Hall, 2011).

Studies in the Naga communities have identified many plant-based medicines used by Naga tribes. Changkija notes 109 species of plants in ethnobotanical literature during a field survey (1999). Another study on the ethnic people of Nagaland reports 60 ethnno-medicinal plant species, acknowledging medicinal plants used to cure diseases (Rajaganesh et al., 2023). Vadeo, reviewing the medicinal plants used by the Naga tribe, examines the use of 20 indigenous medicinal plants used in cultural and traditional practices (2023). An ethnobotanical survey conducted in 1993-1997 identified 36 plants predominantly used by the Naga tribes for medicinal purposes (Jamir et al., 1999). In the estimation of Ethnobotanical Plants of Naga tribes, a vast knowledge of the utilization of local plants among the 36 tribes of Nagas (Pfoze et al., 2016). During the investigation of Mao Naga folk medicinal plants, 61 plants used by the ethnic community were reported (Lokho, 2012). A survey and documentation of plants of Nagaland investigates 142 edible plants and highlights the need to promote the plants for food security and income through sustainable conservation (Deb et al., 2019). The traditional knowledge of medicinal plants used in Nagaland records 34 plants with scientific names by specifying the plant parts used in treatments (Kirha and Kere, 2023). Lanusashi and Martemjen describe the Nagas' perceptions of nature and their surroundings in relation to beliefs, myths, and taboos in folklore and folksongs to elucidate biodiversity conservation (Lanusashi Lkr, and Martemje, 2014). Nagaland, endowed with rich and diverse biodiversity, is included in the 34 Mega Biodiversity regions of the world, with



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approximately 2,431 plant species, among which 113 are underutilized medicinal plants (Konyak and Swuro, 2021). Recording the Indigenous Knowledge on Utilization of plant biodiversity in the 2005-2010 survey, 241 plant species were listed from eight Naga tribes, and it is argued that

Traditional healing system is unique and suitable strategies are adopted by the tribals for sustenance as they are endowed with a vast knowledge concerning the use of these wild plants. Several reasons act upon for use of traditional medicinal plants by tribal communities. Because the tribal's living in rural areas, they cannot afford or access to formal health care systems and therefore, largely depend on the indigenous knowledge of traditional medicines. Still today, the bioresources are so intrinsically interwoven with the lifestyle of tribals that medicinal plants are inseparable to the poor tribal communities (Zhasa N.N. et al., 2015, pp. 89-106).

Beyond the source of medicine and food, plants and trees are also integral components of cultural identity, rituals, and ecological understanding (Schaal, 2019). Additionally, ethnobotanical surveys and the vast research collections on the indigenous knowledge in plants, there remains a scope to study relationship between the Naga community and plants, because of the Naga communities' recognition of plants as participants in their societal institutions and giving space for plants and plant materials in their culture, tradition, customs, rituals, and taboos, gives us intriguing opportunity to understand the communities relations with plants, unlike the most Western, European and White who drive to dominate and shape landscapes that marginalized trees (Shimrah et al., 2026, pp. 1-11) (Nitzke and Braunbeck, 2021).

Intersection of Human-Plant Relations in Naga Social Values and Beliefs

Value has been a fundamental in human society; it can mean standards, beliefs, principles, moral obligations, and social norms, but also desires, wants, needs, or interests. It can also mean the worth, importance, or significance of a thing or object of interest (Ahmad, 2013). And Schwartz's theory of basic human values identifies values recognized across cultures to explain the motivational bases of attitudes and behavior. He specifies six main features of values: (values are beliefs; values refer to desirable goals; values transcend actions and situations; values serve as standards or criteria; values are ordered by importance; and the relative importance of multiple values guides action), but distinguished from them is the type of goal or motivation that the value expresses. Based on the underlying motivation that inspires the values, ten broad values are identified as universal requirements. (Schwartz, 2012, pp. 3-5). Among those ten values, Universalism; Benevolence (grouped under Self-Transcendence) and Conformity; Tradition; Security (grouped under Conservation) are significant to consider to understand the human-plant relation in the indigenous community because, as argued by Schwartz, Benevolence is a defining goal in preserving and enhancing the welfare of the those with whom one is in frequent personal contact (p. 7). Benevolence values derive from the basic requirement for smooth group functioning (Kluckhohn 388-433) in the need for affiliation (Maslow, 1965) with an emphasis on others' welfare through the variables of helpfulness, honesty, loyalty, friendship, love, forgiving, and responsibility (Schwartz, 2012, p. 7). Another type of value, Universalism, is a defining goal to understand, appreciate, tolerance, and protection for the welfare of all people and for nature through the variables like broadmindedness, social justice, equality, a peaceful and beautiful world, unity with nature, wisdom, protecting the environment, harmony, and spiritual life (Schwartz, 2012, p. 7). The types of values categorized under conservation; conformity value is a restraint of actions, inclinations, and impulses that are derived from the requirements of an individual who emphasizes obedience, self-discipline, politeness, and honor. Whereas Security value is a defining goal in the safety, harmony, and stability of society, of relationships, and of self, through the variables: social order, family security, national security, cleanliness, and reciprocation of favors. And finally, the value of Tradition shares a defining aim of respect, commitment, and acceptance of the customs and ideas that one's culture or region provides through the variables of religious and cultural customs in practices, symbols, and beliefs (Schwartz, 2012, p. 6).

These conservation and self-transcendence values in indigenous communities are not limited to human social groups; they are also applied to plants and trees in their environmental landscape. The rituals, customs, and practices that center on plants and trees highlight the shared value and belief of the human society to vegetative entities



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because, as Cajete states, “each part of the Earth is a manifestation of the spiritual center of the universe. Stone, trees, animals, or plants may be venerated as expressions of the sacred and representations of the greater family of life from which they come” (Cajete, 2000, p. 109). This greater family is an intersection of humans and non-humans, including plants, that become part of their spiritual and religious values and belief systems. The Naga community exhibits shared values and beliefs with plants and trees in many Taboos and Omens centered on plants and trees.

Plants and Spiritual Entities

The Angami Naga worldview of “oneness” and the “sentient landscapes”(Heneise, 2020, pp. 80, 126) perfectly mirror Schwartz's “Unity with Nature” value. The animated forests and rivers are equal with humans; the Universalist drive isn't just an abstract political stance; it is a biological and spiritual necessity, and to harm a plant is to harm the life-force that sustains the self. Schwartz (2012) defines Tradition as respect for and commitment to cultural or religious customs, while Security focuses on safety and stability. The informant falling ill after entering a sacred forest links these two, and the “spirits demanding respect”(Heneise, 2020, pp. 6, 12) function as a mechanism of Schwartz's conformity and security. By adhering to traditional taboos, the community maintains the “oneness,” suggesting that in the Angami Naga worldview, universalism is actually maintained through the rigid structures of tradition and security, rather than being a separate, “liberal” value as it is often framed in Western contexts. Because trees are “sentient beings”(Heneise, 2020, p. 126), the act of respecting spirits is a benevolence toward a non-human kin group.

When a tree falls or a mushroom grows in a dream, it is felt as a literal disturbance in the human soul. Therefore, “plant awareness” is not just about knowing how to use plants; it is a constant, high-stakes awareness of how to coexist with them without violating the laws of the spirit masters who own the land. These taboos and omens could be considered as variables of value type of universalism and broadmindedness to be aware of the welfare of forests, trees and plants upholds plant awareness in the Naga community. These indigenous values are conservation biology driven by spiritual reverence. By labeling forests as sacred and attributing illness to their disturbance, the community effectively creates protected biological zones where biodiversity is preserved through spiritual fear. This awareness shows that the Nagas perceive a “consubstantiation”(Heneise, 2020, p. 80) a oneness-between their own bodies and the physical environment specially with plants and trees.

Plants as Prophetic Symbols

In the Naga worldview, taboos and omens are a sophisticated moral and environmental codes. The forest is a sentient landscape governed by ancestral laws and spirit masters. The Angami Naga consider that crossing spiritual boundaries between human and nature, whether in reality or in a dream, triggers immediate consequences, ensures human relationship with the botanical world, and maintains a deep respect and cessionary conduct towards sacred forests and trees. (Heneise, 2020, p. 121). Plants and forests also act as the physical markers of territories and violating them is seen as an act of spiritual trespassing. “...an informant ...unwittingly enters a sacred forest, falls immediately ill and requires significant intervention [of] dream prophetess and the spirit.”(Heneise, 2020, pp. 6, 127)Local villagers explicitly warn against entering forests “guarded by a master spirit.” The illness that follows a violation is seen as a physical manifestation of a broken spiritual taboo. “You know, when you dream of mushrooms it's a bad omen... It kept growing and growing until I thought it was going to consume me”(Heneise, 2020, p. 105).Small, often overlooked mushrooms are elevated to powerful symbols of decay or personal threat, showing that no part of the plant kingdom is viewed as “neutral.” And “dream in which a giant tree fell... it is a particularly tragic dream as it is attached to the well-being of the family”(Heneise, 2020, p. 43).Because the tree stands as a metaphor for the clan, its “fall” in a dream is a taboo event that requires communal vigilance to prevent an actual death.

In the Naga worldview, performative taboos like genna or kenyu are spiritual safeguards. The Sangtam Naga tribe believed that “it is taboo to use trees and items struck by lightning” (Kire, 2019, p. 176). Not using a tree that is struck by lightning for human needs shows that the Naga community views trees as capable of interfering with their social and spiritual beliefs. The specific plants like “ayilo and zunhebo” (Kire, 2019, p. 181) usedfor protection by Sumi Naga, or the use of michem leaves to signal the birth of a child, demonstrate a precise knowledge of botanical beings,



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and the Naga communities accept such mediation because of their awareness of plants and trees. And their mediation is not limited to the earthly life, "since the Angamis believed in life after death, the deceased would be buried with his agricultural tools and seed grains"(Heneise, 2020, p. 69). This belief underscores the human-plant relationship. By burying a person with "seed grains," the community acknowledges that the cycle of life, labour, and growth does not end at death. It suggests that the essence of a person's life is defined by their role as a cultivator and that the spiritual world mirrors the physical one, requiring the same botanical foundations as seeds to sustain the soul in the afterlife. It's seen as a preservation of the past by burying the deceased with agricultural tools and seed grains that have been used by their ancestors. These beliefs demonstrate a profound plant awareness that goes far beyond simple utility; it reveals a "botanical intelligence" where plants are recognized as holders of power, omens, and protective energy. While it comes under benevolence, it has more to do with deep-rooted traditions as it focuses on tribal aspects and their connection to an agrarian lifestyle.

The Chang Naga community sees the forest as a specific map of meanings. The Michem tree is believed to be the guardian for a newborn's placenta (Kire, 2019, p. 136), the wild nut (wei) is a vessel for prophecy, and the head-tree is the spiritual anchor of an entire village's security. And by observing whether a branch falls from a specific tree or if a seed "bursts" inside or outside a home (Kire, 2019, p. 94) the community displays an intimate sensitivity to the life cycles and physical properties of local flora. This belief system suggests that, for the Naga communities, plants are not just resources to be consumed but sentient witnesses to human history, capable of communicating the health, future, and morality of the village. This manifests Schwartz's security variable of the conservation value. These rigid Naga community beliefs and taboos are believed to protect the household from bringing any bad luck and life-threatening problems to their clan.

These taboos and omens prove that "plant awareness" in the Naga community is a form of indigenous conservation biology driven by spiritual reverence. By labeling certain forests "sacred" and attributing illness to their disturbance, the community effectively creates protected biological zones where biodiversity is preserved through spiritual fear. This awareness shows that the Nagas perceive a "consubstantiation"(Heneise, 2020, p.80), a oneness between their own bodies and the physical environment. When a tree falls or a mushroom grows in a dream, it is felt as a literal disturbance in the human soul (ruopfü). Therefore, "plant awareness" is not just about knowing how to use plants; it is a constant, high-stakes awareness of how to coexist with them without violating the laws of the spirit masters who own the land.

While elements of Security (the fear of death or "being consumed") and Benevolence (the birth of a rightful heir) are present, the mechanism of dreaming and the specific meanings assigned to certain plants are anchored in the shared symbols and customs of the Angami tribe. The "giant tree falling" is codified as foretelling the death of a clansman (Heneise, 2020, p.43). The meaning of the tree is not subjective; it is a traditional truth. By adhering to these interpretations, the individual reaffirms their commitment to the collective cultural wisdom over personal or "modern" logic. The mushroom dream is described as a "bad omen" that threatens to "consume" the dreamer (Heneise, 2020, p. 105). Prophetic plant symbols provide a psychological sense of Security even when the omen is negative. Knowing what is coming (death or birth) allows the clan to prepare. The plants act as an early-warning system, maintaining social order by reducing the chaos of the unknown. The bamboo penetrating the roof signifies a "baby boy... the rightful heir."(Heneise, 2020, p. 44) The gender of the newborn in Ao Nagas is revealed by purring up a tall bamboo pole outside the house, right in the middle of the front of the house for a boy, and slightly off-center for a girl (Kire, 2019, p. 84). And the Lotha Nagas, in the process of establishing a new village, specifically look for a water source and a suitable tree to serve as a head-tree (Kire, 2019, p. 132). The plant is a messenger for the human clan, aligning with Schwartz's Benevolence, as the prophecy is not about individual wealth but about the continuity and strength of the in-group (the family/clan lineage). The dreamer does not argue with the omen; they accept it. This limits impulses that might upset the social balance. Thus, plant awareness in the Naga community is holistic and non-extractive. The Naga community views the forest as a sentient mirror of their own society. By linking the falling of a tree to the death of a human, the community acknowledges a profound biological and spiritual interdependence. In other form the tree is a clansman that creates a culture of deep environmental respect, where one does not simply



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cut a tree or clear a forest without considering the spiritual consequences. It elevates plants from objects to subjects with the agency to warn, protect, and guide the human community. In the Naga cosmology, plants are living spirits through which the spiritual world communicates with the human realm. The dream of Nagas is a legitimate space for negotiation and revelation. Whether it is a warning of death or a promise of prosperity, the state of a plant in a dream is believed to manifest directly in the physical life of the clan.

The rapid, vertical growth of bamboo is a metaphor for the continuation of a lineage. This dream was powerful enough to halt a legal property distribution, proving that plant signs carry judicial weight. "if you dream of paddy, it is a premonition for quarrel ...dream of mushrooms it's a bad omen... it was like a giant boil in the floor... until I thought it was going to consume me"(Heneise, 2020, pp. 41, 105). These symbols show that even small plants are "read" as indicators of social disharmony or personal illness. This prophetic relationship proves that "plant awareness" in the Naga community is holistic and non-extractive in their value and belief system designed for the welfare of the humans and plants or trees who are in personal and close contact. It shows that the Nagas do not view the forest as a collection of "timber" or "crops," but as a sentient mirror of their own society. By linking the falling of a tree to the death of a human, the community acknowledges a profound biological and spiritual interdependence; the tree is a "clansman" in another form shall be associated with the variable of Benevolence value type. This awareness creates a culture of deep environmental respect, where one does not simply cut a tree or clear a forest without considering the spiritual consequences. It elevates plants from the status of "objects" to "subjects" that possess the agency to warn, protect, and guide the human community (Swaraj & Mishra, 2026).

Botanical Material Culture Among Nagas

Material culture is the study of physical objects, resources, and spaces that people create, use, and share as part of their culture. "Material culture is fundamental to being human. Things are the medium through which we act, understand ourselves and relate to each other. They habituate our reflexes, make meanings concrete and intervene as agents in our lives" (*Material Culture* | Department of Archaeology, n.d., 2026). It is about the social relationship between people and things and is important because,

...it is essential to examine the concept of the artifact, as it constitutes the primary source of information for the archaeological discipline. Archaeology relies on the analysis of artifacts to understand past societies, particularly those that lacked written systems for transmitting knowledge and information. In the case of Prehistory, where no written records exist, the detailed study of material objects, such as tools or pottery, is crucial for reconstructing key aspects of the ways of life and cultural dynamics of these societies (Sánchez-Climent, 2024, p. 116).

The categories of material culture include Art (paintings, drawings, prints, sculpture, photography); Diversions (books, toys, games, meals, theatrical performances); Adornment (jewelry, clothing, hairstyle, cosmetics, tattooing, other alterations of the body); Modifications of the landscape (architecture, town planning, agriculture, mining); Devices (machines,, vehicles, scientific instruments, musical instruments, implements) these material agents are significant since, people in all societies express and have expressed their beliefs more explicitly and openly in their material forms and aspects of their mind can be discovered through their material culture (Prown, 1982). Plants and plant materials used in any of the above-mentioned categories of material culture make them eligible for inclusion in the study to understand attention, attitudes, knowledge, and relative interest, which are contributing factors to the disparity in plant awareness. By investigating the plant material culture, it is possible to understand the complex and overlooked relationships between humans and plants. Plants and trees as biocultural actors bridge the nature-culture divide (Cornish and Hourigan, 2025). Considering both the material properties of plants and social implications of plant–people relations, the historic relationship between people and plants is often seen as reciprocal (van der Veen, 2014), and

Specifically, in societies where culture and nature are entwined through diverse traditions and regulated by indigenous knowledge systems, native trees and other natural features provide cultural and social functions. This forms eco-cultural synergy, which recognizes that human cultures are deeply embedded in their natural





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environments and that ecological health and cultural vitality are mutually reinforcing (Roba, 2025). This socio-cultural construct in the indigenous Naga community holds that people create and interpret meanings through interactions and assign plant and tree materials to experiences (Schaefer, 2004). The symbolic significance of trees in a number of cultures conceptualizes human interaction with the natural environment and natural resources, reflecting the human urge to share or preserve ideas through material signs, which is important for becoming conscious of thought or ideas by fixating them on the material object itself (Rival 1998). The nature and culture of the indigenous Naga communities underpin the plant and tree materials as active constituents in their social institutions draws the perspective of agency to the plant and tree materials in their culture and social institutions in the form of infrastructure, tools, symbols, weapons, etc.

Plants Material in Ritual Foundations

Schwartz defines Benevolence as the preservation of the welfare of the "in-group." The use of banana leaves for "gift exchange culture" and the "doubling" of meat (Heneise, 2020, p. 39). The plant is the material medium through which Benevolence is expressed. You cannot have the "gift" without the "leaf." By using local plants to wrap and share food, the community reinforces the bonds of the in-group. The plant becomes an extension of the giver's intent to support the collective. The "bamboo basket" and "thin strands of bamboo" used to secure food (Heneise, 2020, p. 104), the precision in how the soybeans are "tightly wrapped" reflects a need for order and preservation. In a material sense, plants ensure food security and domestic stability. These material uses are not merely efficient; they are correct. To use a different plant would be to deviate from the Naga social identity.

In the Naga cultural landscape, the head-tree (*mangkotürong* or *Mingetung*) functions as a quintessential biocultural actor, and the biological properties of the plant around the village gate are inseparable from the social identity of the village.

Every Ao village has an open space which houses the head-tree. In large villages, each khel had its own head-tree. The head-tree, also called mangkotürong (Chungli) oryimzung (Mongsen), was integral to the village. The heads of enemies would be hung on the head-tree for all to see. People placed round stones known as prosperity stones at the foot of the tree. It was common to see another set of stones beneath the tree, which were markers of peacemaking between two villages. The stones were said to breed and increase in number on their own. (Kire, 2019, p. 73)

As a primary form of material culture, the head-tree is more than a backdrop; it is a deliberate modification of the landscape that anchors the community's history and spiritual life. By serving transforms abstract tribal valour and diplomatic treaties into tangible, visible reality. This interaction reflects an eco-cultural synergy, where the plant material culture bridges the nature-culture divide. The tree is an active constituent in social institutions its physical growth and presence are entwined with the village's survival and status. By assigning experiences to these botanical forms, the Naga community fixates their belief systems upon the tree's living structure, turning it into a material sign of collective consciousness. Thus, the head-tree is not merely a natural resource but a sophisticated technological and symbolic device that habituates the reflexes of the community, proving that plants are fundamental agents in the construction of human social relationships.

In animist times, the presence of a head-tree, called Mingetung in Lotha, was a significant part of village architecture in those Naga villages that followed... The heads of enemies were hung on the head-tree. (Kire, 2019, p. 36). Every Ao Village has an open space which houses the head-tree. In the large village, each khel had its own head-tree. The head-tree, also called mangkotürong, was integral to the village. The heads of enemies would be hung on the head-tree for all to see. (Kire, 2019, p. 73) The Western Rengma village had a head trees, which were great trees in a prominent place under which the sacres stones were buried and where enemy heads hoisted on long bamboos were places against its branches. The head-tree was highly revered. If a branch fell from a head-tree, a no-work day was immediately announced. (Kire, 2019, p. 158)



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The central role of the head-tree suggests that the Plant Awareness Disparity prevalent in modern, "civilized" expansionism was historically absent in indigenous Naga spaces. Unlike the "green backdrop" effect described by Wandersee and Schussler (2001), the Naga's animistic worldview ensured plants were perceived as autonomous, volitional beings. By integrating the tree into the village's architectural and judicial core, the community actively resisted plant blindness, maintaining a high level of relative interest and attention. This relationship illustrates a tenacious, historical plant awareness where trees were not inferior to humans or animals, but were instead vital, communicative partners in sustaining communal life and memory.

The log drum serves as a sophisticated artifact of plant material culture, where a single tree is transformed into a device that habituates the social reflexes of the village. In some villages, the log drum occupied a very important space. In the Ao villages, the village drum was placed close to the *morung*, as it was the members' responsibility to look after it, and they would beat it to convey messages to the villagers during calamities or to call people to celebrate headhunting raids, festivals, etc. Sheds were built to protect the drums from the weather.

Today the villagers still know how to play four different rhythms: festival rhythms are played very slowly, rhythms to signal an attack are played faster, and a beat to signal fire in the village is played the fastest. When the governing body, the Putu, was changed every thirty years, a special rhythm was played. An interesting theory of the origin of the log drum says that Nagas might have migrated from Southeast Asia on boats that they later turned into drums. (Kire, 2019, p. 37)

According to Prown's (1982) cultural framework, the drum is a modification of the landscape and a communicative machine; its placement near the *morung* and the construction of protective sheds demonstrate a high degree of relative interest and plant awareness. This architectural integration ensures the tree remains a central "biocultural actor" rather than a marginalized green backdrop. The four distinct rhythms, ranging from festive to emergency signals represent a concrete social relationship between people and things, where the plant material is assigned the agency to regulate village life. This intimate knowledge of the drum's voice actively resists Plant Awareness Disparity; the villagers do not suffer from plant blindness because the drum is a volitional, communicative partner essential for survival. By fixating their history, the Nagas maintain an eco-cultural synergy that treats the tree as an enduring, living archive of human civilization.

Schwartz argues that Tradition maintains social significance; following the botanical protocols is an act of cultural preservation. This material and ritual reliance proves that plant awareness among the Nagas is integrative and dynamic. It shows that the community possesses a sophisticated, inherited knowledge of botanical properties, knowing exactly which wood to burn for a sacred fire, which bamboo shoots to cook for a wedding, and which leaves will best preserve fermented soybeans. This awareness is not just technical; it is deeply relational. By using plants as the wrapper for their gifts and the flavor of their celebrations, the Nagas acknowledge that their social survival is impossible without the forest. This creates a culture in which the physical life of the plant world is converted into the spiritual and physical strength of the human clan.

Plant and tree products have an aesthetic material significance in the Naga communities and are used in many forms and occasions. The Zelianf Nagas have decorative necklaces made of plant and tree materials, a "henaktsitei is a black necklace made locally from wild plantain seeds... Machipumatei is another necklace made from acrylics of different colours" (Kire, 2019, p. 198). The use of plant or tree material in socially and personally highlights how the Naga people bridge the gap between the botanical agents and personal identity. By transforming wild plantain seeds into jewellery, the community demonstrates that plants are not just for consumption or construction; they are the literal fabric of their aesthetic and social expression. It shows a resourcefulness that finds beauty and utility in the smallest parts of the botanical world, the seeds turning raw nature into a local craft that distinguishes one tribe or status from another. The material significance of these botanical entities reveals a profound plant awareness rooted in technical mastery and ecological intimacy. This dependence on botanical materials deepens understanding of the physical properties of plants and trees, including strength, flexibility, and longevity across various species.





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This awareness is a form of living science where the community has mapped the utility of their entire ecosystem. Whether it is felling big trees among Sangtam Nagas (Kire, 2019, p. 174) or selecting medicinal herbs like peshe by Rengma Nagas for bandages (Kire, 2019, p. 159), the Naga communities are not just passive residents of the forest, but active engineers. Their material culture is a testament to a society that has spent centuries observing plant life cycles, resulting in a sustainable lifestyle where every part of a plant from the "hardened bamboo cup" in Lotha Nagas, to Zeliang Naga's "wild plantain seed Necklace" (Kire, 2019, pp. 136, 198) recognizes unique contribution of plants and tress to human material culture.

CONCLUSION

The integration of plants into every taboo, culture, values, beliefs, and material culture, the Naga tribes show an ancient understanding of ecology where the survival of the community is inextricably linked to the respect shown to the flora surrounding them. The Naga community's relationship with the botanical world presents a powerful rebuttal to the theory of Plant Awareness Disparity. While modernization typically marginalizes plants into a green backdrop (Wandersee and Schussler, 2001), Naga material culture and spiritual values, specifically Universalism and Benevolence, elevate plants to biocultural actors. By integrating trees like the *mangkotürong* or botanical material products like the log drum into the village's architectural and judicial core, the community ensures high levels of attention and relative interest, effectively neutralizing plant blindness. Through the lens of Schwartz's Basic Human Values, the Nagas do not view plants as inferior objects but as sentient clansmen and prophetic symbols. This eco-cultural synergy creates a living science where technical mastery, such as ritual use, is driven by spiritual reverence rather than extractive utility. Consequently, the sentient landscape functions as a protective biological zone. By assigning agency to botanical materials in everything from birth rituals to legal property distribution, the Naga community demonstrates that a deep, reciprocal bond with nature is not an ancient relic but a sophisticated, persistent strategy that overcomes generational environmental amnesia and preserves biodiversity through cultural vitality.

The traditional folklore and material culture of the Naga indigenous community offer a robust rebuttal to the phenomenon of Plant Awareness Disparity (PAD). While modern urbanization often relegates flora to a green backdrop, the Naga worldview elevates plants from passive objects to biocultural actors and sentient clansmen. This study demonstrates that plant awareness is strategically encoded within the community's spiritual and social infrastructure to pre-emptively combat generational environmental amnesia (Straka et al., 2025, pp. 1165–1184). By analysing Naga belief systems through Schwartz's theory of values, it becomes evident that universalism and benevolence are not merely human-centric, but extend to the botanical realm. For example, the head-tree and the log drum function as physical anchors of judicial and social identity, ensuring that plants remain at the forefront of collective attention. Furthermore, prophetic symbols such as dreaming of falling trees or mushrooms transform botanical life into a sentient mirror of human survival, where harming a plant is perceived as harming the self. Ultimately, this botanical intelligence fosters an eco-cultural synergy where spiritual reverence creates protected biological zones, preserving biodiversity through cultural vitality rather than mere extractive utility.

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RESEARCH ARTICLE

Structuring Reality through Language: Discourse Strategies in Media Communication

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ABSTRACT

Media discourse plays a crucial role in shaping public perception by constructing and organizing social reality through language. This paper examines how media institutions employ specific linguistic and rhetorical strategies to frame events, influence interpretation, and guide audience understanding. Drawing upon theoretical perspectives from Critical Discourse Analysis, framing theory, and media linguistics, the study explores how language choices in news reporting, headlines, and narrative structures contribute to the formation of ideological meanings. The paper investigates the ways in which discourse strategies such as lexical selection, metaphor, presupposition, intertextuality, and narrative framing function within media texts. These strategies are not neutral; rather, they reflect institutional priorities and sociopolitical contexts that shape the representation of events and actors. By analyzing selected media samples from contemporary news platforms, the study demonstrates how linguistic framing can foreground certain viewpoints while marginalizing others, thereby influencing public opinion and reinforcing dominant ideologies. Ultimately, this study emphasizes the importance of critical engagement with media language. By uncovering the discursive mechanisms that structure reality in media communication, the paper contributes to a deeper understanding of the relationship between language, power, and representation. The findings underscore the need for media literacy and critical awareness among audiences to recognize how discourse practices shape perceptions of social and political realities.

Keywords: Media Discourse, Critical Discourse Analysis, Media Representation, Discourse Strategies.





INTRODUCTION

Language is a powerful tool that does more than merely convey information; it actively constructs reality. In contemporary society, media institutions serve as primary sources of information, making media discourse a significant site for the production and circulation of meaning. News reports, editorials, headlines, and digital media content shape how audiences perceive events, individuals, and social issues. Media discourse is not neutral or objective; it is shaped by institutional ideologies, editorial policies, and socio-political contexts. The selective use of language influences how reality is framed and interpreted. As Fairclough (1995) argues, discourse is both socially constitutive and socially conditioned, meaning that it both shapes and is shaped by social structures. This paper explores how discourse strategies in media communication structure reality. By analyzing linguistic choices and rhetorical techniques, it seeks to reveal the underlying ideologies embedded in media texts. The study is grounded in Critical Discourse Analysis (CDA), framing theory, and media linguistics, offering a comprehensive understanding of how language functions in media contexts.

Background of the Study

The study of media discourse has gained prominence with the rise of mass communication and digital media. Scholars have increasingly recognized that media language plays a crucial role in shaping public opinion and social knowledge. The concept of “constructed reality” suggests that what people perceive as reality is often mediated through language and representation (Berger & Luckmann, 1966). Critical Discourse Analysis provides a framework for examining how power and ideology are embedded in language. Fairclough (1995) emphasizes that discourse is a form of social practice that reflects and reinforces power relations. Similarly, van Dijk (1998) highlights the role of discourse in reproducing dominance and inequality.

Framing theory, developed by Entman (1993), further explains how media selects certain aspects of reality and makes them more salient in communication. Frames influence how audiences interpret events by emphasizing specific elements while downplaying others. Media linguistics focuses on the stylistic and structural aspects of media language, including headlines, narrative patterns, and lexical choices (Bell, 1991). Together, these theoretical perspectives provide a foundation for analyzing discourse strategies in media communication.

Statement of the Problem

Despite the widespread belief that media provides objective and factual information, research suggests that media discourse is inherently selective and ideological. Language choices in media texts often reflect institutional biases and sociopolitical agendas, which can shape public perception in subtle but powerful ways. The problem lies in the lack of critical awareness among audiences regarding these discourse strategies. Many readers and viewers consume media content without recognizing how language influences their understanding of reality. This can lead to the reinforcement of stereotypes, misinformation, and dominant ideologies.

Therefore, this study seeks to examine how discourse strategies in media communication structure reality and influence audience perception.

Research Questions

- How do media institutions use linguistic and rhetorical strategies to frame events?
- What role do discourse strategies play in shaping ideological meanings in media texts?
- How do lexical choices, metaphors, and narrative structures influence audience interpretation?
- In what ways does media discourse reinforce or challenge dominant ideologies?

Objectives of the Study

- To analyze the role of language in constructing reality in media discourse
- To identify key discourse strategies used in media communication
- To examine the relationship between language, ideology, and power





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- To promote critical awareness of media language among audiences

REVIEW OF LITERATURE

Media discourse has been extensively studied across disciplines such as linguistics, communication studies, and sociology. Fairclough (1995) argues that media discourse is a site where language and power intersect, shaping social identities and relationships. His work emphasizes the importance of analyzing discourse as a form of social practice. Van Dijk (1998) focuses on the cognitive and social dimensions of discourse, highlighting how media representations influence mental models and public opinion. He argues that discourse plays a key role in reproducing social inequalities. Entman (1993) introduces framing theory, which explains how media selects and emphasizes certain aspects of reality. Frames guide audience interpretation by defining problems, diagnosing causes, making moral judgments, and suggesting remedies. Bell (1991) examines the language of news media, focusing on how journalists construct narratives through linguistic choices. He highlights the importance of headlines, tone, and structure in shaping audience perception. Fowler (1991) explores the ideological nature of news language, demonstrating how linguistic features such as transitivity and modality reflect underlying power structures.

Together, these studies provide a comprehensive understanding of how media discourse functions and its impact on society.

Research Gap

While previous studies have explored media discourse and framing, there is a need for integrated analysis that combines multiple discourse strategies within a single framework. Many studies focus on individual aspects such as framing or lexical choice, but fewer examine how these strategies interact to construct reality. Additionally, there is limited research focusing on contemporary digital media platforms, where discourse strategies are rapidly evolving. This study addresses these gaps by providing a holistic analysis of discourse strategies in modern media contexts.

Hypothesis

Media discourse employs specific linguistic strategies to construct and frame reality.

These discourse strategies reflect and reinforce dominant ideologies.

Audience perception is significantly influenced by the framing and representation of events in media language.

Theoretical Framework

This study is grounded in an interdisciplinary theoretical framework that integrates Critical Discourse Analysis (CDA), Framing Theory, and Media Linguistics. These theoretical perspectives collectively provide a comprehensive lens to examine how media discourse constructs social reality through language, while embedding power relations and ideological meanings within communicative practices.

Critical Discourse Analysis (CDA)

Critical Discourse Analysis (CDA) serves as the primary theoretical foundation of this study. CDA conceptualizes language as a form of social practice that both reflects and shapes power relations in society (Fairclough, 1995). It emphasizes that discourse is inherently ideological and cannot be separated from its social and political context (van Dijk, 1998).

Fairclough's (1995) three-dimensional model of discourse is particularly relevant to this study:

Text (micro level): Analysis of linguistic features such as vocabulary, syntax, and rhetorical devices

Discursive practice (meso level): Processes of text production, distribution, and consumption

Social practice (macro level): Broader socio-cultural and institutional structures shaping discourse

CDA enables the identification of how media texts reproduce dominance, legitimize institutional authority, and marginalize alternative voices (Wodak & Meyer, 2009). It is especially useful in analyzing discourse strategies such as lexical selection, presupposition, and intertextuality, which often carry implicit ideological meanings.



**Framing Theory**

Framing Theory, developed by Entman (1993), provides a complementary perspective by explaining how media selectively represent reality. According to Entman (1993), framing involves selecting certain aspects of perceived reality and making them more salient in communication, thereby shaping audience interpretation.

Frames perform four key functions:

- Define problems
- Diagnose causes
- Make moral judgments
- Suggest remedies (Entman, 1993)

Media framing operates through linguistic and structural elements such as headlines, visual imagery, and narrative emphasis (Scheufele, 1999). For instance, describing an issue as a “crisis” versus a “challenge” can significantly alter audience perception. Framing Theory is crucial for this study as it highlights how discourse strategies guide interpretation and influence public opinion. It complements CDA by focusing on the cognitive and interpretive effects of discourse on audiences.

Media Linguistics

Media Linguistics focuses on the stylistic and structural features of language used in media communication. Bell (1991) argues that news language is carefully constructed to meet both informational and ideological purposes. Media texts are shaped by institutional norms, audience expectations, and communicative goals.

Key linguistic features examined in media discourse include:

Lexical choices: Words with ideological connotations (Fowler, 1991)

Headline structures: Designed to attract attention and frame interpretation (Bell, 1991)

Narrative patterns: Organization of information to guide audience understanding

Metaphorical language: Simplifies complex issues and evokes emotional responses (Lakoff & Johnson, 1980)

Media linguistics provides the analytical tools to examine how language operates at the textual level, complementing the broader socio-political insights of CDA and framing theory.

Conceptual Integration of Theories

The integration of CDA, framing theory, and media linguistics allows for a multi-dimensional analysis of media discourse:

CDA explains how discourse is linked to power, ideology, and social structures (Fairclough, 1995; van Dijk, 1998)

Framing Theory reveals how meaning is structured and how audiences interpret media messages (Entman, 1993; Scheufele, 1999). Media Linguistics analyzes the specific linguistic mechanisms that shape discourse (Bell, 1991; Fowler, 1991). Together, these frameworks enable a comprehensive understanding of how discourse strategies—such as metaphor, presupposition, intertextuality, and narrative framing—function to construct social reality in media communication.

METHODOLOGY

This study adopts a qualitative research approach based on Critical Discourse Analysis (CDA). Selected media texts from newspapers and digital news platforms are analyzed to identify discourse strategies.

Data Collection

News articles and headlines from major media outlets, Editorials and opinion pieces, Online news reports, Analytical Framework

The analysis focuses on the following discourse strategies:

Lexical selection, Metaphor, Presupposition, Intertextuality, Narrative framing, Procedure



**Case Study: Media Framing of Farmers' Protests in India****Introduction to the Case**

The coverage of the Indian Farmers' Protests (2020–2021) provides a compelling example of how media discourse constructs reality through language. The protests, which emerged in response to three agricultural reform laws, received extensive attention from national and international media. However, different media outlets framed the same events in contrasting ways, revealing the role of discourse strategies in shaping public perception.

Data Selection

This case study examines headlines and excerpts from:

National English-language newspapers

Television news reports

Digital media platforms

The analysis focuses on identifying discourse strategies such as lexical selection, metaphor, presupposition, and framing.

Analysis of Discourse Strategies**Lexical Selection**

Media outlets used different lexical choices to describe the protesters. For example:

Some reports referred to them as “farmers” or “protesting citizens”, emphasizing legitimacy

Others labeled them as “agitators” or “disruptors”, implying disorder

Such lexical variation reflects ideological positioning and influences audience perception (Fowler, 1991). According to van Dijk (1998), lexical choices are key tools in constructing in-group and out-group distinctions.

Framing of the Event

The protests were framed differently across media platforms:

Economic frame: Focus on agricultural reforms and market efficiency

Law-and-order frame: Emphasis on protests as disruptions to public order

Human rights frame: Highlighting police action and protesters' rights

Framing determines how audiences interpret events by making certain aspects more salient (Entman, 1993). For instance, describing the protest as a “crisis” versus a “movement” leads to different evaluative responses.

Use of Metaphors

Metaphorical language was frequently used in reporting:

“Battle between farmers and government”

“Siege of the capital”

“Waves of protest”

These metaphors frame the protests in terms of conflict, urgency, and scale, shaping emotional engagement (Lakoff & Johnson, 1980). Metaphors simplify complex realities but also introduce ideological bias.

Presupposition

Many media texts contained implicit assumptions:

“The protests continue to disrupt normal life” presupposes that protests are inherently disruptive

“The government's reforms aim to modernize agriculture” presupposes positive intent

Presuppositions present particular viewpoints as given or unquestioned, thereby influencing interpretation (Fairclough, 1995).

Intertextuality

Media coverage frequently referenced:

Past protest movements

Political speeches





International reactions

These intertextual references shape meaning by linking current events to broader narratives (Wodak & Meyer, 2009). For example, comparing the protests to earlier social movements adds legitimacy or controversy depending on context.

Ideological Implications

The analysis reveals that media discourse is not neutral but ideologically driven. Different representations of the same event reflect institutional biases and political alignments. Media outlets supportive of government policies tended to emphasize economic benefits and law-and-order concerns, while critical outlets highlighted issues of democracy and rights.

This aligns with CDA's assertion that discourse reproduces power relations and dominant ideologies (Fairclough, 1995; van Dijk, 1998).

Impact on Public Perception

The variation in discourse strategies influenced how audiences perceived the protests:

Positive framing increased sympathy toward farmers

Negative framing generated concerns about disruption and instability

Framing effects play a crucial role in shaping public opinion and policy debates (Scheufele, 1999).

DISCUSSION

This case study demonstrates how discourse strategies function together to construct multiple versions of reality. Lexical choices, metaphors, and frames interact to produce meanings that align with specific ideological positions. The findings highlight the importance of critically analyzing media language. Without such awareness, audiences may unknowingly adopt biased interpretations presented as objective facts.

CONCLUSION

The media coverage of the Farmers' Protests illustrates the powerful role of discourse in structuring social reality. By employing various linguistic and rhetorical strategies, media institutions influence how events are understood and evaluated. This case reinforces the need for media literacy and critical engagement with news discourse to recognize the underlying ideologies shaping public narratives. Texts are examined to identify patterns in language use and their ideological implications. The analysis considers both linguistic features and socio-political contexts.

FINDINGS AND DISCUSSION

The analysis reveals that media discourse employs a range of strategies to structure reality.

Lexical Selection

Word choice plays a crucial role in shaping perception. For example, terms like "freedom fighters" versus "terrorists" reflect ideological positioning. Such lexical choices influence how audiences interpret events and actors.

Metaphor

Metaphors are frequently used to simplify complex issues. For instance, describing the economy as "recovering" or "collapsing" frames it in terms of health, influencing emotional responses (Lakoff & Johnson, 1980).

Presupposition

Media texts often contain implicit assumptions that are presented as facts. These presuppositions shape audience understanding without explicit argumentation.

Intertextuality

Media discourse frequently references other texts, events, or narratives. This creates connections that reinforce certain interpretations while excluding others.



**Chamundeswari et al.,****Narrative Framing**

Narrative structures organize information in ways that highlight specific aspects of events. For example, focusing on conflict rather than cooperation can create a sense of tension and urgency.

Case Study 2: Media Coverage in India

In the Indian context, media coverage of political events often reflects ideological divisions. Different news outlets present the same event in contrasting ways, emphasizing different aspects and using varied linguistic strategies.

For example:

Some reports highlight government achievements using positive language

Others focus on criticism and dissent using negative framing

This demonstrates how media discourse constructs multiple realities based on linguistic choices.

Implications

The findings highlight the importance of media literacy in contemporary society. Audiences need to critically evaluate media content to recognize underlying biases and ideologies.

Educational institutions should incorporate media literacy programs to develop critical thinking skills. Policymakers and media organizations should also promote transparency and ethical journalism.

CONCLUSION

This study demonstrates that media discourse plays a significant role in structuring reality through language. Discourse strategies such as lexical selection, metaphor, presupposition, intertextuality, and narrative framing are not neutral; they reflect institutional ideologies and sociopolitical contexts. By analyzing these strategies, the study reveals how media language shapes public perception and reinforces power structures. The findings underscore the need for critical engagement with media discourse to understand the relationship between language, power, and representation. Ultimately, fostering media literacy and critical awareness is essential for navigating the complex landscape of modern communication.

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RESEARCH ARTICLE

Transforming Engineering Communication Skills: A Quantitative Study of Role Play, Self-Assessment, and Learner Autonomy

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ABSTRACT

This study attempts to explore the integration of roleplay and self-assessment as pedagogical strategies to enhance communication skills among the second-year students of engineering in a Tier 1 institution in the western part of Tamilnadu, India. The study also aims to foster learner autonomy aided through self-assessments by implementing a 30-hour course titled Mastering Conversations which focused majorly on roleplay scenarios. The students engaged in thematic roleplays by adapting various academic, social and professional settings. All roleplays were assessed by the teacher and were followed by a structured self-assessment and peer feedback. Both quantitative and qualitative data were collected and analysed to measure performance and developments in terms of clarity, content, body language, voice modulation and non-verbal communications including exhibiting confidence and expressions. A significant progress in verbal delivery and improvements in non-verbal expressions and body language was found among the learners after repeated performances. It is also found that learners take responsibility of assessing their performance through reflective goals settings and strategic use of feedback after every role play. It is also evident from the study that learner autonomy developed as the learners actively applied the feedback they received from peers and self. Learners practiced along with self-directed preparation and overcame stage fear over time. The study finally states that combining role play with reflective self-assessment and peer assessment provides a transformative learning experience which shift communication pedagogy from teacher-centered instruction to learner-driven development. These insights underscore the value of active and reflective learning approaches in engineering education to better prepare students for professional scenarios.

Keywords: Communication skills, engineering education, learner autonomy, role play, self-assessment.

INTRODUCTION

Communication in engineering is many-sided which includes verbal, written, interpersonal, and digital competencies. These skills have been found to be crucial for collaborating within teams, presenting complex technical

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knowledge clearly, engaging with clients and stakeholders, and steering multidisciplinary and diverse environments. Accordingly, today's highly dynamic field of engineering which keeps evolving at a higher rate clearly tells us that technical competence alone will no longer be sufficient for professional success. Effective communication directly influences the academic achievements, professional growth, and contributions of the learners to the engineering community. In the present scenario, engineering projects have become all the more complex and globalized, where the capability to communicate efficiently across diverse platforms becomes the key determining element of success. Therefore, engineers are expected to interact flawlessly not only with colleagues and superiors but also with clients, suppliers, investors, and even government officials. Consequently, poor communication, whether in handling technical details or addressing complaints, can have significant consequences in today's interconnected digital world, where a single insensitive remark can escalate quickly through platforms such as social media.

Furthermore, English language has taken a dominant role in today's globalized world. Globalization without any doubt has made English as the medium of professional and academic exchange in many parts of the world. A lack of proficiency in English communication may prove aversive to the learner community, where opportunities for individual advancement and professional mobility is hindered. As a result, teaching communication skills to engineers requires careful reflection of the content provided, pedagogy used, and techniques tailored to suit respective programmes. Such interdisciplinary courses aim to equip engineering students with relevant communicative and professional competencies, using English as both a tool and a facilitator for their future careers. All stakeholders including employers, accreditation bodies like NAAC & NBA also consistently emphasize that oral and written communication skills are crucial for employability, leadership, and career progression. Despite these prevalent benefits and recognition, many engineering students continue to face challenges in expressing their ideas effectively, which undermines their ability to work collaboratively, and bleak out their chance of adapting to the demands of professional environments. Now to address this issue, various pedagogical approaches are adopted that emphasize engaging students in numerous activities apart from the conventional learning methodologies which mirror real-world scenarios. Roleplay is one such active learning method that has gained momentum in the past decade. Roleplay is recognized as an effective active learning method that provides opportunities for students to actively participate and eventually bridges the gap between classroom engagement and workplace demand.

Roleplay As An Active Learning Method

Roleplay is a powerful learning strategy that moves out from conventional teacher centered pedagogy by providing chances to students to actively engage and apply their communication skills by interacting and collaborating in real-world scenarios. Roleplay is no doubt an interactive tool where students assume the role of engineers, team leaders, stakeholders, clients and many more that they may have to face in their academic and professional career. As Kolb (1984) mentioned, learning is a cyclical process involving concrete experience, reflective observation, abstract conceptualization, and active experimentation and roleplay is one such strategy that aligns with this concept as it offers a realistic environment to the learner to apply the theoretical communicative tactics that he had learnt over the years. Roleplays help in developing several 21st century skills like communication skills, empathy, flexibility, problem-solving, and confidence building in professional setting. It without any doubt also focuses on verbal and nonverbal communication capabilities. Moreover, role play promotes critical self-awareness, peer collaboration, and active participation, all of which are critical for developing learner autonomy. It has become an essential tool for communication training, especially in engineering education because it converts the abstract learning objectives into concrete, skill-based competencies by involving students in real-world communication tasks.

Self-Assessment As A Reflective Practice:

Assessments are an integral part of education where the teacher collects and analyses the knowledge level, learnings and skills of the students to evaluate and provide outcomes on students' advancement. These assessments come in the form of tests, projects, assignments, individual and group presentation and are named as Formative and Summative assessments. Since roleplay is learner based active learning process, apart from teachers' performance-



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based assessments, Self-assessments play a crucial role in identifying the strengths and weaknesses of the individual learner through self-reflection. Self-evaluation employs certain tools like checklist, open-ended responses, self-evaluation and Peer evaluation which enables individuals' capacity to set goals and monitor their own progress, resulting in empowering learners to take ownership of their progress.

This process of self-evaluation strengthens learners' autonomy as it shifts the responsibility of learning and growth from the teacher to the learner. Holec, who is considered the father of learner autonomy, defines it as the capacity to take responsibility for one's learning in terms of setting goals, choosing learning methods and evaluating outcomes. In short, learner autonomy refers to the ability of an individual to take control and responsibility of their own learning, especially by identifying strategies and self-assessment. The learners who have been in the passive role of receiving information now become active and take charge of their learning outcomes. This learner autonomy plays a significant role in skills-based education, particularly in communication skills training. It enables the learner to be more self-directed, reflective and confident in applying strategies to improve their performance and adapt to diverse communication settings. A wide range of research has underscored the significance of learner autonomy, stressing that it is not an inborn quality but a competence that can be nurtured and strengthened through well-designed pedagogical approaches.

Transformative Learning In Engineering Education:

With the practice of active learning methodologies like roleplay and implementation of self-evaluation leads to learner autonomy transforming the way the learner interprets and engages with the learning process. This transformation has shifted the focus from conventional teaching method of rote memorization and theoretical aspect of the learner towards approaches that encourage foster critical analysis and practical application of concepts in real-world environment

Roleplay and self-assessment are popularly recognized pedagogical tools; nevertheless, it has been observed that the focus of engineering education is mostly on the theoretical or qualitative aspects of the concepts rather than the quantitative insights. Not many studies on the impact of how roleplay and self-assessment foster learner autonomy in terms of data-driven research are available that demonstrates measurable outcomes.

Research Objectives:

This study aims to evaluate how role-plays and self-evaluation promote learner autonomy and improve communication abilities in engineering education. In order to provide quantifiable insights into how effective these strategies are, the study examines student reflections and by doing so, it demonstrates how traditional communication pedagogy can be transformed by active and reflective learning approaches.

- To examine if roleplay enhances communication skills such as fluency, confidence, and teamwork.
- To explore how self-assessment promotes learner autonomy by enabling students to identify strengths, weaknesses, and goals.
- To investigate whether roleplay and self-assessment can facilitate a transformative shift from teacher-centered to learner-centered communication pedagogy.
- To analyze assessable patterns emerging from student reflections on role play and self-assessment.

LITERATURE REVIEW

The students face challenges in applying engineering education in real-world situations. To bridge this academic-industry gap in software engineering education, Bittal and Alfatmi (2025) introduced the Roleplay Peer Review Learning approach. This approach assigns students different roles from software development to encouraging active participation, critical thinking, hone their communication skills and make them industry ready by carefully fostering actual workplace dynamics.



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Li et al. (2024) in their research work titled “Fostering Autonomous Learning in Oral English Through Role Play: An Exploration in Course Setting” explore how roleplay fostered autonomous learning among the primary school students of China. Li et al. conducted this research as a three-month long action study where they introduced Roleplay Oral English Course (RPOEC) designed for primary school students of China. This study was structured on 4 themes which are set around learning interactive communication, cooperative learning, and evaluative discussions. The research findings showed that roleplays in schools enhanced engagement, reflection, self-assessment and self-learning. The research work concluded that experiential active learning approaches like RPOEC can for sure impressively foster oral proficiency by promoting learner autonomy in interactive and team building settings.

Tatiana, B., & Valentina, S. (2018) conducted a research study with 38 second-year students at a Russian University. They in their study investigated how roleplay can foster learner autonomy in an English for Specific Purpose course (ESP). This study compared the scores of the study group who were involved in roleplays with that of a control group students using IELTS speaking scores and questionnaire that focused on learner autonomy. The study concluded that the students involved in roleplay had significantly improved in IELTS speaking, which was through self-reflection, hence proving that roleplays are efficient strategies for developing autonomous language learning.

Thanh, N. T. (2019) in their research study titled “Promoting Learner Autonomy through Self-Assessment and Reflection” had conducted a framework of self-assessment and reflection. A 15-session programme for the second-year non-English major students was conducted which enabled the learners to perform practical listening and speaking tasks outside the classroom encouraging them to assess themselves and reflect on their performance. The study showed that the use of self-assessment and reflections conducted after each roleplay activity effectively supported students in becoming more self-directed language learners.

Benson (2006), in his research titled “Autonomy in Language Teaching and Learning”, categories autonomy into five models: resource-based, technology-based, curriculum-based, classroom-based, and teacher-based, with a focus on learners’ beliefs, motivation, and identity. He states that learner autonomy is central to language learning but requires a strategic approach where learners learn to balance individual control with institutional demands.

METHODOLOGY

Roleplay was introduced as an exclusive course under the name “Mastering Conversations” to the second-year students of engineering programmes in a Tier 1 institute in the western part of Tamilnadu, India. This course was designed to provide a platform for students to practice real-world conversations on various topics and themes that would suit both academic and professional scenarios. The course on roleplay was designed to be conducted for 30 hours of practical sessions across the semester in regular timetable. The purpose of the course was to foster communication skills to the engineering students through roleplay methodology, where the learners engage in real-time interactions based on the scenarios provided.

The course Mastering Conversations has 5 modules which are organized thematically. The first module serves as an introduction to roleplay, where it focuses on gesture tone modulation and provides strategies for building conversations which includes framing questions and reflect on the answers. The second module “Social Skills” focuses on conversations in social settings which include ordering food, making reservations, shopping and participating in community related activities. The 3rd module titled “Education and Technology” emphasises on personal growth, offline and online interactions addressing academic tasks such as participating in workshops, presenting research or simply explaining a scientific concept. The 4th module “Strategic Insights” aims to train the learners in critical thinking problem solving enhancing negotiation skills and entrepreneurship scenarios. The last module named “Cultural Exchange” fosters to explore traditions, cultural events, media, entertainment and art of different states and countries. The learners are also encouraged to create advertisements and plan events that suit the scenario.



**Mythili et al.,****Procedure:**

A total of 5 roleplays were conducted over the given 30 hours. The learners were put in 2- & 3-member team according to the requirement of the scenario they participated. The team formation was done by both the learner for 2 modules and for the rest of the 3 modules the teacher created the teams. For the modules 2 & 3 the learners were put in teams a week ahead and the scenarios were shared which allowed the students to prepare for the presentation. The time was given keeping in mind the learners' need to research, rehearse, and collaboratively plan their roles so that the presentations would reflect both fluency and confidence in real-life communicative contexts. For the modules four and five a days' time was given for research and practice. All the four modules were considered for Formative assessment and the last roleplay, a collective scenario of all the four modules, was considered for Summative assessment. No separate end semester practical exam was conducted. After each role play activity, the learners were asked to complete self-assessment feedback using a structured MS Form. The self-assessment consisted of two parts: a quantitative section, where Likert scale and agree-disagree items were used, and a qualitative section, where students responded to open-ended questions by reflecting on their performance in the role play. The data collected through MS Forms was exported into an excel spreadsheet for further analysis. The Likert scale responses were represented using charts and graphs while the qualitative open-ended questions were thematically organised by identifying common pattern expressed by the learners.

RESULTS AND DISCUSSION

To study and analyse the development of learners' performance across roleplays, the 1st and the 5th roleplay reflections were considered for the question "I used appropriate body language, tone, and expressions" because it directly aligns with the awareness of verbal and non-verbal communications which form the basis of any effective conversations. The comparison clearly provides proof of improvement over repeated practice and reflection from 1st to 5th assessment, where the number of students who disagree with the point have significantly reduced. The learners' response on 'one thing they did well during their roleplay' was recorded after 4 roleplays and 78 students responded. Six common parameters were identified. It is to be noted that most students mentioned fluency and clarity (20) in their performance and confidence/no stage fear (18), showing growth in speaking skills. Others focused on body language (15), teamwork (10), improvisation (8), and content preparation (7). These themes suggest that role play helped students improve both communication and performance skills.

Analysis of students' self-reflections on confidence revealed four patterns: high confidence (e.g., 'Yes, I felt confident because I had practiced well'), partial confidence where students balanced confidence with stage fear ('Partially yes and partially no'), low confidence due to nervousness or lack of preparation ('No, I didn't feel confident while performing as I have stage fear'), and evidence of confidence growth ('Not in the first but now I am okay with confidence'). The majority of responses fell under high and partial confidence, indicating that while many students felt prepared, stage fear and anxiety continued to influence performance for a notable proportion of learners.

Student reflections on communication skills applied during the role play were coded into eight thematic categories: fluency and flow, confidence and public speaking, voice modulation and expression, pronunciation and vocabulary, active listening and response, body language, improvisation, and general communication skills. The most frequently cited areas of improvement were fluency and flow (20) and voice modulation and expression (18), followed by confidence and public speaking (15). Fewer students reported progress in improvisation (7) and body language (8). These findings suggest that the activity primarily strengthened verbal delivery aspects, while non-verbal and spontaneous communication skills received comparatively less emphasis.

Peer feedback received after role play activities clustered around five major themes: voice and audibility, confidence and stage presence, body language and eye contact, clarity and fluency, and positive reinforcement. The most common suggestions were related to audibility (20) and confidence (15), indicating that peers recognized the



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importance of projection and stage presence. Several students were also reminded to maintain eye contact and manage body language (12). Positive feedback was also evident, with peers appreciating natural speech, improved pronunciation, and noticeable progress since earlier sessions. A portion of students (18) reported not receiving feedback. These findings highlight that peer feedback emphasized both strengths and areas for improvement, complementing self-assessment data.

CONCLUSION

The findings of the study revealed that most of the students agreed or strongly agreed that roleplay activities significantly improved their communication skills including body language, tone and expression. Learners found it initially difficult to perform on stage with various factors to be included in their roleplay like content, expressions, body language etc they in course of time showed tremendous improvement. This improvement that the learners were able to achieve was not only because of the feedback from the teacher but with self-assessment and reflection on their performance including peer reviews. Though learners have noticeably improved in several areas, they consistently report improvement in fluency, clarity of expression, reduced stage fear and improved confidence across repeated performances. Non-verbal cues such as body language, tone and expression also show considerable improvement when compared to the data between the first and the fifth roleplays. Self-assessment and reflection after roleplay have tremendously decreased the negative responses and a steady increase in the number of students progress can be witnessed. In the analysis of self-assessment, it is revealed that fluency and flow are two aspects of communication that has seen significant improvement and the same is followed by tone, voice modulation, and expression. Improvement in choice of vocabulary, pronunciation and active listening is also mentioned but not as frequently as the others. From this it is evident that the learner places more emphasis on the verbal and expressive aspects of communication. Evidence of learner autonomy was clearly demonstrated through the goals students set for subsequent role plays. Students' responses on how they planned to use feedback in subsequent role plays revealed seven themes. The most frequently cited strategies were practice and preparation (20), voice and audibility (18), and constructive use of peer/teacher suggestions (16). Many also planned to improve body language and eye contact (15) and increase confidence and stage presence (14). Fewer students mentioned communication development in broader terms (12), while a small group admitted to not planning specific improvements (10). These findings indicate that students viewed feedback primarily as a tool for refining delivery aspects such as rehearsal, voice projection, and stage presence, showing a practical orientation toward continuous improvement. Overall, the results confirm that role play combined with self-assessment not only strengthens communication skills but also fosters learner autonomy by promoting self-reflection, strategic goal setting, and responsibility for one's learning path.

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Table 1 One thing I did well during the roleplay

Theme	Example Student Responses	Frequency (n)
Confidence / No stage fear	"I did my role with confidence"; "No stage fear"	18
Body language & gestures	"I expressed my body language"; "Maintaining posture"	15
Fluency & clarity	"Spoke clearly"; "No stammering"; "Flow of speech"	20
Collaboration / teamwork	"Collaborated with peers"; "Coordinate with my teammates"	10
Improvisation / adaptability	"Managed even when script was forgotten"	8
Content preparation	"Remembering sentences"; "Prepared script delivery"	7

Table 2. Did I feel confident while performing? Why or why not?

Category	Example Responses	Frequency (n)
High Confidence	"Yes, I felt confident throughout the role play."	28
Partial Confidence	"Confident but a bit nervous." / "Partially yes and partially no"	22
Low Confidence	"No, I didn't feel confident because of stage fear."	14
Confidence Growth	"Not in the first but now I am ok with confidence."	10

Table 3. What communication skills did I apply or improve during this activity?

Category	Example Responses	Frequency (n)
Fluency & Flow	"Fluency in speaking," "Flow of my language"	20
Confidence & Public Speaking	"Spoke boldly," "Reduced stage fear"	15
Voice Modulation, Tone & Expression	"Voice modulation," "Tone of my dialogue"	18
Pronunciation & Vocabulary	"Professional vocabulary," "Pronunciation"	10
Active Listening & Response	"Active listening," "Respond to others"	12
Body Language & Non-Verbal Skills	"Gestures," "Posture," "Body language"	8
Improvisation & Spontaneity	"Spontaneous speaking," "On-spot improvisation"	7
General Communication Skills	"Professional communication," "Conversation building"	12





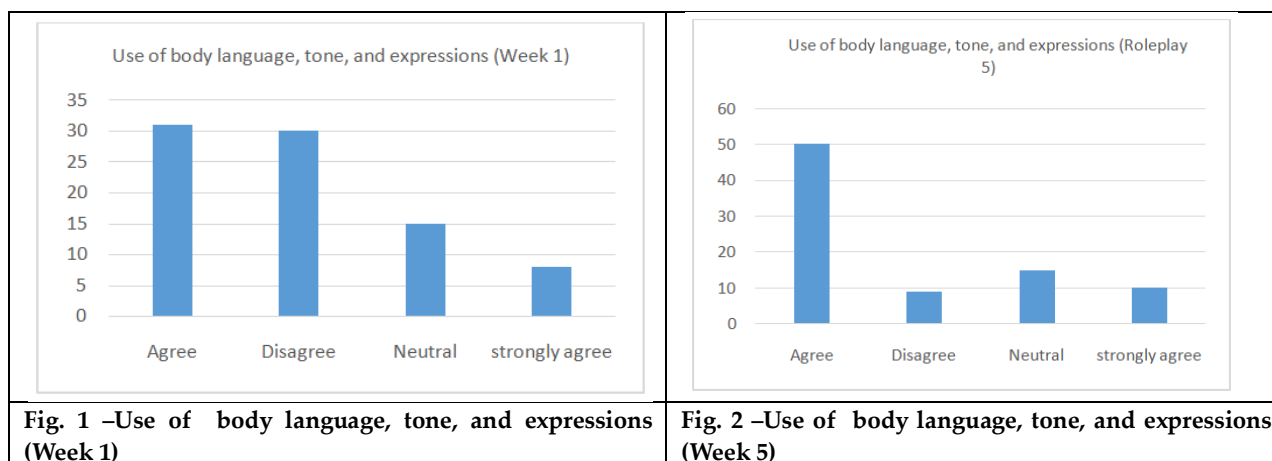
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Table 4 Did any of your peers give you feedback after the role play? Summarise one useful comment or suggestion you received

Theme	Example Responses	Frequency (n)
Voice & Audibility	"Speak louder," "Voice was low"	20
Confidence & Stage Presence	"Be confident," "Don't panic"	15
Body Language & Eye Contact	"Improve body language," "Maintain eye contact"	12
Clarity & Fluency	"Speak more clearly," "Avoid stammering"	10
Positive Feedback / Appreciation	"Good pronunciation," "Well done"	14
No Feedback / Not Applicable	"No feedback received"	18

Table 5 How do you plan to use this feedback in your next performance?

Theme	Example Responses	Frequency (n)
Voice, Tone & Audibility	"Talk loudly," "Project voice," "Improve clarity"	18
Body Language & Eye Contact	"Maintain eye contact," "Improve gestures"	15
Confidence & Stage Presence	"Lose stage fear," "Perform confidently"	14
Practice & Preparation	"Practice lines," "Rehearse," "Take notes"	20
Communication Skills Development	"Improve fluency," "Better expression"	12
Constructive Use of Feedback	"Use feedback as guide," "Apply suggestions"	16
No Action / Unclear	"No," "Didn't plan," "I don't know"	10



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RESEARCH ARTICLE

Differentiated English Language Curriculum: An Outcome-Based Approach for First-Year Engineering Learners

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ABSTRACT

English language proficiency and employability skills are critical determinants of career success. While India holds distinct advantages in English language learning and related employability competencies, several persistent challenges hinder optimal outcomes. This study proposes a differentiated curriculum framework for first-year engineering students, grounded in the principles of Outcome-Based Education (OBE), to address these challenges effectively. Students were classified into three proficiency-based groups—beginner, intermediate, and advanced—based on initial language competency assessments. Each group followed a tailored curriculum and distinct assessment strategy. Beginner-level learners received foundational language instruction complemented by a creative podcast production task; intermediate learners engaged in industry-relevant assignments and case-based analyses; and advanced learners undertook independent, project-based language learning (PBLL). The findings indicate measurable improvements across all levels, with advanced learners demonstrating capabilities beyond conventional classroom expectations, intermediate learners showing notable progress, and beginner-level learners requiring additional targeted support. All groups achieved the intended learning outcomes in alignment with OBE principles.

Keywords: Language learning, Beginner, Intermediate, Advanced, PBLL, OBE.





INTRODUCTION

Engineering graduates are anticipated to demonstrate excellent communication skills, professional behaviour, critical thinking skills, leadership ability in addition to the technical competency. The first-year engineering students have different levels of proficiency which is a challenge to work on the language skills and the employability skills by a teacher. Heterogeneous groups often result in a confusing state because of the understanding capacity of the different levels of students in the same cohort. In order to overcome this challenge, the grouping is necessary to be modified in to homogeneous. If this grouping is done at the graduate level education, the expected outcome in terms of knowledge, skills, and attitude / behaviour which is in alignment with OBE will be obtained.

This research paper aims at presenting a language learning framework for the homogeneous group of learners in alignment with the Outcome Based Education framework. The diagnostic test at the beginning of the course helped in categorising the levels of students, the course content helped the learners to achieve the desirable results, the assessment methods validated the learning outcomes, and, overall, the expected results were in alignment with the OBE.

The OBE principles adopted for this research are from the three verticals of OBE:

1. Knowledge – Theoretical understanding of English language usage in professional contexts.
2. Skill – The capacity to apply language skills for various professional purpose like academic, industrial, and societal.
3. Attitude/Behavior – The ability to be confident, collaborative in nature , and being professional behavior.

LITERATURE REVIEW

Rong Luo (2025) in his research article examines how Outcome-Based Education (OBE) help create an innovative English Classroom Instruction. After analyzing the limitations, Luo offers a groundbreaking model that gives space for revision of curriculum, preparation of learning objectives, plan for interactive teaching techniques, and wide-ranging evaluation strategies. Similarly, P. Qian's (2023) in his research article discuss on how English Education can shift focusing the teaching from exam point of view to application point of view. The paper highlights that the English Classroom has outdated teaching methods and emphasis too much on tests. At this point, the author brings OBE as a reformative and transformative approach that provides long term change in English Language Teaching in higher educational institutions.

Huaqian Fu's (2023) in his research article offers a unique and strategic study on how vocabulary teaching can be strengthened with the application of OBE principles. Fu integrates vocabulary teaching with multimodal approaches and outcome-based methods and highlights on how OBE complements vocabulary teaching in a dynamic way. Similarly Chuan-hui Zhou's (2019) in his article speaks on the design of English teaching strategies with the TOPCARES-CDIO model and OBE model. He integrates project-based learning and outcome-based assessment to argue that this combination can bring a connection between academic learning and professional application, thus achieving both linguistic and employability outcomes.

LiLi Sun and Dr. Elvira Balinas in their research article expands the scope to vocational education. In this study, the authors acknowledge that there is an insufficiency in the use of digital resources and confrontation to adapt to new methods. The authors approve a course design that comes with iterative improvement. Their study reflects on the importance of developing hybrid OBE instruction, reflective teaching practices and tech-integrated models that can support vocational English education in a rapidly changing job market. Similarly Talha Memon and Waqar Ali Shah's (2024) in their research article acclaim that ELT through OBE is a new and flexible approach that reshapes language learning environment. The study highlights that this method brings autonomy to the teaching strategies as well as recognition to teachers' individuality at engineering universities.





METHODOLOGY

A total of 597 learners is enrolled in the first year English language course in the academic year 2024 -2025. The total number of learners is categorised into three verticals, beginners, intermediate and advanced. The categorization of the homogeneous group of first-year engineering students is done with a diagnostic test before the commencement of the programme. The 597 students enrolled in the programme appeared for a diagnostic test, the diagnostic assessment included listening, speaking, reading, writing and some of the essential grammar components. Based on the scores secured by the learners, they are categorised into three levels. The diagnostic test assessed the skills in terms of the reliability and the validity in connection to the globalised environment and to fall in line to achieve the OBE principle.

1. Beginner Level– Learners who scored less than 60 % are identified to this level. This level is to make the learners have the foundational language development to get well along with their regular courses and have a comfortable learning environment.
2. Intermediate Level – Learners who scored between 61 and 90 are identified to this level. This level is to make the learners engage with professional communication tasks and go ahead in learning and have more meaningful academic engagement.
3. Advanced Level – Learners who scored more than 91 are identified to this level. This level of learners should be proficient and capable of applying autonomous learning with problem solving and project-based approach including participation in various research forums and set a standard.

Out of the 597 total enrolments, 351 learners are enrolled in beginner level course, the beginner level course is titled '*Effective Communication*'. 183 learners are enrolled in intermediate course; the course is titled '*Professional Communication*'. 63 learners are enrolled in advanced level course; the course is titled '*Fluency Through Practice*'.

As stated above, the three different courses have unique focus areas that support the requirement of the proficiency level. Each course is designed to facilitate various skillsets ranging from basic language competency to industry-ready skills. The table given below displays the three courses and their focus area. The curriculum for the courses across the three levels was aligned with the three verticals of the OBE domains, as shown in the table.

Pedagogical Strategies

Pedagogical strategies are the key requirements to accomplish effective outcomes in the learners. The chosen strategies must align with specific learning outcomes in relevance to the real world application. The pedagogical strategies must align with the expected outcomes and proficiency levels to achieve the desired results. Given below are the different pedagogical strategies and the proficiency levels of the different learners.

1. Beginners: Problem Based Language Learning, Task-based learning, structured writing exercises, listening labs, introduction to digital production (podcast preparation).
2. Intermediate: Case studies, Problem Based Language Learning, blended learning with digital tools, workplace-simulated writing tasks.
3. Advanced: Project-based learning, teamwork, output creation (websites, mobile apps, books, creating digital tools for language learning and research publications).

The teaching methodologies and strategies employed in the study were designed to be both diverse and adaptable to meet the varying needs of learners. The courses Effective Communication and Professional Communication adopted a Problem-Based Learning (PBL) framework. Broad problem statements were developed, supported by specific guiding statements for each topic, ensuring that the scope and complexity of the problems aligned with learners' proficiency levels. The course instructor played a key role in ensuring that each problem statement was both relevant



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and appropriately challenging. For instance, one problem statement required students to prepare a “Freshman Guide.” This task began with a reading-focused activity, as incoming students must be familiar with institutional rules and regulations. Learners were required to read the college rulebook or relevant sections of the institutional website. Subsequently, the activity progressed to drafting a procedural guide for online course registration, thus integrating reading comprehension with procedural writing.

Both courses incorporated two continuous written assessments and spoken assignments. For example, beginner-level learners worked on producing podcasts, which were later presented in class. These assessments, combined with end-semester examinations, were used to validate learner performance. Notably, the end-semester examination questions were not prepared by the course instructor but were generated using Artificial Intelligence (AI) tools. This approach ensured uniformity, standardization, and comparability of examination experiences across proficiency levels. Question difficulty was calibrated according to each group’s competency level. Performance evaluation was thus based on a combination of formative assessments conducted by the course faculty and summative assessments generated by AI, aligning with the principles of Outcome-Based Education (OBE).

Advanced-level learners were engaged in independent, project-based language learning. Students worked in teams of four to six members, with 63 participants forming 15 teams. Each team developed a project aimed at enhancing language skills. The outputs included publishing podcasts on commercial digital platforms, producing short educational videos, developing content for Learning Management Systems (LMS), publishing storybooks, and creating websites focused on placement-related English skills. Project evaluation comprised two interim reviews—the first conducted two weeks into the course and the second at mid-semester—followed by a final review at the end of the course, during which teams presented their completed outcomes.

RESULTS AND ANALYSIS

The teaching strategies used at the three levels aligned with the OBE principle paved way to measure the desired results. These desirable results are achieved because of the following strategic actions and plans.

1. Homogeneous group of learners
2. Course content specific to the proficiency level
3. Problem Based Language Learning
4. Project Based Language Learning
5. Case study analysis
6. Industry relevant tasks
7. Continuous monitoring

Figure 2 clearly depicts the performance of the different level of students and their performance based on the scores.

Effective Communication: The results for the *Effective Communication* course demonstrated a normal distribution of marks across the cohort. Out of 351 learners, 61 students (17.37%) scored between 80 and 89, 159 students (42.29%) achieved scores between 70 and 79, and 89 students (25.00%) scored between 60 and 69. Only 6 students (1.70%) failed to meet the basic performance requirements. These results suggest that learners, particularly at the beginner level, were distributed across a wide range of achievement levels. The performance patterns provide clear evidence of measurable learning outcomes, reflecting the varied impact of differentiated instruction. Moreover, the distribution highlights the need for targeted interventions to support those at the lower end of the spectrum, while continuing to challenge and extend the higher-achieving students in line with Outcome-Based Education (OBE) principles.

Professional Communication: The results for the *Professional Communication* course indicated a marked improvement in performance compared to *Effective Communication*. Out of 183 learners, the majority—119 students (65.02%)—scored between 80 and 89, positioning them at the higher end of achievement. A further 49 learners (26.77%) scored



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between 70 and 79, while 9 learners (4.92%) achieved scores in the 90–100 range, demonstrating advanced proficiency. Notably, only 6 learners (3.27%) scored between 50 and 69, indicating a minimal proportion of students at the lower performance band. This distribution reflects a higher overall competency level and suggests that the differentiated curriculum and targeted learning strategies employed in *Professional Communication* were effective in supporting learners toward higher achievement levels. Fluency Through Practice: The score distribution for this course was heavily concentrated at the higher end, with no learners scoring below 60. The largest cohorts—30 students each—were in the 80–89 and 90–100 ranges, representing 47.00% of the total in each category. Only 3 students (4.76%) scored between 70 and 79, indicating that most participants demonstrated high proficiency. This concentrated distribution at the upper performance bands suggests that the instructional design and learning activities were highly effective in facilitating advanced-level achievement.

Skill Development and OBE Attainment

The results and the scores of the learners convey various ideas according to the different levels of learners. Beginner level learners progressed from basic sentence construction to producing structured reports and podcasts. The Intermediate level learners demonstrated fluency in professional writing, digital communication, industry-relevant tasks, drafting effective blogs and analyzing critically and the advanced level learners displayed autonomous project management, innovation, and leadership in producing concrete specialized outcomes. The research analysis clearly depicts the outcomes of knowledge, skills, and behaviors / attitudes at all levels. The assessment at two verticals, by the course handling faculty and the aid of AI validates outcome and the strategic element in OBE-based curriculum design. Fluency through practice encompasses visible and measurable outcomes by the autonomous projects.

CONCLUSION

This Outcome-Based Approach validates that aligning course delivery to learner proficiency levels empowers effective attainment of defined outcomes. Homogeneous grouping encouraged the course instructors to be specific and pay more to the learner's needs. This ensured the beginners concentrated more on the basic language development, intermediate users to build real-time workplace skills, and advanced learners involved in autonomous language development projects. The integration of reliable tasks such as podcasts, digital profiles, project reports and case studies ensured relevance in both academic and employment contexts. The research and the results convey that the similar approaches can be employed to all first-year engineering students to learn English. This methodology does not make the advanced learners repeat the learning what is already familiar to them and waste time. Instead, they can learn more in advance and support their peers in improving them. Similarly, the beginners need not be in a class where the content is too heavy and not able to follow or understand which results in failure. The intermediate learners also find it difficult to fall between the other two learners. Hence, the model discussed depicts a differentiated, OBE-driven curriculum that can address heterogeneous proficiency in first-year engineering students. This will ensure measurable learning outcomes.

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Table 1. Course Allotment and Focus Areas

Level	Course Title	Focus Areas
Beginner	<i>Effective Communication</i>	Fundamental language skills, Reading Aloud, Paragraph writing, Data interpretation, Drafting Email, Note-making, Report writing, Listening, podcast creation etc.
Intermediate	<i>Professional Communication</i>	Industry-Specific Terminology, Professional email writing, Digital and Online Communication tools, Review and Essay writing, Creating Digital Profiles, Video Resumes, Case Studies, Project Report Writing Blog Writing etc.
Advanced	<i>Fluency Through Practice</i>	Independent projects (Eg. Podcasts publication, mobile pronunciation apps, websites, book publications, paper presentations), advanced writing, case studies, real-world application tasks.

Table 2 Curriculum Design and OBE Mapping

OBE Domain /Levels of the learners	Beginner	Intermediate	Advanced
Knowledge	Grammar, sentence structure, paragraph organisation	Industry-specific vocabulary, report writing conventions,	Research conventions, publishing procedure and formats
Skills	Writing emails, interpreting charts, note-making, Writing error free sentences, Speaking in digital platform (Podcast)	Creating digital profiles, Drafting Professional Email, drafting project reports	Website content for language development, podcast production, public speaking Content creation for LMS platform Presentation skills, Pitch presentation
Attitudes/ Behaviours	Confidence in expressing ideas, basic teamwork, willing to acquire global skills	Professionalism in digital communication, responsibility in group work, accepting the needs and working on the same.	Leadership, initiative, social responsibility, project making, entrepreneurial thought



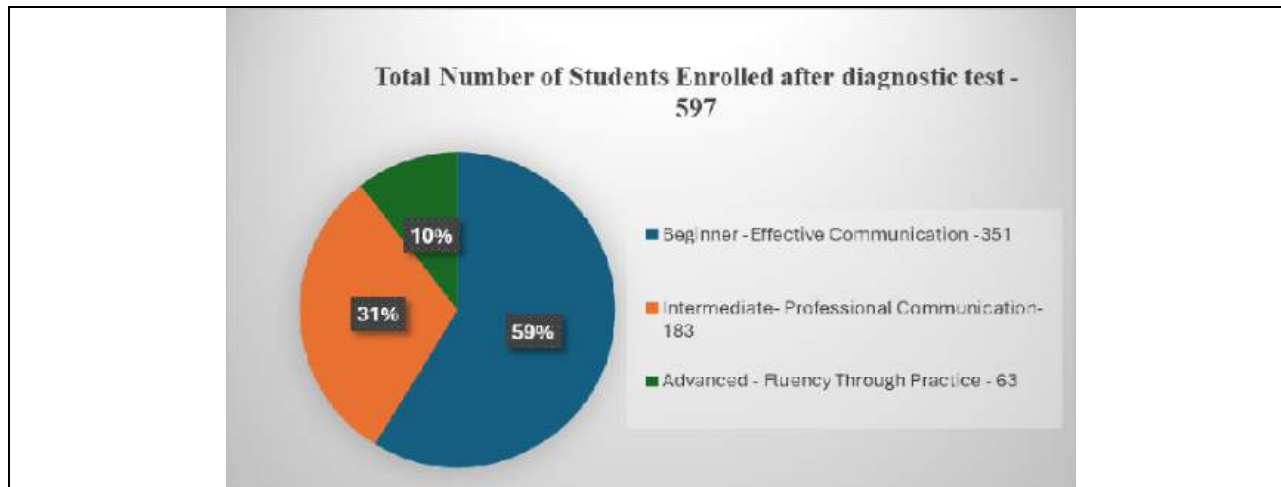
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Fig. 1. Student Enrolment Status in Three Courses

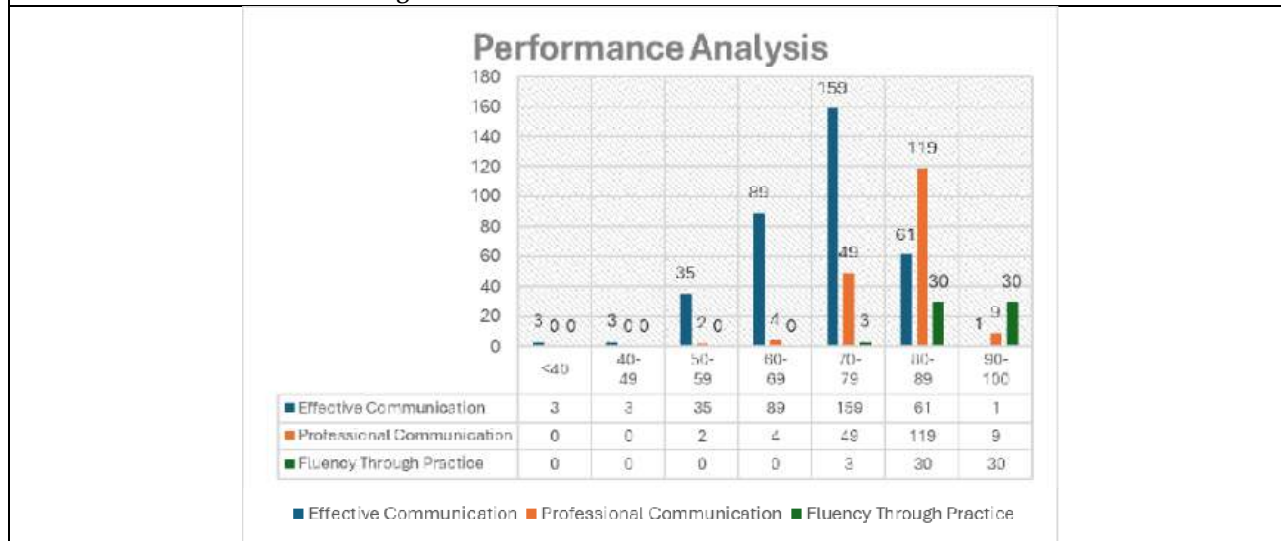


Fig. 2. Performance Analysis of Different Levels of Learners.

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RESEARCH ARTICLE

Selfhood or Survival? Lavender Marriages and Trauma in Harshavardhan Kulkarni's *Badhaai Do* (2022) and Jeo Baby's *Kaathal – The Core* (2023)

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ABSTRACT

“Supreme court of India heard several petitions to legalise same sex marriages and its nuances in detail for over 10 days and reserved its verdict saying it cannot give a declaration on the anticipation as to how the parliament is likely to respond to it” based on the point that marriage is not a fundamental right promised under the Indian Constitution. (*Supriyo @ Supriya Chakraborty v. Union of India*). In this context, a Film like *Badhaai Do* directed by Harshavardhan Kulkarni, occupies a significant position in discourses on same sex marriages in India. An academic dissection of nuances surrounding the institution of marriage in India and the traumatic crisis in it, is the need of the hour. Is lavender marriage a moral solution pleasing the society? Is it an escape from societal pressure leading to dual lives? The researcher attempts to study lavender marriages as a space to negotiate queer identities with society and the aftermath of it which includes trauma as a major concern. The chosen film texts portray pressure on queer individuals leading to unsuccessful Lavender marriages resulting in traumatic lives. Using Judith Hermen’s theory of complex Trauma, and identify the trauma that queer individuals go through in the institution of marriages wherein ‘queer desire,’ ‘sex’ and sexuality are unspoken and misunderstood. The paper situates the chosen visual texts against the backdrop of Indian society and marriages and explores the consequences of compulsory heterosexuality.

Keywords: Queer, trauma, Lavender marriage, performativity, negotiation



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INTRODUCTION

Marriage in general has been an integral part of human society for eons and the reason why one chooses to be married and who to be married to, has been instrumental in deciding one's social status and dignity in any society across the globe. What is it that significantly bothers the mainstream society about same sex marriages? An answer to this question needs a good understanding of why marriage in general is such a great deal in heteronormative society. Is it for the mere companionship? Is it for the reproduction? Or is it just a social institution to ensure security in terms of one's wellbeing? But can all these be attained even without marriage? Society in India and across South Asian countries has always considered marriage especially that of daughters as a great responsibility and a destiny. It is very common for Indian parents to save money for their daughters' weddings. There is a taboo against daughters that do not end up married either by choice or by chance. Therefore, it is common in India and south east Asian countries, for parents to pressurise their children to get married once they reach a certain age and for gays and lesbians that are in closet, the pressure becomes even more intense. Advertisements in matrimonial sites speak volumes on the same. Gays and lesbians who succumb to this pressure, try to find relief in what is called the lavender marriage. Lavender marriages become not mere compromises with society but a calculated and psychological strategy to survive within the constraint of heteronormative structure.

METHODOLOGY

Using qualitative analysis of the chosen film texts namely *Badhaai Do*, a Bollywood film and *Kathal the Core*, a Malayalam film. Judith Herman's theory of Complex trauma is used to base the arguments. The theory states that exposure, could be just one if prolonged to atmospheres that are toxically pressured restricting freedom and self-expression lead to complex trauma. The intention of the research is not to pathologize queer individuals portrayed in the films rather canter variation, survival, and restricted agency under heteronormative pressure.

LITERATURE REVIEW

Most researchers have viewed lavender marriages from a law and society point of view and seldom from that of what queer individuals might experience in the process. Relatively, less work has been done from a trauma point of view. The researcher takes interest in positing lavender marriages as a space for three agents to contribute to trauma. Firstly, the queer individuals themselves, their immediate families, and then the society in the form of neighbours as seen in both the film texts. The main argument is that lavender marriages can more comprehensively be dissected using the theory of complex trauma as theorised by Judith Herman as emerging from a long-term exposure to constant pressure where self-expression is destroyed in a structured by hindering freedom.

DISCUSSION

Is lavender marriage a negotiation with society and queer individuals or a Trauma adaptive survival strategy?

Complex trauma involves Long, recurrent exposure to forcible or dangerous environments, rather than one shattering event. Gay and lesbian individuals often forced to enter heteronormative marriages experience complex trauma as seen both the film texts. It is not only that queer person in the marriage suffers trauma because of excessive pressure to perform the role of spouse and then live his/her nocturnal life but also the other partner who is heterosexual or homosexual also experiences trauma from not receiving the reciprocation of love and affection. As seen in *Kaathal the core*, after twenty-five years of marriage, when they have the college going daughter the wife files for a divorce as she comes to know of her husband's homosexuality. The amount trauma on her is equally significant here just like that of the character played by Mammootty. It is the victim victimising. Queer individuals experience Chronic familial surveillance, which can be seen in *Badhaai Do* where in constantly their families and neighbours





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keep interfering into their personal; space and as such it was Emotional coercion that led to their marriage. Lavender marriages although gives initial relief to queer individuals as they feel they have put an end to their pressure from families, it only turns into a trauma-containment strategy, if not a trauma origin. It further leads Emotional numbing for both partners in the marriage and the queer partners that they are within their secretive lives, which can be seen in *Badhaai Do* where in Bhumi Pednekar's character loves babies but cannot adopt one, so numbs her feelings and tries to stay strong. Dissociation, Fragmented sense of self, and Difficulty with intimacy are other significant ways they experience trauma. In *Kaathal* the core, Jyotika's character, on being asked by their intimacy says they have had sex only thrice in 25 years. Lavender marriages become adaptive responses to complex trauma that takes its base in survived heteronormative pressure. Positioning lavender marriages within the outline of complex trauma permits survival strategies shaped by chronic pressure and forced choice rather than as separate psychological dysfunctions (Herman).

A marriage of convenience has been part of Indian culture ever since the idea of marriage evolved from being just a couple living their lives to that of two families playing a huge role in it. Shradul, a gay man in *Badhaai Do*, is a police officer, an epitome of what any straight woman would desire for. He is portrayed to be this well built, tall, dark, handsome, macho man with a gym toned body, husky voice and charming with a cleanshaven face and a moustache. This aspect of detailed working of his character as a police officer is a realistic approach that he shouldn't be compromised with machoism, however, the story takes an interesting turn when Shradul expresses to his wife Suman, a Lesbian woman, that it was all because of extreme pressure of being a man, ostensibly forced him to develop masculinity to the society's orders. The ambiguity of whether Shradul really wanted to have that gym toned body and be that macho speaks volumes on the condition of gay men in India.

The idea of performativity as stated in *Gender Trouble* by Judith Butler holds good here. "Gender proves to be performative— that is, constituting the identity it is purported to be. In this sense, gender is always a doing, though not a doing by a subject who might be said to pre-exist the deed." Butler does not claim that gender is a performance, and she distinguishes between performance and performativity. Shradul's character in the film exemplifies what Butler calls gender performativity. He is demanded to perform as a macho man in the heteronormative structure of the society. The whole notion of being a man, being a macho man adds on to his already existing trauma of accepting himself as gay. It is also significant to note that to be a man and to be gay could mean different as the latter is sexual orientation whereas to be a man is to perform a set of repeated acts as Butler puts it. Gay men in India have that extra pressure to play the role of men while processing their sexuality's nuances. To come to terms with one's homosexuality while playing the gender role is a process. Following Connell's types of masculinity, Shradul tries to put on hegemonic masculinity as the society demands whereas he could potentially fall into subordinate masculinity. So cultural archiving plays the role in shouldering the societal expectation and demand that deeply rooted in India and never admit any kind of incestuous passion.

The opening scene of the film deals with an identity marker when Shradul's sister says he is the light of the family: "Kul Deepak." This shows how men are considered in India. His obsession with body building in his introducing scene in the film, makes the audience think he is a macho man and take his sexuality for granted meaning thinking that he can only be straight. He also wants a transfer from a female police station. The officer says people die for a posting in female police stations, shows the mindset about men. He is already portrayed with a hint that he is not into women, only when keenly observed. The family has called for a meeting to discuss about his marriage. He has always told them that he is in love with a girl to keep the discussion away and when all of them agree, he says she got married to someone else. This shows how he kept lying to keep the marriage discussion far from him, which is a representation of several gay men in India who try to put on a macho pose and say that they are in a relationship with a girl to the outer world while they continue their closeted gay lives.

Rather than signalling repression or moral failure, emotional withdrawal within such marriages reflects trauma-adaptive behaviour shaped by chronic threat (Herman). In a scene where his constables are catching couples in a public park, a female constable sees two men making out behind a bush and calls them lesbians, and a male constable



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sees them to say no, they are homo. Though the scene is portrayed comically, it shows the lack of awareness on who is what? When they report those two men to Shradhul, there is an instant way of how he connects with them with a certain sense of empathy, he immediately asks them to leave and says “people like this spoil the country” only to not surprise and bring a doubt in the minds of the two constables. This is the first instance where it can be known that he plays the role. A man that is straight and cisgender is expected to not support any act of two men making out, and more importantly abuse them. The linguistic gender performativity is seen here.

The demand for silence within marriage illustrates how survival is negotiated through self-erasure in contexts of institutional betrayal (Freyd). In a monologue scene, drunk Shardul expresses himself to Suman saying he never wanted to be this body, he takes his shirt off and shows his body. He displays his strong muscles. He gets emotional calling him a homocop and a gay man became a police officer thinking of catching thieves, but gays are even more scared of police. This shows that he perhaps wanted to be someone else, beyond that gym toned body. He has been performing his macho gender all this while. Suman happens to meet a north eastern girl Rim Jim, a lab technician working at a hospital, they both connect instantly and fall in love however when Suman tells her about her lavender marriage with Shardul, the way Rim Jim asks her questions about the lavender marriage gives that there is a sense of hopelessness about them being together, yet they manage to laugh it out. So, potentially after lavender marriage, finding love becomes even more challenging for queer people as no other queer individual might take interest in someone who is in a lavender marriage or if the potential lover is not in favour of a lavender marriage.

s van der Kolk notes, chronic trauma conditions individuals to prioritise safety over desire, a dynamic that is evident in the formation of lavender marriages (van der Kolk). Shardul and Suman manage to get a flat outside the city to hide themselves but they soon end up shifting to a police quarter. When a neighbour senior couple visits them, Shardul says they do not want a maid because “Suman will do all the chores.” Shardul takes on a hegemonic masculine trait and controlling husband role in front of the guests. When she is about to sit, he orders her to go and make coffee like a typical husband. On being questioned why he is acting like this suddenly; he says they should feel like they were husband and wife. Up on a condition, Suman behaves like a wife and takes his order of making coffee. The senior woman goes to the kitchen and asks Suman to keep him under control while the senior man appreciates Shardul for his dominating husband behaviour. This shows how both performed their gender in front of a heteronormative structure that is based on patriarchy.

heteronormative structure based on patriarchy is seen here. For instance, when Rim Jim shifts with Suman, Shardul does not like it, though he does not strongly express it. So, even though a lavender marriage initially seems to work out, eventually when the queer couples respectively find their love partners, it gets complicated. Rim Jim's entry does create an impact on their heteronormative portrayal to society. In a scene where Rim Jim has her arms around Suman in a public park, Shardul comes and immediately puts his arms around Suman as a husband, showing how he was always conscious of what others perceive about them. He is not so happy with Rim Jim being with Suman in their flat, though this is portrayed in a subtle way with humour. Rim Jim gets uncomfortable with seeing Suman and Shardul being like a husband and a wife outside, she fights with Suman asking her how she can so comfortably act like this, to which Suman says for the first time in her life she is living on her own terms and if it demands lying, she would not hesitate, which is yet another instance showing how queer individuals enjoy even a little freedom of being themselves in the oppressing heteronormative society.

General cultural sphere creates an ideological formation in the minds of people and expects them to live according to the formatted sphere and thus Suman's attire accounts important in the role being played as daughter-in-law though it's a feigned relationship according to them. It adds to the narrative the expectation of heterosexual couples to go with the momentum with procreation that amplifies relationship further in a coherent ordination, expectation to remain as the daughter in law without getting disturbed by authoritative questions by the elder is another example for the woman to remain passive in the idyllic relationships. Authority of predisposition regulated in their mind of men tend to blame women for their discomfort in mentioning about their incapacibilities is well mentioned in the movie with the example of this scene depiction. when his uncle asks why they are not having children, says that



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Suman cannot get conceived. Cultural hybrid irrespective of man or gay, likes to blame women. Masculine ego emerges in this argument that filament in the frame of heteronormative structure of family. Cultural attitude embedded in the system and they are so uncritically accepted to monitor the couples personal and private affairs to watch their behaviour towards each other is never be surprising and this attitude is brilliantly captured in the movie by appointing Shardul's mother to keep an eye on them.

By now, the couple have almost become impatient, they just do not know what to do. The mother starts reporting about the couple's lifestyle to the family. Shardul's grandmother, asks her to tell Suman's parents to talk to her saying "it is also their responsibility." The couple are forced to sleep on a same single bed because the mother is at home. The mother is forced by the family to ask Suman to come home early and dress like a lady to attract her husband. All these are portrayed slightly on a comical note. In fact, the mother watches an adult scene on TV in front of Suman. At one point due to increased pressure, the couple even think of having sex just to have a baby. the whole idea seems so technical in their mind. Rim Jim does not give her consent for the idea. So, they leave it at that. This shows how in a lavender marriage, queer couple even think of having children which could further complicate the case.

Drawing on Freyd's theory of betrayal trauma, this paper argues that lavender marriages often require individuals to suppress awareness of harm in order to preserve vital familial and social bonds (Freyd). Suman one day tells her mother-in-law that the problem is with Shardul. The mother cries on hearing this. When Suman says let us get your sperm count tested at the hospital where Rim Jim works and she can give a report that his sperm count is less and that would give them time to be away from the pressure of having children. Shardul, though is not happy, goes with the plan. Upon knowing that it is the problem of their son, the family agrees for them to adopt a baby. Assertive authority of the family members blames suman being caught having sex with Rim jim, blames her for being the lesbian by citing their common behaviour with her, such as sleeping next to her and changing their dress in front of her, assertion over their body and mind is not surprising in these contexts, rectitude expectance is relatively common and considerably accepted norm for Indian woman to follow the mass as the 'self' remains as the 'constructive self' and it is much expected that these kind of exhaustion and disappointment is not new for the homosexuals or lesbians as suman expresses her disappointment with her father that these reaction is quite expected and her suffering is right from childhood deep within expecting that one day they will have to deal with their family's reaction. And in the journey, they would have taken so many decisions that put them into stress, trauma, and pressure. Garrulity and dominance in blaming the other gender is easy to posit blame on women and establishes their power to retain their self -constituted invasion in couple's life though not chosen by them rather imposed on them by severing their personal lives. Family gets shell shocked by shardul reply in accepting that he is the gay and even he has the disease if it is so mentioned Lesbianism as the disease. "I also have that disease, and I am gay." Interesting response in the film, assertion of the practice drives them to remain as the couple choices for adopting the baby, conditioned to the system again with the foreclose expectation of adoption given exclusively to the heterosexual couples according to the Indian Law of adoption. Movie concurrently gives the glimpse for a change in the system of adoption by highlighting the law that forces couple to remain in the family system irrespective of the family and cultural acceptance. Movie ends in questioning the system turbulent demand by the family, choice of the individual, customised expectation of enforced law commands the individual to play the role in the constituted family axiom with the clear mention to the family about their mutual understanding by reasoning them with their identity requirement, but subordinate to the functional system of the society.

CONCLUSION

Lavender marriages act more as responses to adapt to long term pressure handled in a heteronormative structure. According to Judith Herman's framework of complex trauma, lavender marriages are a result of queer individuals' frustration with their families due to chronic surveillance about playing the roles by families, general stigma from the society, and institutional extermination. These conditions, make the marriages function as a shielding construction



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that lessens exterior hazard although they amplify the psychological pain inside. Therefore, the deliberate determination of lavender marriages replicates violence deeply structured by heteronormativity rather than individual dishonesty.

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RESEARCH ARTICLE

Fostering Industry - Ready Engineers: Transforming English Language Education through Problem-based Learning

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ABSTRACT

Problem-based language learning serves as an impactful pedagogical approach for engineering students, which equips them with career skills that are necessary for their professional life along with language development. This study investigates the implementation of this learning model to first-year engineering students and evaluates its effectiveness and the challenges faced by the learners. This work explores how PBL makes the students to meet the demands of professional life by equipping them with the necessary skill sets. The results of this work indicate that this mode of learning improves the linguistic proficiency of the learners along with other professional skills like collaboration, problem solving, teamwork, communication and presentation skills. The learners overwhelmingly reported that they had increased motivation during the classes, and they simulated real-life conversations while completing the tasks assigned. They also endorsed that they would recommend this model to others and for a broader adoption in other science and engineering courses. This work affirms the fact that adoption of PBL in English language learning makes the engineering students both professionally and linguistically competent. This work also insists the researchers to ensure inclusivity of all the learners during implementation of any teaching-learning process.

Keywords: Problem-based language learning, innovative pedagogy, experiential learning, professional skills, learning through real-life scenarios



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INTRODUCTION

Engineering graduates are expected to communicate in English in a number of professional situations, especially considering globalization and working with multicultural teams. English language proficiency becomes crucial for them to be successful in their academics and to become employable. As engineers, they are expected to communicate clearly, collaborate with others efficiently and attack to various situations. Despite this reality, it is often found that engineering students face consistent challenges in language learning. Frequently it is observed that these challenges come as a result of limited exposure to the language, limited use of English in their daily activities and lack of confidence prevailing in the learners. Conventional mode of language learning does not seem to help this scenario since it is dominated by grammatical components to the most part and long lectures where the student participation is minimal. This situation prevails in most of the engineering institutions in India, thereby calling for an innovative teaching model which would cater to the needs of the Gen Z learners.

Problem based learning seems to be a promising approach which is student centered and stimulates language learning. The students will be able to use this as a tool to communicate with others by simulating real world situations. This also would help the students to learn other 21st century skills along with the air English language. Problem based language learning was introduced in a Tier 1 institute in the western part of Tamil Nadu, India, to overcome the above problems and to increase the motivation of the learners. This model was implemented after thoroughly exploring its potential to enhance English language proficiency among the engineering graduates. This research article will examine the student perceptions how this model impacted their English language learning and its application in India's real life professional contexts. This work will also analyse the different skills that they have developed through this mode of learning like teamwork, collaboration, critical thinking, digital literacy and problem solving.

REVIEW OF LITERATURE

KoK and Duman (2023) examined the problem-solving abilities developed by the learners who learnt English language through problem-based learning mode. The study was carried out in a public university in Türkiye for a controlled group of students who were split into 2 groups. One group of students was taught using PBL and the other group was taught using traditional instruction. The results showed that there was a significant difference between both the groups. Students who learnt through PBL developed more problem-solving abilities. Ali (2019) explored the effectiveness of problem-based learning in English language classes. The results depict that there was a transformation from a teacher-centered approach to a learner-centred approach in this mode of learning. The students were found to actively engage in all the tasks aligned to real-world problems. It was witnessed that PBL promotes self-directed learning and improves the communication skills of the learners. Jaleniauskienė (2016) investigates the impact of language learning in the higher educational institutions through problem-based learning. The study explores how the traditional learning methods often fail to engage the learners. The study also investigates the gap between the learning environment and the real-life language use. Fitriyah et al. (2024) come up with an instructional design for this mode of learning. It is evident in their study that PBL promotes higher-order thinking skills in the learners. By providing authentic problem-solving tasks, the students were trained and evaluated on their ability to analyse, question and evaluate. This work advocates for the use of PBL to enhance critical thinking in the learners.

RESEARCH METHODOLOGY

A mixed-method design was applied to analyse the effectiveness of this implementation, and this enabled us to obtain both quantitative and qualitative analysis of the data. A survey was conducted using MS Forms, and this allowed to get the student perceptions systematically and enabled the faculty to explore and understand the



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individual student experiences in the English classes conducted through Problem-Based Learning. The responses collected through MS Forms allowed to carry out a statistical interpretation of student perspectives and the qualitative dimension helped to understand the subjective perceptions of the students. This innovative teaching pedagogy was carried out for a class of 61 first-year engineering students from a Tier 1 institution in the western part of Tamil Nadu, India.

The class comprised of students from various engineering programs – Mechanical Engineering 35, Electronics and Communication Engineering 12, Mechatronics Engineering 6, Automobile Engineering 4, Civil Engineering 3 and Aeronautical Engineering 1. This was found to be a heterogeneous group of students where there were 47 boys and 14 girls out of which 23 of them hailed from rural background and 38 students came from urban and semi-urban areas. The educational background also differed with 42 students completing their higher education in English medium schools and 19 students completing their schoolings from Tamil medium and other vernacular medium schools.

The English language course, which was a part of their regular curriculum, was taught through the Problem-Based Learning mode. Real-life scenarios related to academic and professional environments were given in the class and the topics like email writing, letter writing, blog writing, group discussion, report writing, preparing agenda and minutes of meeting, creating advertisements, product review, reading comprehension, listening for specific purpose, listening to TED talks, oral presentation, and proposal writing were aligned to these scenarios and the students were made to respond to the situations. A few real-life activities were carried out to make the classes more interesting and to make the learners involved in the course. For instance, while handling email writing, the students were instructed to write emails to their friends, teachers and to a few companies by providing specific situations. Role plays were conducted where each student was assigned with different roles, and they were asked to enact their part for a specific situation. This made them to explore the real-life situations and how people behave in professional situations in industries.

Engagement of students was continuously monitored with utmost care throughout the classes. The faculty served to be the observer and facilitator guiding the learning process. There were individual and group activities throughout the course. The candidates were divided into groups of 4 to 5 members and brainstormed on the activities. The usage of English language was consistently monitored during the brainstorming sessions and group discussions. English language use was monitored during the activities like role play, presentations and other interactive activities and in the written texts. The candidates were observed on their behaviour, self-confidence, critical thinking and problem-solving abilities. They were encouraged to develop leadership qualities and work collaboratively in order to become a good team player. A checklist was created and used to track the progress of the students with specific rubrics for evaluation. The intervention of the faculty members was minimal during the activities, and the students were given a free hand to present with confidence.

Data was collected using a questionnaire consisting of multiple choice, multiple selection, Likert-scale, and open-ended questions. It was then tabulated digitally to ensure accuracy. Open-ended questions in the MS Forms helped the faculty to critically analyse the motivation, confidence level and the challenges faced by the learners. The students were encouraged to give authentic and self-reflective responses in order to understand the effectiveness of the training model. The candidates were brainstormed on the specific skill that they developed after each activity ensuring that they are aware of their learning.

RESULTS AND DISCUSSION

A survey was conducted using a questionnaire to understand the effectiveness of the Problem-Based Language Learning. Insights of the survey responses provided the effectiveness of this teaching methodology and how the



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students were able to develop various language skills. A chi-square test was applied to understand the distribution of language skills and other skills among the candidates. This analysis compared the expected frequencies of skill selection with the frequencies that the learners have reported. It was expected that all the mentioned skills are to be developed equally by the learners through this mode of learning.

Descriptive Analysis

- A strong majority (70.5%) of students found that problem-based learning was very effective, while 27.9% of students thought that it had a moderate impact. Only 1.6% reported that there was no impact, revealing that this teaching methodology is impactful in motivating the learners to understand their course efficiently.
- 78.7% of the learners perceived that problem-based language learning motivated them to apply their knowledge in real-life situations, while only 3.3% took a different stand. 18% of the candidates were not certain about whether this teaching model motivated them, which is deemed to be a part of difficulty in implementation.
- 72.1% have stated that this mode of learning made them think out-of-the-box, whereas 11.5% of the learners disagreed with the statement. 16.4% of learners were not able to come to a conclusion and the overall scenario pictures that this teaching methodology is cognitively stimulating.
- When it comes to learner motivation, 75.4% of the students felt extremely satisfied, while only 4.9% felt that they were not motivated. The remainder of 19.7% found it difficult to understand whether this model motivated them or not, and this indicates that this pedagogy largely facilitates learner motivation.
- Overall, it was observed that 73.8% of the learners recommend this teaching pedagogy, while only 4.9% of the students hesitate to recommend the model to others. 21.3% of the candidates were uncertain, and the overall thought processes of the learners indicate the model's effectiveness.
- When it comes to learning new technology, 57.4% of the students agreed that this learning methodology warranted them exploring new technologies in order to complete the tasks, while 14.8% differed. 27.9% of the learners were unsure about learning new technology during the course, and this suggests moderate effectiveness of problem-based language learning in inducing the learners to explore new technologies.
- It was evident from the feedback of the students that they were able to improve many skills in the form of collaboration, communication, confidence, problem solving and speaking skills, while the scope to improve their negotiation skills was comparatively less. Thus, the student responses suggest that this mode of learning is highly effective in developing various skills that are essential for their future personal and professional life.

The 3D pie chart represents the distribution of skills developed by the students through this mode of learning. This reveals that the teamwork and collaboration of the learners along with their communication skills dominated the outcome with teamwork (13.1%), communication skills (12.8%), and confidence (12.2%) which represents a collective total of over 38% of the reported improvements. Divergently, negotiation skills (2.7%) and critical thinking (7.1%) appeared as minimal sections, which suggested that the present pedagogy fosters interpersonal skills and collaboration more than the higher-order cognitive skills. This could be possibly because of the fact that only first-year engineering students were the participants of the course.

The stacked bar chart illustrates the students' perceptions on five significant learning outcomes in the form of application of the learning in real-life scenarios, encouraging the learners to think out of the box, motivating the learners to improve their English language proficiency, learning new technology for completing the tasks during the course, and the satisfaction level of the learners. There were high affirmative responses ("Yes") for real-life application (78.7%), cognitive engagement (72.1%), motivation (75.4%), and peer recommendation (73.8%), with technology adoption (57.4%) showing moderate acceptance. The limitations of this mode of learning are evident through the responses of a small group of learners ("No" $\leq 14.8\%$ across all categories). The "Maybe" responses (18–27.9%)—which can be specifically witnessed in technology integration—advocates the limitations of individuals in learning new technologies. Thus, these perceptions affirm that problem-based language learning has strong efficacy in affective and practical domains.





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The given column bar chart portrays the perceived efficacy of problem-based language learning with its effectiveness. Majority of the learners (70.5%) rated its effectiveness as "Highly impactful," followed by a few students rating it as "Average" perception (27.9%). Only a negligible number of candidates (1.6%) reported as "Did not create any impact." These responses underscore the impact of this mode of learning in enhancing the communication and English language skills of the students. It is also a notable fact that even though a small amount of the learners have given negative comments, it mandates us to revisit the model for refinement to ensure inclusivity.

Chi-Square Test for Skill Development

Objective

To determine whether the distribution of skills developed through problem-based language learning is uniformly distributed or whether some specific skills are significant than others.

Methodology

- **Null Hypothesis (H_0):** The distribution of skill development is uniform (all skills improved equally).
- **Alternative Hypothesis (H_1):** The distribution is **not uniform** (some skills improved more than others).

Data Considered:

- **Total responses:** 61 (assuming each respondent could select multiple skills).
- **Categories analyzed:** 10 skill options (excluding "Other").
- **Expected frequency (if uniform):**

$$E = \frac{\text{Total selections}}{\text{Number of categories}} = \frac{335}{10} = 33.5$$

Chi-Square Test Results

Statistic	Value
Chi-square (χ^2)	31.16
Degrees of freedom (df)	9
p-value	0.00028

Statistical Significance

The p-value (0.00028) is far below $\alpha = 0.05$, indicating **strong evidence against H_0** .

Conclusion: The distribution of skill development is **not uniform**—some skills were significantly more impacted than others.

The chi-square test results ($\chi^2 = 31.16$, $df = 9$, $p < 0.001$) reveal a statistically significant non-uniform distribution of skill development while inducing problem-based English language learning. This indicates that a few specific skills sets have developed prominently while others were found to be on the lower side. Teamwork and communication skills—teamwork (13.1%), communication (12.8%), and confidence (12.2%)—emerged as predominant outcomes of this mode of learning. Consequently, critical thinking (7.1%) and negotiation skills (2.7%) were on the lower side. It is evident that the development of all the skills cannot be equally distributed, and this analysis gives the researchers an opportunity to refine their teaching pedagogy to ensure equal development of all the skill sets.

CONCLUSION

The instructional design of this model of integrating the real-life professional contexts in English language learning mandated the students to engage in peer collaboration and think out of the box to complete the activities. The concept of rote learning almost vanished through this methodology as the students involved themselves, both individually and as a group, to discuss and present their findings related to the context. The results obtained through this study align well with the existing literature on problem-based language learning. This method increased the



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motivation and confidence of the candidates by providing authentic professional environments, which mirrored their situation after graduation. The positive feedback of the students and the increased satisfaction about the pedagogy highlights the success of this model. This serves as a proof that English language learning can happen in a technical context.

Integration of real-life situations warrant the students to use their English proficiency and technical knowledge in practically during discussions and presentations. Development of other life skills during language learning becomes an added advantage. This learning model also fosters moving beyond regular grammar drills in English classes towards task-driven approaches. There was a significant improvement in the soft skills such as communication skills, teamwork, problem solving, critical thinking and confidence during the learning process. Students were able to identify their improvement in handling situations, which served as a great motivation for them. Learning new technologies for completing tasks in English classes reflects the multifaceted impact of this pedagogy.

This teaching methodology comprehensively serves as a model which is engaging, relevant and provides a transformative classroom experience to the learners. This serves as an authentic case study to integrate PBL into English language learning. Adapting this pedagogy to engineering and science subjects would impact the learners to a great extent. Implementation of any pedagogy will have its own limitations. The results that are shared in this research work is limited to a specific set of students studying in one single institution. The effectiveness may vary on a case-to-case basis. A minimal number of students have reported that the model did not create any impact on them. This has to be considered in future studies and it has to be ensured that every student gets benefitted during the implementation of the process.

The multifaceted benefits derived from the model makes it more suitable for the present generation of learners. It encourages the learners to become resourceful and involve themselves in the activities unlike rote learning. It also promotes deeper understanding of the subject and equips them with professional readiness. Institutions adopting this approach can definitely create learning environments where the students are better prepared to face the complexities of the professional setting.

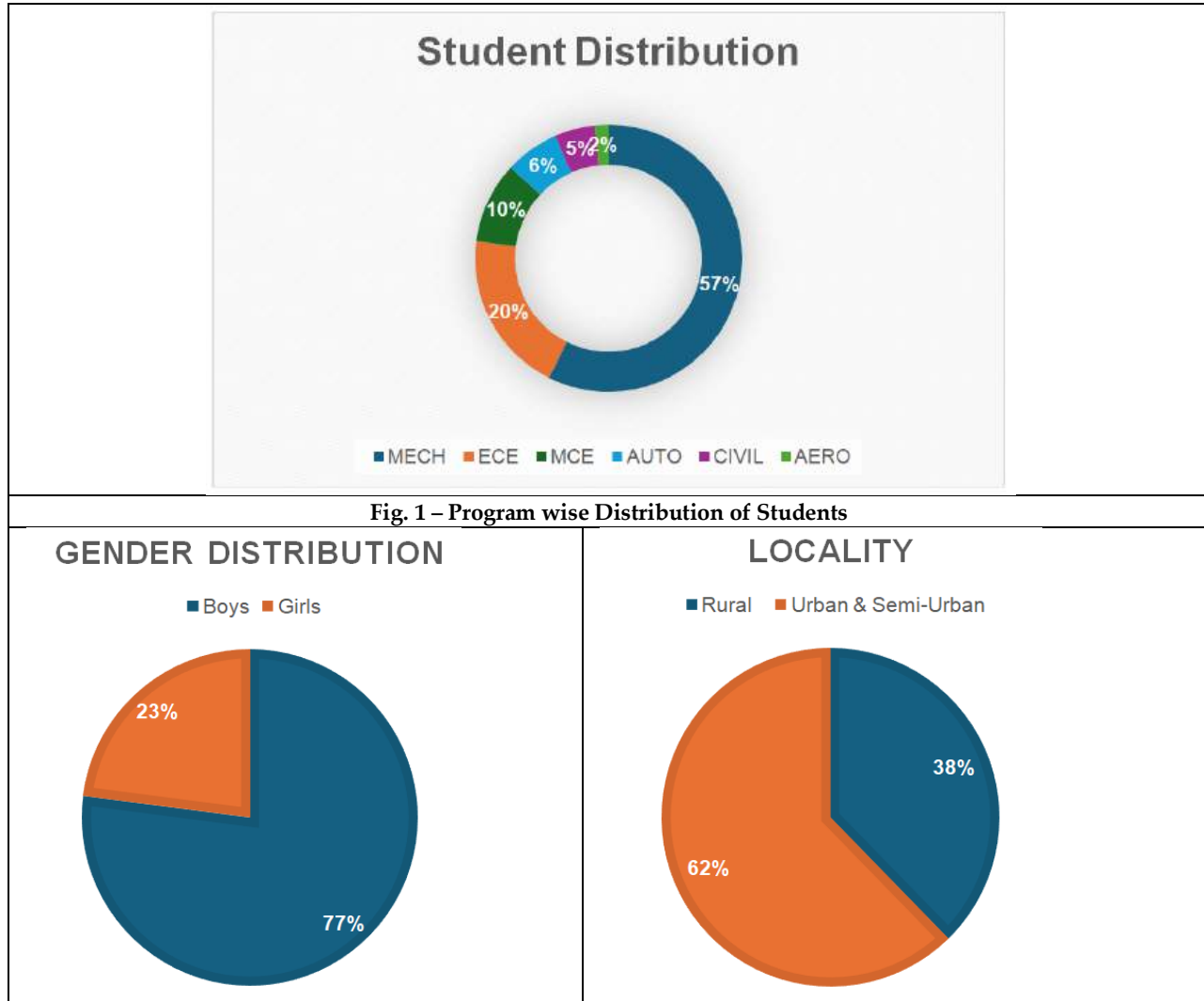
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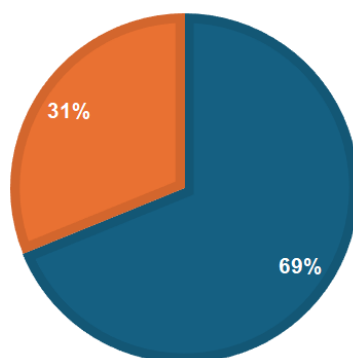




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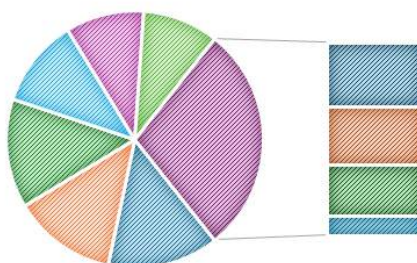
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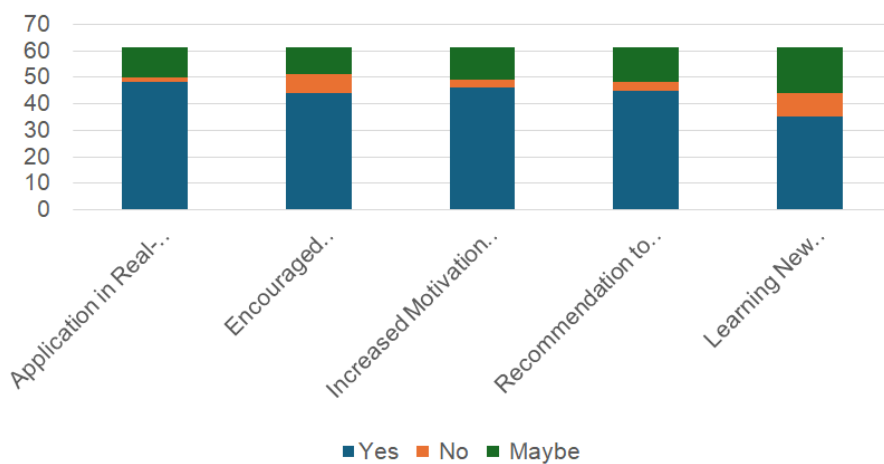


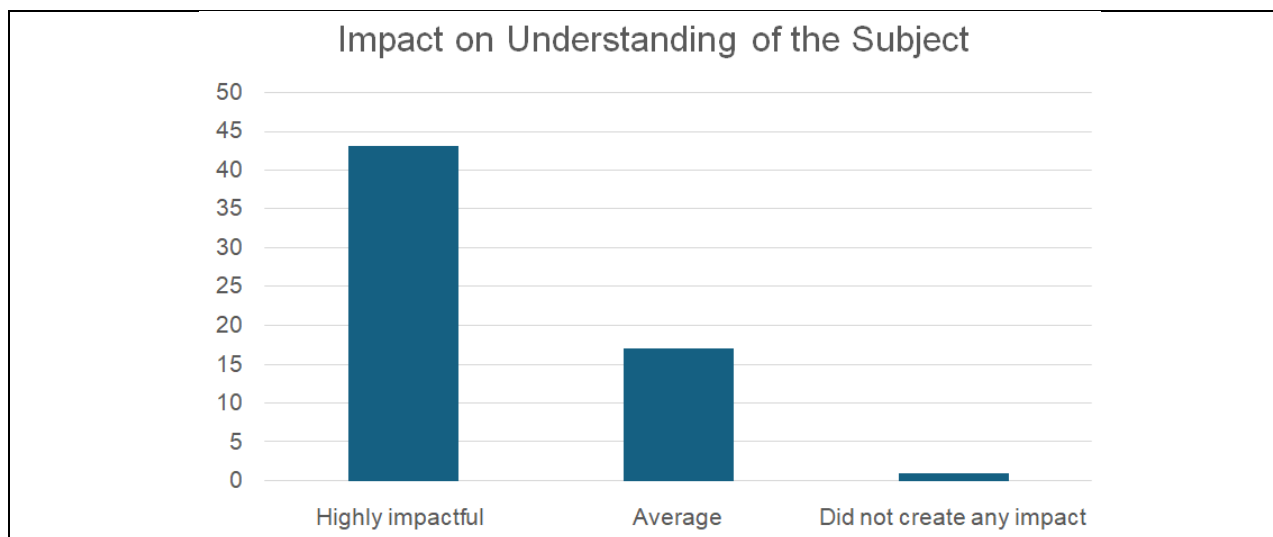
SKILL CHART

- Teamwork
- Confidence
- Communication Skills (
- Speaking Skills
- Presentation Skills
- Overcoming Stage Fear
- Creative Thinking
- Leadership
- Critical Thinking (24)
- Negotiation Skills



Descriptive analysis



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RESEARCH ARTICLE

Language Ideology and the Politics of Power in Society

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ABSTRACT

Language is not merely a neutral tool of communication; it is deeply embedded in systems of ideology and power. This paper examines how language ideology—the beliefs and assumptions people hold about language and its use—plays a significant role in shaping social hierarchies, authority, and access to resources within society. Drawing on theoretical perspectives from scholars such as Pierre Bourdieu, Michel Foucault, and Norman Fairclough, the study explores how language functions as a mechanism through which power relations are constructed, maintained, and sometimes challenged. The paper focuses on the ways dominant language ideologies privilege certain languages, dialects, or accents while marginalizing others. In many societies, the concept of a “standard” language is often associated with prestige, education, and authority, granting social and institutional advantages to its speakers. Conversely, speakers of non-standard or minority languages may experience exclusion, discrimination, or reduced access to opportunities in areas such as education, employment, and governance. These dynamics illustrate how language ideology operates as a subtle yet powerful instrument of social control. Furthermore, the study analyzes how institutions such as education systems, media, and political discourse reinforce dominant language ideologies. Through policy decisions, curriculum design, and public narratives, these institutions contribute to the reproduction of linguistic hierarchies that sustain broader social inequalities. At the same time, the paper also highlights instances where marginalized communities resist dominant ideologies by asserting linguistic identity and promoting linguistic diversity.

Keywords: Language Ideology; Power Relations; Sociolinguistics; Linguistic Inequality; Discourse; Social Hierarchy; Language Policy; Identity.





INTRODUCTION

Language is central to human interaction, yet it is far from neutral. It reflects and reinforces social structures, hierarchies, and relations of power. The concept of language ideology provides a framework for understanding how beliefs about language shape social realities. Language ideology refers to the cultural assumptions, attitudes, and values attached to language forms and their speakers (Woolard & Schieffelin, 1994). In modern societies, language operates as a gatekeeping mechanism. It determines access to education, employment, and political participation. Certain forms of language are institutionalized as “standard,” while others are stigmatized as inferior or incorrect. These hierarchies are not linguistic in nature but are socially constructed and politically maintained. This paper examines how language ideology functions within systems of power. Drawing on critical theories from Pierre Bourdieu, Michel Foucault, and Norman Fairclough, it explores how language contributes to the production and reproduction of inequality, while also serving as a site of resistance.

Background of the Study

Language plays a central role in shaping human interaction, social identity, and institutional structures. Beyond its communicative function, language operates within ideological frameworks that influence how it is perceived, valued, and used in society. The concept of language ideology refers to the system of beliefs, assumptions, and attitudes that individuals and communities hold about language and its speakers. These ideologies are not neutral; rather, they are deeply intertwined with power relations and social hierarchies. Scholars such as Pierre Bourdieu have emphasized that language functions as symbolic capital, granting power and prestige to those who command socially valued linguistic forms. Similarly, Michel Foucault highlights how discourse shapes knowledge systems and regulates what can be expressed within a society, thereby reinforcing structures of power. Norman Fairclough further develops this perspective through Critical Discourse Analysis, demonstrating how language practices both reflect and reproduce social inequalities.

In multilingual and multicultural societies, language ideologies often privilege certain languages, dialects, or accents over others. The notion of a “standard language” is frequently associated with education, authority, and socio-economic mobility, while non-standard varieties are marginalized. This hierarchy is particularly evident in contexts such as education, media, and governance, where dominant language norms are institutionalized. In countries like India, where linguistic diversity is vast, English often functions as a language of power and global access, whereas regional and indigenous languages may be undervalued in formal domains. Such dynamics illustrate how language ideology contributes to unequal access to resources and opportunities. At the same time, emerging movements advocating linguistic diversity and identity challenge these dominant ideologies, making language a site of both control and resistance. This study is situated within this broader sociolinguistic and critical framework, examining how language ideology operates as a mechanism of power in contemporary society.

Statement of the Problem

Despite the recognition of linguistic diversity in many societies, dominant language ideologies continue to privilege certain language forms while marginalizing others. These ideologies are embedded within institutional practices, particularly in education, media, and political discourse, leading to unequal access to opportunities and resources for speakers of non-dominant languages or dialects. The problem lies in the subtle yet pervasive nature of linguistic inequality. Standard language norms are often perceived as neutral and objective, masking the power structures that sustain them. As a result, speakers of marginalized language varieties may experience discrimination, reduced social mobility, and identity suppression. Furthermore, these inequalities are frequently reproduced through institutional mechanisms, reinforcing existing social hierarchies.

Although previous research has explored the relationship between language and power, there remains a need to critically examine how language ideologies function across different social domains and how they contribute to both



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the maintenance and contestation of power relations. This study seeks to address this gap by analyzing the role of language ideology in shaping social inequality and exploring the potential for resistance through linguistic practices.

Research Questions

This study is guided by the following research questions:

- What are language ideologies, and how are they constructed within society?
- How do dominant language ideologies contribute to the formation and maintenance of social hierarchies?
- In what ways do institutions such as education, media, and political discourse reinforce linguistic inequality?
- How does language function as a tool of power and social control?
- What forms of resistance emerge against dominant language ideologies, and how do they promote linguistic diversity and identity?

Objectives of the Study

The primary objectives of this study are:

- To examine the concept of language ideology and its relationship with power and society.
- To investigate the role of institutions (education, media, and politics) in reinforcing dominant language ideologies.
- To explore the impact of linguistic inequality on marginalized communities.

REVIEW OF LITERATURE

The relationship between language, ideology, and power has been extensively explored within sociolinguistics, linguistic anthropology, and critical discourse studies. Early foundational work by William Labov (1972) demonstrated that linguistic variation is systematic and socially meaningful rather than deficient. Labov's work challenged deficit theories by showing that non-standard dialects possess their own internal logic and structure. The concept of language ideology gained prominence through the work of scholars such as Woolard and Schieffelin (1994), who define it as the cultural system of ideas about language and its role in social life. They argue that language ideologies mediate between social structures and linguistic practices, shaping both perception and usage. Pierre Bourdieu (1991) provides a critical framework by introducing the notion of symbolic power and linguistic capital. According to Bourdieu, the dominance of a "legitimate language" is maintained through institutional mechanisms, particularly education. Speakers who possess this linguistic capital gain social mobility, while others are systematically disadvantaged.

Similarly, Michel Foucault (1972) conceptualizes language as discourse, emphasizing its role in constructing knowledge and regulating power. Foucault argues that discourse determines what is considered truth, thereby shaping social reality and controlling subjectivity. Building on these perspectives, Norman Fairclough (1995) develops Critical Discourse Analysis (CDA) as a methodological tool to examine how language reproduces social inequalities. Fairclough highlights the interconnection between discourse and social structures, arguing that language both reflects and constructs power relations. Further contributions by Braj B. Kachru (1985) on World Englishes highlight the global spread of English and its localized adaptations. Kachru's model challenges the dominance of native-speaker norms and emphasizes the legitimacy of diverse English varieties, particularly in postcolonial contexts.

Phillipson (1992) introduces the concept of linguistic imperialism, arguing that the global dominance of English perpetuates cultural and economic inequalities. This perspective is particularly relevant in multilingual societies where English functions as a gatekeeping mechanism. Recent studies have focused on the role of media and digital platforms in shaping language ideologies. Androutsopoulos (2014) notes that online spaces allow for greater linguistic diversity, enabling users to challenge traditional norms and assert identity. However, digital discourse also reproduces existing hierarchies, reflecting broader societal inequalities. Overall, the literature establishes that





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language ideology is deeply embedded in social structures and plays a crucial role in maintaining and contesting power relations.

Research Gaps

Despite extensive research on language ideology and power, several gaps remain:

Contextual Gap:

Much of the existing literature is based on Western contexts. There is a need for more studies focusing on multilingual and postcolonial societies, particularly India, where linguistic diversity is complex and layered.

Institutional Integration Gap:

While individual institutions such as education or media have been studied, there is limited research examining how multiple institutions collectively reinforce language ideologies.

Contemporary Digital Context:

Although recent studies address digital discourse, there is insufficient exploration of how social media simultaneously challenges and reproduces linguistic hierarchies.

Resistance Narratives:

Existing research often focuses more on domination than resistance. There is a need to highlight how marginalized communities actively negotiate and resist dominant language ideologies.

Interdisciplinary Approach:

There is scope for integrating sociolinguistics, discourse analysis, and political theory more comprehensively to understand language ideology in contemporary society.

This study aims to address these gaps by providing a critical and context-sensitive analysis of language ideology across institutional and social domains.

Theoretical Framework

Bourdieu: Language and Symbolic Power

Pierre Bourdieu conceptualizes language as a form of symbolic capital. According to Bourdieu (1991), linguistic competence is not merely the ability to produce grammatically correct sentences but the ability to use language appropriately within a given social context. This competence is unevenly distributed across social classes. The notion of the “legitimate language” is central to Bourdieu’s argument. Standard language varieties are often associated with dominant social groups and institutions. Speakers who possess this linguistic capital gain access to power and prestige, while others are marginalized. Thus, language becomes a tool for reproducing social inequality. Educational systems, for example, often reward students who already possess the dominant linguistic code, thereby reinforcing class divisions.

Foucault: Discourse and Power

Michel Foucault views language through the lens of discourse. For Foucault (1972), discourse is not just language but a system of knowledge that defines what can be said, by whom, and with what authority. Power, in this sense, is not centralized but diffused across institutions and practices. Language plays a crucial role in shaping what is considered “truth.” For example, political discourse can construct certain groups as “others,” legitimizing their marginalization. Foucault’s framework highlights how language is implicated in systems of control and surveillance. It shapes subjectivity and governs social behavior.

Fairclough: Critical Discourse Analysis

Norman Fairclough develops Critical Discourse Analysis (CDA) as a method for examining the relationship between language and power (Fairclough, 1995). CDA focuses on how discourse practices reproduce or challenge social inequalities.

Fairclough identifies three dimensions of discourse:

Text (linguistic features)

Discursive practice (production and interpretation)

Social practice (broader socio-cultural context)





Through this framework, language is seen as both constitutive and constituted by social structures. It plays an active role in shaping ideologies and power relations.

METHODOLOGY

Research Design

This study adopts a qualitative research design, grounded in interpretive and critical paradigms. It seeks to explore the relationship between language ideology and power through textual and discourse-based analysis.

Data Sources

The study uses secondary data, including:

Educational materials (textbooks, policy documents)

Media texts (news articles, advertisements, television discourse)

Political speeches and public statements

Digital discourse (social media posts, blogs)

These sources are selected to represent key institutional domains where language ideologies are produced and circulated.

Data Analysis Method

The analysis follows Fairclough's three-dimensional model:

Textual Analysis:

Examining vocabulary, grammar, and rhetorical features to identify ideological patterns.

Discursive Practice:

Analyzing how texts are produced, distributed, and interpreted within specific contexts.

Social Practice:

Linking discourse to broader social structures, including power relations and institutional frameworks.

This multi-level analysis allows for a comprehensive understanding of how language ideology operates across different domains.

Sampling Technique

A purposive sampling method is used to select texts that are representative of dominant and marginalized language ideologies. The selection is based on relevance to the research questions and diversity of contexts.

Scope and Limitations

The study is limited to qualitative analysis and does not include quantitative data.

It focuses primarily on selected institutional domains rather than all aspects of society.

Interpretation of discourse may involve subjective analysis, though theoretical frameworks ensure rigor.

Language Ideology and Social Hierarchies

Language ideologies often reflect broader social hierarchies. The idea of a "standard language" is a prime example. Standardization is typically linked to nation-building, education, and governance. However, it also marginalizes regional dialects and minority languages. In many societies, speakers of the standard language are perceived as more educated, intelligent, and competent. Conversely, non-standard speakers are often stigmatized. This linguistic discrimination can lead to social exclusion and reduced opportunities. For instance, in multilingual countries like India, English often functions as a language of power. It is associated with higher education, corporate employment, and global mobility. Meanwhile, regional languages may be undervalued in formal domains. Such hierarchies demonstrate that language ideology is not merely about communication but about power and identity.

Language, Identity, and Inequality

Language is a key marker of identity. It reflects one's social background, ethnicity, and cultural affiliation. However, dominant language ideologies often impose normative standards that suppress linguistic diversity. Marginalized communities frequently experience linguistic insecurity. Their speech is labeled as "incorrect" or "inferior," leading to internalized stigma. This phenomenon has been documented in sociolinguistic studies (Labov, 1972). Language-based discrimination intersects with other forms of inequality, including class, race, and gender. For example, women's speech has historically been judged more harshly than men's, reflecting gendered power dynamics.



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Thus, language ideology contributes to the construction of social identities and the perpetuation of inequality.

Institutional Reinforcement of Language Ideologies

Education

Educational systems play a crucial role in reinforcing language ideologies. Standard language is often the medium of instruction and assessment. Students who do not possess this variety face disadvantages. Curriculum design may exclude minority languages, leading to their gradual erosion. Teachers may also unconsciously favor students who speak the standard language, reinforcing linguistic hierarchies.

Media

Media discourse shapes public perceptions of language. News anchors, television programs, and advertisements often promote standard language norms. Accents and dialects are sometimes used to stereotype characters, reinforcing social biases. Media also plays a role in legitimizing certain narratives while marginalizing others. Through repeated exposure, audiences internalize dominant language ideologies.

Political Discourse

Political language is a powerful tool for constructing reality. Politicians use rhetoric to shape public opinion and legitimize policies. Language can be used to include or exclude groups, often reflecting underlying power dynamics. For example, terms like “illegal immigrants” or “outsiders” carry ideological implications. Such language influences how individuals and groups are perceived and treated.

Language Ideology as Social Control

Language ideology functions as a subtle mechanism of social control. By defining what constitutes “correct” language, institutions regulate behavior and maintain order. This control is often internalized. Individuals modify their speech to conform to dominant norms, a process known as linguistic accommodation. While this may facilitate social mobility, it can also lead to the loss of linguistic identity. In this way, language ideology operates not through coercion but through consent, aligning with Foucault’s notion of power as pervasive and internalized.

Resistance and Linguistic Diversity

Despite the dominance of standard language ideologies, there are numerous instances of resistance. Marginalized communities often reclaim their linguistic identity as a form of empowerment. Movements promoting linguistic diversity emphasize the value of all language varieties. For example, the recognition of indigenous languages and dialects challenges dominant narratives. Digital media has also provided new spaces for linguistic expression. Social media platforms allow users to communicate in diverse languages and styles, challenging traditional norms. Such resistance highlights the dynamic nature of language ideology. It is not fixed but constantly negotiated and contested.

Implications for Language Policy

Understanding language ideology has important implications for policy-making. Inclusive language policies can promote linguistic diversity and social equity. Educational reforms should recognize the value of multilingualism. Incorporating students’ native languages into the classroom can enhance learning outcomes and cultural identity. Similarly, media and political institutions should adopt more inclusive language practices. This can help reduce linguistic discrimination and promote social cohesion.

FINDINGS AND DISCUSSION

The analysis of institutional discourse across education, media, and political domains reveals that language ideology operates as a powerful mechanism for structuring social hierarchies and maintaining unequal power relations. The findings are discussed thematically in relation to the research questions and theoretical framework.

Language as Symbolic Capital and Social Stratification

The study confirms Pierre Bourdieu’s (1991) assertion that language functions as symbolic capital. Standard language varieties—particularly English in the Indian context—are associated with prestige, authority, and access to socio-





economic opportunities. Individuals who possess proficiency in these varieties are more likely to succeed in education and employment. Conversely, speakers of regional languages or non-standard dialects are often marginalized. This reinforces social stratification, as linguistic competence becomes a criterion for inclusion or exclusion. The findings demonstrate that linguistic inequality is not merely cultural but deeply structural.

Institutional Reinforcement of Language Ideology

The study finds that institutions play a critical role in reproducing dominant language ideologies:

Education: Curriculum and assessment practices prioritize standard language norms, disadvantaging students from diverse linguistic backgrounds. Media: News and entertainment media reinforce stereotypes by associating certain accents with intelligence or authority. Politics: Political discourse strategically uses language to construct identities and influence public perception. These findings align with Norman Fairclough's (1995) view that discourse is both shaped by and shapes social structures. Language is not simply reflective but constitutive of power relations.

Discourse, Knowledge, and Power

From a Foucauldian perspective, the study demonstrates how discourse regulates knowledge and authority. Michel Foucault (1972) argues that power operates through discourse by defining what is "true" or "acceptable." For example, policy documents and media narratives often frame English as a "global necessity," thereby legitimizing its dominance. This discourse marginalizes other languages by positioning them as less valuable. Such narratives are internalized by individuals, shaping their linguistic preferences and aspirations.

Linguistic Inequality and Identity

The findings highlight that language ideology significantly impacts identity formation. Speakers of marginalized languages often experience linguistic insecurity and social stigma. This can lead to code-switching or language shift in an attempt to conform to dominant norms. At the same time, language serves as a marker of cultural identity. The suppression of linguistic diversity can result in the erosion of cultural heritage. This dual role of language—as both a tool of exclusion and identity—underscores its complexity.

Resistance and Emerging Linguistic Practices

Despite dominant ideologies, the study identifies various forms of resistance:

Use of regional languages in digital platforms

Revival of indigenous languages through cultural movements

Increased recognition of linguistic diversity in education

These practices challenge traditional hierarchies and promote inclusivity. Digital media, in particular, has created spaces where non-standard varieties gain visibility and legitimacy.

Case Studies (India-Focused Examples)

To contextualize the findings, the following case studies illustrate how language ideology operates within India.

English as a Gatekeeping Mechanism in Education

In India, English-medium education is often associated with quality and prestige. Access to English education is uneven, with urban and private institutions offering greater opportunities than rural or government schools. Students from non-English backgrounds face challenges in comprehension, participation, and assessment. This creates an educational divide that mirrors socio-economic inequalities. The preference for English reinforces its status as linguistic capital while marginalizing regional languages.

Linguistic Hierarchies in Media Representation

Indian media frequently portrays English-speaking individuals as modern, educated, and elite. In contrast, characters using regional dialects are often depicted as rural or less sophisticated. Such representations reinforce stereotypes and influence public perception. Media discourse thus plays a crucial role in shaping language ideology and sustaining social hierarchies.



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Language policy in India has long been a site of political contestation. Debates over the promotion of Hindi versus regional languages reflect deeper issues of identity and power. For example, resistance from southern states against the imposition of Hindi highlights the role of language in regional identity. These debates illustrate how language ideology intersects with politics and governance.

Digital Media and Linguistic Democratization

Social media platforms such as YouTube, Instagram, and X have enabled users to create content in multiple languages and dialects. This has led to the rise of regional influencers and content creators who challenge traditional language hierarchies. Digital discourse allows for greater linguistic experimentation and inclusivity, although inequalities still persist.

CONCLUSION

Language ideology plays a central role in shaping power relations within society. It influences how languages and their speakers are valued, often reinforcing existing inequalities. Through theoretical insights from Pierre Bourdieu, Michel Foucault, and Norman Fairclough, this paper has demonstrated how language functions as a mechanism of both domination and resistance. While dominant ideologies privilege certain language forms, marginalized communities continue to challenge these hierarchies. Recognizing and valuing linguistic diversity is essential for creating a more equitable society. Ultimately, language is not just a means of communication but a site of power, identity, and social transformation.

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RESEARCH ARTICLE

Nurturing Analytical Thinking Competence in the English Language Classroom: A PBL Instructional Model

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ABSTRACT

The research paper presents an instructional model designed for a module “Analytical Thinking Skills” as part of a course “Mastering Sustainable Skills,” which was conducted over a 4-month period for first-year engineering learners at a Tier I college located at the western part of Tamil Nadu, India. The module was structured within the Problem-Based Learning (PBL) instructional framework. The study explores the effectiveness of problem-based learning as a transformative pedagogical approach that nurtures analytical thinking skills in language learning contexts. The research delves into the comprehensive cultivation of analytical thinking skills in learners through diverse activities, tasks, problem scenarios and effective teaching strategies, with a pivotal focus on adapting PBL within the context of language acquisition. Ultimately, the article proposes the integration of PBL to facilitate the progress of analytical thinking skills within a carefully aligned language learning environment.

Keywords : Analytical Thinking, Language Learning, Problem-Based Learning Pedagogy, Transformative Education.

INTRODUCTION

The pursuit of holistic skill development has become the primary component within the scope of today’s engineering education. The integration of analytical thinking skills within language teaching practices has emerged as a



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foundational objective for a better learning experience. This amalgamation is further enriched when coupled with a problem-based learning pedagogy—a transformative approach that propels learners beyond repetitive memorization, encouraging active inquiry, collaboration, and practical application in their learning process. In today's ever-changing world, the ability to analyze information, solve complex problems, and make informed decisions is of immense importance. Kumar and Refaei restates the fact that, "The 21st century demands a new response to become productive contributors to society, where we must quickly master the learning innovations, technology, and career skills needed for work and life" (2017). This analytical thinking skill plays a crucial role in helping individuals navigate the challenges of a dynamic and rapidly evolving environment. As a result, there is a growing emphasis on equipping learners with the tools and techniques to enhance their analytical thinking abilities. This paper delves into the concept of cultivating analytical thinking and explores how it can be fostered through effective educational approaches like problem-based learning. By examining the key components of analytical thinking and its real-world applications, we aim to shed light on the significance of this skill and the systematized curriculum specifically designed for the purpose of cultivating critical thinking. Analytical thinking holds great significance. It involves proficiency in deconstructing intricate issues, critically evaluating data, and deducing sound conclusions. This capability has become increasingly indispensable in preparing learners for the demands of our rapidly evolving world. In this context, the English language classroom emerges as a vibrant arena where the amalgamation of pedagogical approaches and cognitive skill refinement can thrive harmoniously.

Analytical Thinking

Kek Megan & Henk Huijser mentioned that "Analytical thinking for the learners of higher education is important to prepare them for today's complex and rapidly changing world" (2011). The same has been widely accepted by scholars from different research fields. Analytical thinking is the ability to analyze, evaluate, and construct reasoned arguments and serves as the cognitive compass guiding learners through the maze of information that characterizes our interconnected world. When intertwined with language learning, it empowers learners to not only comprehend language structures but also to unravel the nuanced meanings embedded in communication. Through the lens of critical thinking, learners can deconstruct texts, question assumptions, and formulate interpretations that transcend the surface level, fostering deeper engagement with language content. Fadhlullah and Ahmad defines "Analys as critical thinking focused on parts and their functionality in the whole." (2017).

Analytical thinking holds immense significance for learners as it equips them with a multifaceted set of skills and abilities that extend far beyond the classroom. In this information era, building analytical skills and the ability to solve complex global problems is crucial for promoting deeper understanding, effective problem-solving, strong communication skills, cognitive flexibility, and informed decision-making in all areas of life. The learners need training to think in an organized, fair, and open-minded way. With these skills, learners can reason confidently and use critical thinking in any subject or field and be successful, said Lundquist (1999). In consolidation, analytical thinking is considered the essential key to lifelong learning and individual growth. It encourages learners to face and resolve the complexities of this current world by ensuring that they not only surpass in terms of education but also evolve as responsible individuals who can bring in a positive change in the society they live in.

Problem-based learning

The conventional teacher-centered paradigm is reinterpreted by putting the learners at the center of their learning process, where PBL fosters a sense of agency and curiosity in learners by exposing them to real-world problems, which forces them to tackle intricate issues that require multifaceted solutions. The PBL approach meets the demands of today's workplace, in which critical thinking and flexibility are considered as desirable traits in an employee. The combination of Problem-Based Learning (PBL) and Analytical Thinking is a much-desired pedagogical strategy that gets the most of both methods to produce an engaging and life-changing learning environment. This collaboration takes a comprehensive approach to teaching languages by fostering problem-solving abilities, contextual learning, autonomous learning, real-world application, and lifelong learning. According to Legg (2007), Problem-Based Learning (PBL) uses real-world problems as a starting point for acquiring and integrating new knowledge. This approach can be applied in university English classrooms to enhance teaching and learning (2007). It equips learners



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with language proficiency, cognitive flexibility, problem-solving prowess, and adaptability needed to thrive in an interconnected, complex world.

Bridging Analytical Thinking in the Language Learning Classroom

The development of analytical thinking has gathered significant attention in today's educational scenario. Within the scope of engineering education, Guerra and Holgaard (2016) propose translating critical thinking into tangible elements, integrating it into ongoing work through problem identification, analysis and formulation, inquiry, and argumentation to achieve the best outcomes. The acquisition of a new language involves mastering linguistic aspects and cultivating a deeper understanding of its structures, nuances, and cultural implications. Critical thinking, which involves the ability to break down complex ideas, evaluate information objectively, and draw well-reasoned conclusions, plays a key role in enriching the language learning process. When learners practice skills such as reading, writing, listening, and speaking, critical thinking enables them to examine the finer details of language, recognize patterns, and interpret meaning with accuracy. This, in turn, strengthens their overall language competence. While acquiring a language, critical thinking has numerous benefits. It refines the capacity for critical analysis of language use, enhances understanding, and enhances problem-solving capacities. Moreover, it makes communication more effective, supports learners' understanding of cultural environments, and enhances independent language research. These skills ultimately result in enhanced critical participation and intellectual adaptability, besides enhanced language competence.

LITERATURE REVIEW

As we delve into the literature surrounding problem-based learning and its interplay with analytical thinking, we uncover a rich mosaic of insights that illuminate the effectiveness of this pedagogical strategy. The study by Heilyn Camacho and Ellen Christiansen, 'Teaching Analytical Thinking Within an Institutionalized Problem-Based Learning Paradigm—Quite a Challenge,' examines a 'Professional Inquiry' course that was taught over four years to Information Studies learners at Aalborg University, Denmark, using the Problem-Based Learning (PBL) approach. It was identified that despite assuming that analytical thinking is integral to PBL, unexpected conflicts arose during the course, risking learners' development of critical reflection skills. It is also observed that time constraints and the need for personalized attention intimidate the learning process.

In this research paper, "The Problem-Based Learning in Enhancing Learners' Critical Thinking for Reading Skills in English Teaching at Vocational School," Iskandar and others focus on how Problem-Based Learning (PBL) was designed and implemented to teach English to vocational school learners in Indonesia. The goal was to enhance critical thinking skills through this approach. Both qualitative and quantitative methods were employed. The findings revealed that the PBL strategy's design was effective for teaching English as a foreign language in a vocational school setting. Consequently, this strategy could be adopted to boost critical thinking skills among vocational school learners learning English.

Megan Yih Chyn A. Kek and Henk Huijser's study aims to explore the essence of critical thinking, its skills, effective teaching methods, and the potential of PBL in teaching these skills. Ultimately, it reflects on how PBL can foster critical thinking as an aligned pedagogical approach within the learning and teaching environment.

Research Design

The design of this research paper outlines a part of a skill development credit course, "Mastering Sustainable Skills," conducted for the first-year engineering learners during the academic year 2024-2025. The structure of this research paper encompasses the module's objectives, instructional design, and assessment strategies. The prime objective of the module was to introduce and refine learners' learning approach towards critically dissecting and comprehending information. The classroom environment was optimized to accommodate two cohorts of batch sizes of 50 and 60 learners, respectively. This facilitated a tailored approach to instruction, catering to the unique dynamics of the



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different class strengths. To achieve this, the module was strategically curated over a comprehensive timeframe of 15 hours of classroom engagement, including workshops. During classroom instruction, important analytical thinking strategies like concept mapping, identifying fact or opinion, solving puzzles using guided clues, and finding solutions for problem scenarios were practiced, fostering an active learning environment as well as developing a critical thinking mindset.

Module Objectives and Instructional Plan

The primary aim of designing the “Analytical Thinking Skills” module was to hone learners’ ability to apply thinking and shift perspectives from basic concepts to deal with unique problem situations. The instructional plan of the module foregrounds the connection between the classroom engagement activities and the step flow of the essential analytical skill. The module underscores five classroom engagement activities that include determining whether the given scenario is fact or opinion, integrating the concept into a visual representation, devising innovative solutions for the problem scenario, employing deductive reasoning to solve puzzles, and critically evaluating the arguments with evidence.

Demonstration of Classroom Engagement Activities

In this section of the paper, the five classroom engagement activities that are aligned with problem situations and analytical thinking strategies are explained to show how each complements the other for the successful execution of the module.

Fact or Opinion

In this part of the module, learners are facilitated to differentiate between factual statements and opinionated expressions. The learners are taught to highlight key characteristics that help them evaluate facts and opinions. They are first introduced to a variety of statements, including an explanation. Learners should evaluate the statement and the explanation based on the evidence sourced from various resources like academic texts, news reports and articles, research papers, and everyday conversations. This helps them differentiate how facts are identified with the help of objective evidence, whereas opinion is based only on the subjective interpretation.

Example Statements:

Mark F for Fact; O for Opinion

Greenland is farther from the North Pole than the South Pole.

More than one-third of Earth’s surface is covered by oceans.

As discussed, the activity cultivates the learners’ ability to differentiate between verifiable facts and personal viewpoints. This process strengthens their capacity to assess information with a critical lens and provide evidential confirmation.

Concept Mapping

In this part of the activity, the learner is introduced to the technique of connecting concepts through organizing and comprehending information. This activity teaches the learners how intricate ideas can be simplified through concept maps for clearer interpretation. It is also emphasized that concept maps can help in showcasing the challenging concepts through visual aids. Learners are instructed to collaborate in small groups. And each group is assigned a topic. Learners create concept maps capturing key concepts and their interconnections. This hands-on activity helps the learners analyze underlying connections and helps visualize the concept in a very clear and creative way. After this phase, the learners are encouraged to exchange insights and reflect on each other’s interpretations, thereby promoting deep analytical thinking skills.

Problem-Solving Scenarios

In this session, the learners are facilitated to play a crucial role in analyzing a real-life scenario related to learners’ academic situations. Learners are presented with an outline of how the scenarios should be brainstormed, evaluated,



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and analyzed. This equips the learners to skillfully evaluate complex and challenging situations. In addition, the learners are encouraged to critically scrutinize each part of the scenario, from identifying the elements to the issues that demand solutions. The learners are expected to apply a case study model called the PACER framework, which includes identifying problems, alternative solutions, evaluating alternative solutions, and arriving at the best solution possible.

Example Scenario:

It is Friday, and you have a midterm exam on Wednesday. You just found out you have been scheduled to work all weekend, and you have class all day Monday and Tuesday? If you do not work this weekend, you risk the chance of getting fired, and you need this job. This is leaving you very little time to study. What should you do?

This activity is designed in such a way that learners are encouraged to do a collaborative activity, endorsing multiple perspectives. The initial phase of analysis involves analyzing the scenario and breaking it into manageable components, which directly leads to simplifying the complex problem. In the second part of the analysis, collective brainstorming brings a series of potential solutions. This reflects the practice of interpretation. In the evaluative process, the learners are challenged to assess the merits and drawbacks of alternative solutions. By evaluating pros and cons, learners apply analytical aptitude needed for evaluating resolutions. Eventually, learners reflect on the findings and potential solutions.

Puzzle-Solving with Clues

This section of the module introduces puzzle-solving as an activity to stimulate critical thinking. The learners are given some puzzle statements and clues that form the basis for sequential reasoning and analytical deduction. In this activity, learners team up to decode puzzles using provided clues. This collaborative approach demands the application of interpretative skill. While doing the activity, the learners discuss deductions and reasoning within their groups. This discussion brings an exchange of analytical insights and interpretations.

Analyze and Discuss

This section of the module prepares the learners to engage in a structured formal debate where opening statements, rebuttals, and closing arguments are encouraged. The learners are provided with a topic relevant to the learners' field of study, and they are guided to have a constructive discourse. During this structured session, learners are divided into affirmative and opposing sides, creating an environment for dynamic conversation. Learners are encouraged to prepare arguments based on their point of view, expecting them to critically assess the strengths and weaknesses of their arguments. This stage involves evaluating evidence, deducing logical reasons, and dissecting the possible assumptions. The learners are actively engaged in defending their arguments, which reflect the presence of analytical aptitude when evaluating and interpreting complex information.

Workshop I & II – Analytical Thinking Skills

The instructional plan of the module included two workshops, and each of the workshops focused on laying a strong knowledge required to interpret, analyze, and evaluate information. Workshop I, conducted for 2 hours, ensured that the learners captured the essence of important skills required for the application of analytical thinking skills. It served as groundwork before delving deeper into the subject matter. Then, Workshop II, conducted for 2 hours, took an advanced-level approach where the learners were equipped with the most important techniques and tools that foster critical thinking, intricate problem-solving, and incisive decision-making. Both the workshops supported the learners in understanding and imparting basic to advanced strategies that help navigate complex problem-solving scenarios and systematically apply analytical competencies.

The tabulation below provides a clear overview of the module, highlighting the objectives, activities, and allotted timeframes for each session.



**Hema et al.,****Assessment**

The assessment pattern for the module “Analytical Thinking Skills” included a wide-ranging evaluation method where learners’ overall competency and application of analytical and evaluative skills were considered. The evaluation was conducted by inviting an external assessor, and the learners were asked to prepare a presentation of the concept mapping. The evaluation criteria were designed in such a way that they supported measuring learners’ deeper understanding and application of analytical thinking skills. Firstly, the learners were expected to share an analysis of the past, present, and future aspects of the chosen topic, accounting for 15 marks. Secondly, the learners presented statistical trends, facts, and figures pertinent to the topic, contributing 10 marks. The quality of the assessment is extended furthermore when learners presented a qualitative discussion on factual elements, which attributed 15 marks. 10 marks were added to the fourth criterion when learners addressed challenging problems and provided potential solutions. Collectively, this assessment approach reinforces learners’ ability to engage in thorough analysis, critical evaluation, and articulate presentation, ultimately reflecting their mastery of analytical thinking and speaking skills.

RESULTS AND IMPLICATIONS

The findings of the research based on the instructional, implementation, and assessment plan resulted in the attainment of enhanced critical thinking skills among learners. It was found that the students were able to achieve a substantial average score of about 35 to 45 marks during the assessment process. Additionally, it was determined that the learners exhibited an average increase of 65% in the ability to analyze arguments and evaluate evidence. During the evaluation process, it was identified that learners showed a significant improvement in applying multiple perspectives to analyze the strengths and weaknesses within arguments. These outcomes indicate that the high contribution of the module’s classroom engagement activities, like concept mapping, discussion and debate, problem-solving scenarios, and collaborative puzzle-solving, supported nurturing analytical thinking abilities in learners. This process also implies that there is no limit or hindrance for planning and implementing any innovative andragogy to significantly impact the skill development in educational settings. Ultimately, the findings of the paper underscore the value of integrating active learning and problem-solving strategies that foster deeper analysis and interpretation skills, setting a model for elevating upcoming educational practices and empowering learners with integral and essential skills.

Challenges And Considerations

Though the process of preparing and implementing the module “Analytical Thinking Skills” through problem-based learning was an enjoyable, challenging as well as fruitful engagement, it has brought a lot of noteworthy challenges. A significant challenge was to engage heterogeneous group of learners having different learning styles. Time management was also another challenge where certain activities required more time than originally assigned. So, to address both these challenges, we refined our activities to engage the learners in a collaborative way to approach challenging concepts and introduced flexible time management strategies to cover the activities comprehensively. Another notable challenge was to set a clear balance between guiding and fostering independent thinking. Some learners felt overwhelmed by open-ended activities, so we provided structured support, gradually allowing them for autonomous learning. Yet another challenge was identified when the interdisciplinary nature of the learners needed familiar concepts and content. We resolved it by preparing examples to cater to learners’ individual academic backgrounds, thus ensuring modules’ logic. When the external evaluation process was an unbiased assessment perspective, the challenges showed up when aligning the assessment criteria with the module’s objectives. But the assessment ensured fair and accurate evaluation of learners’ analytical skills.

CONCLUSION

The research paper investigates the execution of a meticulously designed instructional module which aimed to enhance analytical thinking skills through problem-based learning within the English language classroom. The





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module's delivery plan, assessment technique and the learners' performance in the classroom demonstrated a substantial improvement in analyzing arguments, evaluating evidence, and learners showed an increased confidence while approaching problem concepts. Engagement strategies, such as concept mapping and collaborative activities, effectively nurtured analytical thinking. Overall, this study emphasized the value of active learning and innovative teaching approaches in enriching educational practices and empowering learners with vital cognitive skills.

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Table 1 Outline of the Module Sessions

Session	Topic	Objective	Activity	Duration
1	Fact or Opinion	Develop critical thinking by distinguishing between information and opinion.	Present statements for analysis to categorize them as fact or opinion.	1.5 hours
2	Workshop I	Build foundational knowledge in effectively analysing and interpreting information.	-	2 hours
3	Concept Mapping	Enable students to visually represent connections between ideas, enhancing analytical abilities.	Create concept maps on the specific core engineering topics.	2 hours
4	Problem-Solving Scenarios	Enhance analytical thinking through real-world problem-solving scenarios.	Breaking down complex scenarios into manageable components through systematic evaluation.	1.5 hours
5	Puzzle-Solving with Clues	Cultivate sequential thinking and critical reasoning skills through collaborative puzzle-solving.	Collaborative puzzle-solving with clues as a deductive reasoning exercise.	2 hours
6	Workshop II	Equip learners with advanced techniques and tools that foster critical thinking, intricate problem-solving, and judicious decision-making.	-	2 hours
7	Analyse and Discuss	Equip students with structured approaches to debates, fostering critical thinking skills.	Team-based debate on a current topic.	2 hours
8	Assessment	Critical analysis of any topic presenting in the form of a concept map.	-	2 hours

Table 2. Comprehensive View of the Assessment Criteria

Criteria	Points	Performance Indicators
Past, Present, and Future Analysis	15	Accurate, relevant, and logically connected perspectives across timeframes
Statistical Trends, Facts, and Figures	10	Uses credible, up-to-date data and interprets it correctly
Quality of Discussion on Factual Elements	15	Clear, logical discussion supported by reliable evidence
Addressing Challenges and Proposed Solutions	10	Identifies realistic challenges and offers practical solutions





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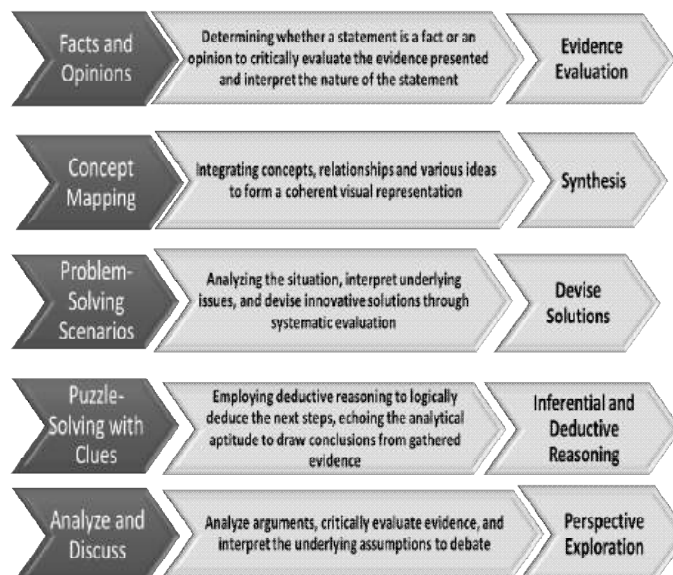


Fig. 1. Mapping of classroom engagement activities and attributes of analytical skills

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REVIEW ARTICLE

Financial Market Forecasting : A Systematic Review of Technical Indicators, Regime Detection, Time-Series Decomposition and Feature Engineering (2019 – 2025)

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ABSTRACT

Accurate financial forecasting is essential for investment decisions, risk management, and economic stability. However, the unpredictable and noisy nature of financial time series renders traditional models unreliable. This review examines 50 significant studies conducted between 2019 and 2025, highlighting the limitations of traditional technical indicators in dynamic market environments and demonstrating the superiority of adaptive methodologies. It further explores the utility of hidden Markov models and online techniques in real-time market change detection. Advanced methodologies, such as complete ensemble empirical mode decomposition (CEEMD) and wavelet transforms, have been employed to identify critical trends. The review discusses enhancing forecasting accuracy through feature engineering, including automated selection and data integration. The integration of multiple methods yields superior results compared to singular approaches, although challenges persist in comprehension, real-time application, and cross-market adaptability. There view under Scores the necessity for standard benchmarks, real-time integration, explain able artificial intelligence, cross-market adaptability, and resilience to market fluctuations. It lays the groundwork for developing improved forecasting systems to enhance investment decision- making and risk management. This review addresses four critical are astomitigate these issues: (1) the limitations of financial indicators, (2) market regime detection, (3) time-series decomposition, and (4) feature engineering for forecasting. There view involved comprehensive literature search, initially encompassing 555 papers, which was refined to 50 key studies from 2019 to



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2025. Key findings indicate that traditional indicators, such as moving averages and the relative strength index (RSI), perform inadequately during market changes. Hidden Markov models and online methods effectively detect market shifts but are not well integrated into forecasting systems. Decomposition techniques, such as CEEMD and wavelet transforms, facilitate the separation of trends from noise, thereby enhancing accuracy when combined with machine learning. Advanced feature engineering, including automated selection and data integration, improves model performance. The combination of diverse methods surpasses single approaches in terms of accuracy and prediction. The review identifies five research gaps: the absence of standard benchmarks, insufficient real-time regime integration, the need for explainable AI, limited cross-market application, and a lack of robustness to market changes. These findings emphasize the need for adaptive, efficient, and comprehensible forecasting systems tested across various markets and conditions.

Keywords: financial technical indicators; market regime detection; time-series decomposition; feature engineering; financial forecasting; machine learning; hybrid models; CEEMD; wavelet transform; Hidden Markov Models

INTRODUCTION

Context and Background

Predicting financial markets is a heavily researched challenge that lies at the intersection of economics, statistics, and computer science. These markets function as complex adaptive systems, marked by extreme non-stationarity, dynamics that depend on different regimes, and high sensitivity to external shocks. These characteristics collectively render accurate predictions extremely challenging, even with significant technological advancements (Chen et al., 2025). In recent decades, there has been a notable shift from traditional statistical models, such as auto-regressive integrated moving average (ARIMA) and generalized auto-regressive conditional heteroscedasticity (GARCH), to more advanced machine learning and deep learning frameworks, signifying a paradigm shift in the field. This evolution has enhanced forecasting accuracy and risk-adjusted performance, especially through hybrid and ensemble methods that combine various methodological approaches (Bukhari et al., 2020). The practical importance of this area extends from individual investment decisions to institutional risk management and the stability of the macroeconomic system (Xie et al., 2018). The incorporation of signal decomposition techniques, such as empirical mode decomposition (EMD) and wavelet transforms, into machine learning frameworks has shown particular promise in capturing the non-linear and non-stationary dynamics typical of financial time series (Zhu et al., 2016). Simultaneously, advancements in market regime detection have paved the way for condition-adaptive forecasting strategies that modify model behavior based on the current market state, representing a fundamental shift from static to dynamic modeling paradigms.

Research Problem and Identified Knowledge Gaps

Although progress has been made, significant obstacles persist in achieving reliable and broadly applicable financial forecasting. These challenges can be categorized into four interconnected areas. First, the reliance on fixed thresholds for technical indicators does not account for the ever-changing nature of financial markets, leading to high rates of false signals during periods of regime shifts and crises (Abir et al., 2025). Second, existing methods for detecting market regimes often struggle with complex, multidimensional, and path-dependent data, which hampers their effectiveness and precision in practical applications (Issa & Horvath, 2023). Third, there is a notable lack of systematic integration of time-series decomposition and dynamic feature engineering, which is crucial for enhancing predictive accuracy across diverse market conditions (Qin et al., 2025; Tsang & Chen, 2018). Finally, there is ongoing debate over the selection and combination of technical indicators, with research offering conflicting evidence on their



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predictive value and vulnerability to false signals (Xu et al., 2024). Consequently, many forecasting models remain suboptimal, exposing practitioners to increased financial risks and missed opportunities (Fozap, 2025).

Conceptual Framework

The theoretical framework supporting this review encompasses four distinct yet interrelated methodological areas:

- Financial technical indicators, which offer quantitative assessments of market momentum, trends, and volatility;
- Market regime detection techniques, which pin point structural shifts in market behavior;
- Time-series decomposition methods, which differentiate meaningful signal components from noise; and
- Feature engineering strategies, which convert raw and decomposed data into valuable inputs for machine learning models. Feature engineering serves as the crucial link that unites these areas by leveraging complementary information from indicators, regime states, and decomposed components within a cohesive predictive framework (Padhi et al., 2022).

Objectives and Scope

This systematic review offers a critical analysis of the current research landscape across all four domains and their intersections. Specifically, this review is as follows:

- This study assesses the effectiveness and limitations of both traditional and adaptive financial technical indicators under various market conditions, asset classes, and volatility regimes.
- Benchmarks techniques for detecting market regimes in terms of adaptability, computational efficiency, and accuracy in volatile settings.
- Evaluate the influence of time-series decomposition methods on the quality of trend extraction, informativeness of features, and accuracy of subsequent forecasts.
- This study compares different feature engineering strategies and their integration with machine learning and deep learning frameworks.
- Identifies hybrid modeling frameworks that effectively combine multiple methodological components and examines their relative performance benefits.

This review focuses on peer-reviewed empirical studies and high-quality preprints published between 2019 and 2025 to ensure relevance to the evolving field of computational finance.

Methodology of Literature Selection

This review utilized a systematic and transparent multistage approach to guarantee comprehensive coverage and in-depth analysis. The entire procedure is outlined in Table 1 and elaborated in the following sections.

Query Transformation and Search Strategy

The central research question, which involves financial technical indicators and their constraints, methods for detecting market regimes, time-series decomposition and trend extraction, and feature engineering for financial forecasting, is divided methodically into three related search queries. The first query addressed all four thematic areas simultaneously. The second focused on studies that combined machine learning with technical indicators and feature extraction to predict prices. The third concentrated on studies that integrated multiple data sources and merged alternative data streams with technical indicators for forecasting and trend detection.

Paper Screening and Inclusion/Exclusion Criteria

Searches were conducted using an extensive academic literature database. Papers were selected if they:

1. Focused on at least one fundamental thematic area.
2. Included empirical analysis or made a significant methodological contribution.
3. Used financial market data.



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4. Were peer-reviewed publications or high-quality preprints that adhered to standards of methodological transparency.
5. Provided sufficient methodological detail for critical assessment and comparison across studies.

Papers were excluded if they:

1. Were published in languages other than English.
2. Were published before 2019 or after 2025.
3. Dealt with financial forecasting solely in non-market contexts (e.g., macroeconomic forecasting without application to asset prices).
4. Lacked empirical validation or were purely theoretical without computational experiments.
5. Were duplicate publications or extended versions of conference papers already included in the corpus.

Citation Chaining

To ensure that foundational works not captured in primary database searches were included, a systematic citation chaining process was applied to highly relevant papers identified during the initial screening. This involved both forward citation analysis, which identifies papers citing key works, and backward citation analysis, which examines the reference lists of key papers. As a result, **90 additional relevant papers** were identified, increasing the total number of candidate papers to **555**.

Relevance Scoring and Final Selection

All **555** candidate papers underwent structured relevance scoring based on six criteria:

- Direct relevance to the review objectives.
- Methodological rigor and innovation.
- Quality of empirical contribution.
- Citation impact.
- Publication venue prestige.
- Recency.

This evaluation identified **50 papers** that met the inclusion threshold in the primary synthesis corpus. The stratified approach ensured the efficient allocation of analytical effort while maintaining comprehensive coverage of the research landscape.

Limitations of the Search Process

This review identified several methodological constraints. The focus on publications from **2019 to 2025** excludes earlier foundational work, and limiting the review to **English-language** sources may overlook significant contributions from non-English research communities.

Instead of a quantitative meta-analysis, a narrative approach was used because of the variability in reported metrics across studies, which prevents formal statistical aggregation. Additionally, publication bias, in which journals tend to favor positive outcomes, may exaggerate the perceived benefits of advanced methods. These limitations should be considered when interpreting the synthesized findings.

THEMATIC REVIEW OF LITERATURE**Financial Technical Indicators and Their Limitations****Static versus Adaptive Technical Indicators**

For many years, traditional technical indicators, such as simple moving averages (SMA), exponential moving averages (EMA), relative strength index (RSI), moving average convergence divergence (MACD), and Bollinger Bands, have been essential tools in algorithmic trading. However, a significant issue highlighted in the literature is that while these indicators work well in stable markets, their performance declines significantly during market regime changes and crises (Deep et al., 2025; Demir et al., 2019; Loubaris, 2025).

Loubaris (2025) provided empirical evidence of this issue by examining the performance of RSI and MACD across various equity indices during the COVID-19 market shock. The study found a notable increase in false buy signals



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and MACD crossover failures during the crisis compared to stable periods, challenging the assumption of temporal stationarity in fixed-parameter indicator configurations. Maddodi and Kunte (2024) demonstrated through a comparative analysis across equity markets under geopolitical stress that optimal indicator thresholds differ systematically across market conditions and that applying thresholds calibrated for one period to another can substantially reduce directional accuracy (Maddodi & Kunte, 2024; Rosillo et al., 2013). Applying thresholds calibrated for one market to another can significantly reduce directional accuracy, sometimes to below-random levels.

Ghanbari et al. (2024) further explored this market specificity in cryptocurrency markets, demonstrating that portfolio-level optimization under varying market conditions requires adaptive parameter selection rather than fixed configurations (Ghanbari et al., 2024). Peng et al. (2023) advanced the field by proposing Bayesian-optimized adaptive thresholds that dynamically adjust in response to detected regime shifts. Their trading algorithm, tested on major currency pairs over several years, showed improved returns and reduced drawdowns compared to static indicator baselines, maintaining relative performance stability during the 2020 market crisis when static-threshold benchmarks suffered significant losses. The method's reliance on Hidden Markov Model (HMM) regime detection introduces operational latency before updating indicator thresholds. Singh (2025) attempted to address this limitation with an LSTM-based regime prediction, although it resulted in higher false regime classifications compared to the HMM baseline.

Integration of Technical Indicators with Machine Learning

Another line of research explores whether machine-learning models can derive predictive insights from technical indicators more effectively than traditional rule-based threshold methods. The reviewed literature consistently indicates that the success of indicator-based machine-learning features depends heavily on the quality of feature engineering. Studies that used raw indicator values as direct inputs for models showed only slight accuracy improvements over threshold-based rules. In contrast, those that incorporated engineered derivatives—such as the rate of change, divergence metrics, and interactions between indicators—achieved significantly greater gains.

The most notable improvements were found in studies that combined engineered features with regime-specific indicator values. This suggests that raw indicators alone do not provide sufficient information for significant machine-learning advancements; however, well-constructed features can reveal hidden predictive potential (Jadhav & Chandre, 2025).

Patil et al. (2024), in their study on predicting foreign exchange volatility, discovered that ensemble methods (XGBoost and Random Forest) gained more from technical indicator features than deep-learning models (Long Short-Term Memory and Convolutional Neural Network). The authors attributed this to the ability of tree-based ensembles to capture indicator threshold effects and regime interactions through recursive partitioning, whereas Long Short-Term Memory models faced challenges with the noise-to-signal ratio in raw indicator series without extensive preprocessing.

Market Regime Detection Techniques**Hidden Markov Models and Statistical Approaches**

Market regime detection addresses the well-documented phenomenon whereby financial markets exhibit distinct behavioral states, each characterized by unique levels of volatility, return patterns, and cross-asset correlation structures. Hidden Markov Models (HMMs) are considered the most theoretically sound statistical method for identifying these regimes, treating market states as hidden discrete variables with observable continuous outputs. In their adaptive trading framework, Peng et al. (2023) utilized a three-state HMM-based regime detection approach to identify bull, bear, and transitional regimes, showing that strategies informed by regime awareness can significantly lower risk exposure while still achieving returns comparable to static strategies.



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Traditional HMM methods encounter two major operational challenges: instability in parameter estimation in high-dimensional contexts and sensitivity to initial conditions, which can lead to inconsistent regime classifications across different model runs. This issue is particularly critical in live trading scenarios.

Non-Parametric and Machine Learning Methods

Rezaei et al. (2020) presented a non-parametric method for online detection that addresses several drawbacks of traditional HMM methods. Their automated system detects regime shifts in high-dimensional financial data by employing path-wise similarity metrics and clustering techniques, functioning in real time without requiring parametric distribution assumptions or manual regime labeling. Empirical tests across various asset classes showed improvements in both the speed and precision of regime-change detection compared with standard HMM models, making this method particularly suitable for operational forecasting systems. Supervised machine-learning techniques, such as Support Vector Machines (SVM), Random Forests, and Recurrent Neural Networks (RNNs), are increasingly being utilized to identify market regimes. These techniques can capture complex nonlinear regime boundaries while simultaneously integrating multiple market variables. However, their primary drawback is the requirement for labeled training data, which can introduce subjectivity in regime definitions and potential look-ahead bias when historical data are retrospectively labeled.

Time-Series Decomposition and Trend Extraction**Empirical Mode Decomposition Methods**

Time-series decomposition is designed to break down financial series into analytically manageable components, such as trends, cyclical patterns, and random noise, allowing forecasting models to work with more stable and predictable subsignals. Leung and Zhao (2021) thoroughly examined the use of Complete Ensemble Empirical Mode Decomposition with Adaptive Noise (CEEMDAN) in conjunction with the Hilbert–Huang Transform (HHT) for non-stationary financial series. Their findings indicated that CEEMDAN efficiently separates intrinsic mode functions (IMFs) across various time scales, and the instantaneous frequency features generated by HHT significantly enhance the accuracy of machine-learning forecasts compared to undecomposed input data across several equity market datasets. Nasir et al. (2025) introduced a hybrid framework combining Local Mean Decomposition (LMD), Autoregressive Moving Average (ARIMA), and Extreme Gradient Boosting (XGBoost), which separates stochastic and deterministic components while addressing the mode-mixing issue found in standard Empirical Mode Decomposition (EMD). This hybrid model showed superior forecasting accuracy compared to baseline ARIMA and standalone machine-learning methods, particularly for medium-term prediction horizons.

Wavelet Decomposition Approaches

Wavelet decomposition offers a multi-resolution analysis framework that is particularly effective for financial time series with localized features and non-stationary volatility clustering. Unlike methods based on Empirical Mode Decomposition (EMD), wavelet decomposition operates within a mathematically rigorous framework with well-established theoretical convergence properties. Verma et al. (2024) developed a multi-stage feature engineering pipeline that combines the Discrete Wavelet Transform (DWT) with hyperparameter-optimized ensemble models, showing that DWT-based decomposition enhances prediction accuracy by maintaining structural signal characteristics while eliminating noise components. Palma et al. (2025) utilized Gaussian Mixture Models (GMMs) on components derived from EMD to predict asset price movements, capitalizing on the complementary strengths of adaptive decomposition and probabilistic modeling. Their integrated approach demonstrated improved directional prediction performance under regime-dependent conditions. The research also highlighted that selecting the optimal decomposition method depends on the forecasting context, including the prediction horizon and market characteristics, requiring systematic evaluation rather than a one-size-fits-all application.

Feature Engineering for Financial Forecasting**Automated Feature Selection Methods**

Feature engineering plays a pivotal role in determining the effectiveness of forecasting models, often having a greater influence than the choice of model architecture when models are evaluated with the same level of feature complexity.



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Pabuccu and Barbu (2024) introduced Feature Selection with Annealing (FSA), an algorithm designed to reduce dimensionality while maintaining predictive accuracy by utilizing simulated annealing optimization within the feature-selection search space. Through empirical testing on various financial time series, FSA consistently identified stable feature subsets that delivered strong out-of-sample performance, surpassing traditional forward-selection and backward-elimination methods (Pabuccu & Barbu, 2024). In 2025, Qin et al. proposed a dual-layer Mamba architecture with convolutional feed-forward networks for efficient financial time-series forecasting, demonstrating that architectural innovation in feature processing can substantially improve prediction efficiency while maintaining accuracy under volatile conditions (Qin et al., 2025). This approach effectively addresses heteroscedasticity in financial return distributions while ensuring computational efficiency, particularly under volatile market conditions where well-calibrated prediction intervals are crucial for risk management.

Dimensionality Reduction and Feature Transformation

Sarıkoç and Celik (2024) developed a hybrid framework that sequentially applies Principal Component Analysis (PCA) and Independent Component Analysis (ICA) for dimensionality reduction. This process is conducted before the transformed features are input into Long Short-Term Memory (LSTM) networks to predict the S&P 500 Index. Their study demonstrates that effective dimensionality reduction can enhance prediction accuracy by eliminating redundant data while retaining crucial market dynamics. The combined method outperformed models that utilized raw features or relied solely on single-stage decomposition. Singh (2025) performed a comparative study of tree-based ensemble models and deep-learning approaches for forecasting equity prices. The study highlighted that although dimensionality reduction improves computational efficiency and mitigates overfitting, it is essential to validate that significant trading signals are not mistakenly discarded as low-variance components during compression. This balance between information compression and signal preservation remains an important methodological challenge (Gong et al., 2025).

Integration of Heterogeneous Data Sources

Recent studies have increasingly focused on incorporating alternative data sources beyond conventional price and volume metrics. Ji et al. (2022) demonstrated that integrating macroeconomic indicators, sentiment data derived from news and social media, and cross-asset relationship features can significantly improve forecasting accuracy. However, incorporating alternative data introduces several methodological challenges, including differing update frequencies, asynchronous timing relationships, propagation of measurement errors, and an increased risk of spurious correlations in high-dimensional feature spaces. Effective integration therefore requires careful feature engineering, appropriate handling of missing data, and rigorous holdout validation. Htun et al. (2023) emphasized the importance of domain knowledge in developing theoretically grounded features that capture meaningful economic relationships. Their study showed that combining data-driven feature selection with expert-guided feature design produces more robust and interpretable forecasting models than relying solely on automated methods. This hybrid approach offers a practical balance between statistical efficiency and economic interpretability.

Identification Of Research Gaps And Future Directions

This review highlights five significant research gaps that present both theoretical and practical challenges, thereby limiting the effective application of advanced forecasting frameworks in real-world financial markets. These gaps, along with the corresponding future research directions, are summarized in Table 3.

Absence of Standardised Benchmarks for Decomposition Methods

Although individual decomposition techniques, such as CEEMD, VMD, DWT, and LMD, have been assessed independently in various studies, there is no standardized benchmark framework for systematically comparing these methods across different markets and prediction timeframes. The lack of a unified framework hinders the objective determination of the most effective methods for particular market scenarios or forecasting goals, resulting in fragmented empirical evidence in this field. Establishing community-standard benchmark datasets and evaluation protocols similar to the shared benchmarks found in computer vision and natural language processing would



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significantly enhance methodological advancement and improve reproducibility (Palma et al., 2025; Bareket & Parv, 2024).

Real-Time Integration of Regime Detection

Most research on forecasting accuracy has evaluated performance through historical backtesting using *ex post* knowledge of regime shifts and market conditions. However, real-time implementation encounters substantially different challenges, including computational latency, delays in data availability, lag in regime-change detection, and the need for continuous model updates. The discrepancy between backtested results and actual trading performance has not been well quantified in the existing literature (Issa & Horvath, 2023). There is an urgent need for research on computationally efficient online algorithms, robust evaluation frameworks that account for realistic operational constraints, and techniques for handling streaming data with varying latency.

Explainability of Complex Hybrid Models

As forecasting models become increasingly sophisticated through the integration of hybrid methods and deep learning, their interpretability correspondingly decreases. This creates two major challenges. First, regulatory compliance, as outlined by frameworks such as the EU AI Act and financial supervisory model risk management guidelines, requires transparent explanations for model decisions. Second, financial practitioners need to understand the reasoning behind model predictions to support informed risk-management decisions. Current research provides limited guidance on preserving interpretability while employing advanced ensemble and neural network architectures (Bisdoulis, 2024; Singh, 2025). Developing explainable artificial intelligence (XAI) techniques specifically designed for financial forecasting—such as SHAP-based regime attribution, wavelet saliency mapping, and indicator causal graph estimation—remains a critical research priority.

Cross-Market and Cross-Asset Generalisation

Most reviewed studies focused on major developed equity indices or individual currency pairs, while only a limited number examined transferability across different markets (Tufekci & Abul, 2020). Models optimized for a specific market frequently underperform when applied to other markets or asset classes unless extensive recalibration is performed. This limitation presents a major challenge for multi-asset portfolio management and global trading strategies. Future research should focus on developing transfer-learning methods that facilitate knowledge transfer across markets, designing meta-learning frameworks capable of rapidly adapting to new environments, and identifying universal feature sets validated across diverse financial instruments.

Robustness to Market Microstructure Evolution

Financial markets continually undergo structural transformation due to regulatory changes, technological advances such as algorithmic and high-frequency trading, and evolving market participant behavior. Forecasting models trained on historical data may systematically fail following significant changes in market microstructure, even when they demonstrate strong backtesting performance (Loubaris, 2025). Future research should therefore emphasize continuous-learning frameworks that incorporate automated structural-break detection, model-update triggers, and microstructure-robust features that remain stable despite changes in the execution environment.

CONCLUSIONS**Summary of Key Findings**

This systematic review synthesized evidence from **50 highly relevant studies** selected from an initial pool of **555 candidate papers**, covering four interconnected methodological domains: financial technical indicators, market regime detection, time-series decomposition, and feature engineering for financial forecasting.

The major findings are summarized as follows.



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First, traditional static technical indicators, including the Relative Strength Index (RSI) and Moving Average Convergence Divergence (MACD), exhibit performance that is highly dependent on market conditions, with effectiveness declining significantly during market regime shifts and financial crises (Loubaris, 2025; Peng et al., 2023). In contrast, adaptive methods incorporating dynamic threshold optimization and regime-specific parameterization demonstrate substantially greater robustness. Second, market regime detection techniques, particularly Hidden Markov Model (HMM)-based approaches and non-parametric online detection methods (Issa & Horvath, 2023), accurately identify distinct market states but remain underutilized in operational forecasting systems.

Third, time-series decomposition techniques such as Complete Ensemble Empirical Mode Decomposition (CEEMD), Discrete Wavelet Transform (DWT), and Local Mean Decomposition (LMD) effectively separate trend signals from noise, substantially improving feature quality for subsequent machine-learning models (Leung & Zhao, 2021; Nasir et al., 2025; Verma et al., 2024). Fourth, advanced feature engineering techniques—including multi-stage feature selection, dimensionality reduction, and heterogeneous data integration—consistently improve predictive performance and model generalizability (Pabuccu & Barbu, 2024; Singh, 2025; Htun et al., 2023). Finally, hybrid forecasting frameworks that integrate all four methodological components consistently outperform single-method approaches in terms of predictive accuracy, directional forecasting, and risk-adjusted performance, although they also introduce greater computational complexity and reduced interpretability.

Theoretical and Practical Implications

From a theoretical perspective, this review supports a paradigm shift in financial forecasting from isolated single-method models toward integrated hybrid systems that combine technical indicators, market regime detection, signal decomposition, and advanced feature engineering.

The consistently superior performance of these integrated approaches demonstrates the limitations of relying solely on individual modeling techniques in complex, non-stationary financial environments.

From a practical perspective, the findings suggest that financial practitioners should:

1. Transition from static indicator settings to adaptive, regime-specific parameterization.
2. Incorporate real-time market regime detection into dynamic risk-management frameworks.
3. Standardize time-series decomposition as a preprocessing step for trend-sensitive forecasting tasks.
4. Invest in robust feature-engineering strategies that combine automated feature selection with domain expertise.
5. Employ rigorous out-of-sample validation methods, including walk-forward analysis and stress testing during crisis periods.

Limitations of This Review

This review has several limitations.

The selected publication period (2019–2025) excludes earlier foundational studies. Rather than conducting a quantitative meta-analysis, the review adopted a narrative synthesis because of substantial variation in evaluation metrics across studies, preventing formal statistical aggregation. Publication bias may also have resulted in an overestimation of the effectiveness of advanced hybrid forecasting methods. Furthermore, the review was limited to English-language publications indexed in academic databases, potentially excluding valuable contributions from practitioner literature and research published in other languages. These limitations should be considered when interpreting the findings presented in this review.

Concluding Remarks

Financial market forecasting remains an exceptionally challenging research domain because of the non-stationary nature of financial data, market regime dependence, and continuous structural evolution.

Although perfect prediction is theoretically unattainable under the Efficient Market Hypothesis, the systematic integration of technical indicators, market regime detection, time-series decomposition, and advanced feature engineering within adaptive hybrid frameworks provides a promising pathway for improving forecasting accuracy,





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robustness, and operational reliability. This review establishes a comprehensive foundation for advancing both the theoretical understanding and practical implementation of next-generation financial forecasting systems, with the broader objective of supporting more informed investment decisions and enhancing overall market efficiency.

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Table 1: Literature Search and Selection Methodology Summary

Stage	Process	Outcome
Query Transformation	The primary research question was systematically expanded into three complementary search queries covering technical indicators, regime detection, time-series decomposition, and feature engineering.	A comprehensive and targeted query set ensuring broad thematic coverage.
Database Search	Queries were executed across a large-scale academic database with inclusion filters applied: 2019–2025 publication period, English language, and peer-reviewed or high-quality preprint sources.	465 candidate papers retrieved.
Citation Chaining	Forward citation analysis (papers citing key studies) and backward citation analysis (reference lists of key studies) were conducted on high-relevance papers.	90 additional papers identified; total candidate pool expanded to 555 papers.





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Relevance Scoring	All 555 papers were evaluated based on thematic relevance, methodological rigour, empirical contribution quality, citation impact, venue prestige, and recency.	50 high-relevance papers selected for full synthesis.
Thematic Synthesis	Selected papers were categorised across four research domains; cross-domain themes, contradictions, and synergies were identified through narrative synthesis.	Integrated findings, research gap analysis, and future research directions developed.

Table 2. Comparative Analysis of Key Studies Across Research Dimensions

Study	Indicator Robustness	Regime Detection	Decomposition Method	Feature Engineering	Key Findings
Peng et al. (2023)	Adaptive regime-conditioned thresholds via Bayesian optimisation	Three-state HMM identifying bull, bear, and transitional regimes	Not primary focus	Bayesian threshold optimisation conditioned on detected regime	Regime-aware adaptive trading demonstrated improved returns and reduced drawdown compared with static-threshold baselines on major forex pairs.
Loubaris (2025)	Documented substantial degradation of RSI and MACD signal quality during the COVID-19 market shock	Not addressed	Not addressed	Analysis of indicator correlation structure under market stress	Provided empirical evidence that traditional technical indicators generated systematically elevated false signals during crisis periods.
Issa & Horvath (2023)	Not primary focus	Novel non-parametric online detection using path-wise similarity metrics and clustering; operates in real time without distributional assumptions	Not addressed	Path-wise similarity metrics for regime clustering	Automated pipeline demonstrated superior speed and accuracy of regime-change detection compared with conventional HMM implementations.
Leung & Zhao (2021)	Not primary focus	Not addressed	CEEMD combined with Hilbert–Huang Transform (HHT) for multi-scale decomposition of non-stationary series	HHT-generated instantaneous frequency features for machine learning forecasting	HHT-enhanced feature sets substantially improved machine learning forecasting accuracy relative to undecomposed baselines.
Verma et al. (2024)	Not primary focus	Not addressed	Discrete Wavelet Transform (DWT) for multi-resolution noise	Multi-stage feature engineering pipeline with hyperparameter-	DWT-based decomposition improved prediction accuracy by





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			reduction	optimised ensemble models	preserving signal structure while reducing noise in equity and index data.
Patil et al. (2024)	Adaptive volatility-regime parameter adjustment for technical indicators	Implicit via volatility regime identification	Not primary focus	Technical indicator integration with ensemble machine learning (XGBoost, Random Forest, LSTM, CNN)	Ensemble tree-based methods benefited more from indicator features than deep learning architectures, attributed to the threshold-capturing ability of recursive partitioning.
Pabuccu & Barbu (2024)	Not primary focus	Not addressed	Not primary focus	Feature Selection with Annealing (FSA): simulated annealing for dimensionality reduction	FSA consistently identified stable, generalisable feature subsets outperforming forward and backward selection across multiple financial time series.
Palma et al. (2025)	Not primary focus	Probabilistic state modelling via Gaussian Mixture Models on decomposed components	Empirical Mode Decomposition (EMD) combined with Gaussian Mixture Models	Regime-specific feature construction from decomposed components	Integrated decomposition–GMM approach enhanced directional prediction, particularly under regime-dependent volatile conditions.
Zhao & Guo (2024)	Integrated within hybrid framework	Implicit via decomposition component analysis	Ensemble-combined multi-method decomposition	Advanced feature selection and transformation pipeline	Hybrid integrative framework consistently outperformed single-method approaches across multiple accuracy and directional prediction metrics.

Note. This table synthesizes the primary methodological contributions and key findings of representative studies across all four thematic domains. *Not primary focus* denotes that a domain was not the central concern of the study, rather than indicating that it was absent.





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Table 3. Research Gaps and Recommended Future Directions

Research Gap	Current State	Recommended Future Direction
Standardised Benchmarks	No unified evaluation framework exists for comparing decomposition methods (CEEMD, VMD, DWT, LMD) across markets, asset classes, and forecasting horizons.	Develop community-standard benchmark datasets and evaluation protocols covering diverse markets, forecasting horizons, and crisis periods, analogous to shared benchmarks in computer vision.
Real-Time Regime Integration	Regime detection is predominantly evaluated retrospectively; live integration with operational forecasting pipelines remains critically under-explored and unquantified.	Design computationally efficient online algorithms and explicitly quantify the performance gap between backtested results and live deployment under realistic latency constraints.
Explainable AI for Hybrid Models	Complex hybrid architectures (ensemble models + deep learning + decomposition techniques) lack interpretability mechanisms compatible with financial regulatory requirements.	Develop XAI toolkits tailored to financial forecasting, including SHAP-based regime attribution, wavelet saliency mapping, and indicator-based causal graph estimation.
Cross-Market Generalisation	Most studies focus on major developed equity indices; transferability to forex, cryptocurrency, and emerging markets requires substantial recalibration.	Investigate meta-learning and domain adaptation approaches; construct and validate universal feature sets across diverse asset classes and market structures.
Microstructure Robustness	Models trained on historical data degrade when market microstructure evolves due to regulatory changes, algorithmic trading growth, or shifts in participant composition.	Develop continual learning frameworks with automated structural-break detection and model-refresh triggers that remain robust to changing execution environments.

Source: Authors' synthesis of the reviewed literature.

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RESEARCH ARTICLE

Regular Dominating Sets and Regular Domination Polynomials of Line Graph of Path

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ABSTRACT

Let $G = (V, E)$ be a simple graph. A dominating set R is a regular dominating set of G if each vertex in $R \subseteq V(G)$ has the same degree. Let $L(P_n)$ be the line graph of a path with $n - 1$ vertices and $n - 2$ edges. Let $D_R(L(P_n), i)$ be the family of all regular dominating sets with cardinality i of $L(P_n)$. Let $d_R(L(P_n), i) = |D_R(L(P_n), i)|$. In this paper, we obtain recursive formula for $d_R(L(P_n), i)$. Using this recursive formula, we construct the polynomial, $D_R(L(P_n), x) = \sum_{i=\gamma_R(L(P_n))}^{n-1} d_R(L(P_n), i) x^i$, where $\gamma_R(L(P_n))$ is the regular domination number of P_n , which we call regular domination polynomial of $L(P_n)$ and also obtain some properties of this polynomials. where $\gamma_R(G)$ is the regular domination number of G .

Keywords: Regular Domination Set, Regular Domination Polynomial





INTRODUCTION

Let $G = (V, E)$ be a simple graph. For any vertex $v \in V$, the open neighbourhood of v is the set $N(v) = \{u \in V : uv \in E\}$ and the closed neighbourhood of v is the set $N[v] = N(v) \cup \{v\}$. For a set $D \subseteq V$, the open neighbourhood of S is $N(D) = \bigcup_{v \in D} N(v)$ and the closed neighbourhood of D is $N[D] = N(D) \cup D$. A set $D \subseteq V$ is a dominating set of G , if $N[D] = V$, or equivalently every vertex in $V \setminus D$ is adjacent to at least one vertex in D . If D is a dominating set of a graph G and each vertex in D has the same degree, then D is said to be a regular dominating set of G . Regular domination number $\gamma_R(G)$ of graph G is defined as the minimum among all regular dominating sets. In 2021, Prabakaran et al. [1] described regular dominating set and regular dominating number $\gamma_R(G)$ in fuzzy graph and studied various properties and bounds of regular domination number in several fuzzy graphs. In 2024, Jothi Rani and Seema Mehra[2] described regular domination number of some simple, connected, and undirected graphs as well as the join and corona of two graphs. Inspiring by this idea, we assess the regular domination polynomial of $L(P_n)$.

Preliminaries

Definition 2.1 [1] Let G be a graph, a set $R \subseteq V(G)$ is supposed to be a regular dominating set of G if i) Each vertex $u \in V(G) - R$ is adjacent to some vertex in R .

ii) Each vertex in $R \subseteq V(G)$ has the same degree.

Definition 2.2[4] The Line graph of a graph G , denoted by $L(G)$, is a graph whose vertices are the edges of G , and if $u, v \in E(G)$ then $uv \in E(L(G))$ if u and v share a vertex in G .

Regular Dominating Sets of $L(P_n)$

Example 3.1 Let us consider $L(P_6)$ as an example.

Here, $V = \{v_1, v_2, v_3, v_4, v_5\}$ and $\deg(v_1) = \deg(v_5) = 1$ and $\deg(v_3) = 2$, if we take $R = \{v_1, v_3, v_5\}$. This set is not a regular dominating set, since $\deg(v_3) \neq \deg(v_1)$. Therefore $R = \{v_2, v_4\}$ is a regular dominating set, since $\deg(v_2) = \deg(v_4)$ and this vertex dominate all vertices in $V - R$.

Lemma 3.2 Let $L(P_n)$, $n \geq 6$ be the line graph of path P_n with $n - 1$ vertices and $n - 2$ edges. Then its regular domination number is $\gamma_R(L(P_n)) = \left\lceil \frac{n}{3} \right\rceil$.

Lemma 3.3 Let $L(P_n)$ be the line graph of path P_n , $n \geq 6$. Then $D_R(L(P_n), i) = \emptyset$ if and only if $i < \left\lceil \frac{n}{3} \right\rceil$ or $i > n - 3$ and $D_R(L(P_n), i) \neq \emptyset$ if $\left\lceil \frac{n}{3} \right\rceil \leq i \leq n - 3$.

Proof. Since the minimum cardinality of the regular dominating set of $L(P_n)$ is $\left\lceil \frac{n}{3} \right\rceil$. If $i < \left\lceil \frac{n}{3} \right\rceil$ or $i > n - 3$ then there is no regular dominating set of cardinality i . Therefore, $D_R(L(P_n), i) = \emptyset$ and $D_R(L(P_n), i) \neq \emptyset$ if $\left\lceil \frac{n}{3} \right\rceil \leq i \leq n - 3$.

Lemma 3.4 If $X \in d_R(L(P_{n-1}), i - 1)$ then $X \cup \{v_{n-2}\} \in d_R(L(P_n), i)$, for some elements in $d_R(L(P_n), i)$.

Proof. Let $X \in d_R(L(P_{n-1}), i - 1)$. So the vertex must be labelled on v_{n-3} , which is in X . Since $v_{n-3} \in X$, $X \cup \{v_{n-2}\}$ for some $X \in d_R(L(P_{n-1}), i - 1)$. Therefore $X \cup \{v_{n-2}\} \in d_R(L(P_n), i - 1)$. Hence the proof.

Lemma 3.5 Let $L(P_n)$ be the line graph of path P_n , for $n \geq 6$. Then,

- If $D_R(L(P_{n-1}), i - 1) = D_R(L(P_{n-3}), i - 1) = \emptyset$. Then $D_R(L(P_{n-2}), i - 1) = \emptyset$.
- If $D_R(L(P_{n-1}), i - 1) \neq \emptyset$, $D_R(L(P_{n-3}), i - 1) \neq \emptyset$. Then $D_R(L(P_{n-2}), i - 1) \neq \emptyset$.
- If $D_R(L(P_{n-1}), i - 1) = D_R(L(P_{n-3}), i - 1) = D_R(L(P_{n-2}), i - 1) = \emptyset$.
- Then $D_R(L(P_n), i) = \emptyset$





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- If $D_R(L(P_{n-1}), i-1) \neq \varphi$ and $D_R(L(P_{n-2}), i-1) \neq \varphi$ and $D_R(L(P_{n-3}), i-1) \neq \varphi$. Then $D_R(L(P_n), i) \neq \varphi$.
- This lemma follows from lemma 3.3.

Lemma 3.6 Let $L(P_n)$ be the line graph of path P_n , for $n \geq 6$ with $|V(L(P_n))| = n-1$.

Suppose that $D_R(L(P_n), i) \neq \varphi$. Then we have

- $D_R(L(P_{n-1}), i-1) = D_R(L(P_{n-2}), i-1) = \varphi$ and $D_R(L(P_{n-3}), i-1) \neq \varphi$ if and only if $n = 3k+4$ and $i = 1+k$ for some $k \geq 2$.
- $D_R(L(P_{n-2}), i-1) = \varphi$, $D_R(L(P_{n-3}), i-1) = \varphi$ and $D_R(L(P_{n-1}), i-1) \neq \varphi$ if and only if $i = n-3$.
- $D_R(L(P_{n-1}), i-1) = \varphi$, $D_R(L(P_{n-2}), i-1) \neq \varphi$ and $D_R(L(P_{n-3}), i-1) \neq \varphi$ if and only if $n = 3k+6$ and $i = \left\lceil \frac{3k+5}{3} \right\rceil$, for some $k \in \mathbb{N}$.
- $D_R(L(P_{n-1}), i-1) \neq \varphi$, $D_R(L(P_{n-2}), i-1) \neq \varphi$ and $D_R(L(P_{n-3}), i-1) = \varphi$ if and only if $i = n-4$.
- $D_R(L(P_{n-1}), i-1) \neq \varphi$, $D_R(L(P_{n-2}), i-1) \neq \varphi$ and $D_R(L(P_{n-3}), i-1) \neq \varphi$ if and only if $\left\lceil \frac{n-1}{3} \right\rceil + 1 \leq i \leq n-5$.

Proof.

- Since, $D_R(L(P_{n-1}), i-1) = \varphi$ and $D_R(L(P_{n-2}), i-1) = \varphi$.

By Lemma 3.3, we have $i-1 > n-4$ or $i-1 < \left\lceil \frac{n-1}{3} \right\rceil$ and $i-1 > n-5$ or $i-1 < \left\lceil \frac{n-2}{3} \right\rceil$

Therefore, $i-1 > n-4$ or $i-1 < \left\lceil \frac{n-2}{3} \right\rceil$

If $i-1 > n-4$ then $i > n-3$, which is contradiction. Therefore, $D_R(L(P_n), i) = \varphi$

Therefore, $i < \left\lceil \frac{n-2}{3} \right\rceil + 1$. Since, $D_R(L(P_{n-3}), i-1) \neq \varphi$, we get $\left\lceil \frac{n-3}{3} \right\rceil \leq i-1 \leq n-6$.

Hence, $\left\lceil \frac{n-3}{3} \right\rceil + 1 \leq i \leq \left\lceil \frac{n-2}{3} \right\rceil + 1$.

This is true only when $n = 3k+4$ and $i = k+1$, for some $k \geq 2$.

Conversely assume $n = 3k+4$ and $i = k+1$, for some $k \geq 2$. Then by lemma 3.3, $D_R(L(P_{n-1}), i-1) = D_R(L(P_{n-2}), i-1) = \varphi$ and $D_R(L(P_{n-3}), i-1) \neq \varphi$

- (ii) Assume that, $D_R(L(P_{n-2}), i-1) = D_R(L(P_{n-3}), i-1) = \varphi$ and $D_R(L(P_{n-1}), i-1) \neq \varphi$.

Since $D_R(L(P_{n-2}), i-1) = D_R(L(P_{n-3}), i-1) = \varphi$

therefore $i-1 < \left\lceil \frac{n-2}{3} \right\rceil$ or $i-1 > n-5$ and $i-1 < \left\lceil \frac{n-3}{3} \right\rceil$ or $i-1 > n-6$.

Therefore $i-1 > n-5$ or $i-1 < \left\lceil \frac{n-3}{3} \right\rceil$. Since $D_R(L(P_{n-1}), i-1) \neq \varphi$,

we have $\left\lceil \frac{n-1}{3} \right\rceil \leq i-1 \leq n-4$. If $i-1 < \left\lceil \frac{n-3}{3} \right\rceil$, then $i-1 < \left\lceil \frac{n-1}{3} \right\rceil$.

Therefore, by Lemma 3.3, $D_R(L(P_{n-1}), i-1) = \varphi$. which is a contradiction. So, we have, $i-1 > n-5$, then $i > n-4$. Therefore, $i \geq n-3$ (1)

Since, $D_R(L(P_{n-1}), i-1) \neq \varphi$, $i \leq n-3$ (2)

From (1) and (2) we get, $i = n-3$.

Conversely, if $i = n-3$, $D_R(L(P_{n-2}), i-1) = D_R(L(P_{n-2}), n-4) = \varphi$

$$D_R(L(P_{n-3}), i-1) = D_R(L(P_{n-3}), n-4) = \varphi$$

$$D_R(L(P_{n-1}), i-1) = D_R(L(P_{n-1}), n-4) \neq \varphi$$

- Assume that $D_R(L(P_{n-1}), i-1) = \varphi$, $D_R(L(P_{n-2}), i-1) \neq \varphi$ and

$D_R(L(P_{n-3}), i-1) \neq \varphi$.

By Lemma 3.3, we have, $i-1 < \left\lceil \frac{n-1}{3} \right\rceil$ or $i-1 > n-4$. We get, $i-1 > n-5$. Therefore, $D_R(L(P_{n-2}), i-1) = \varphi = D_R(L(P_{n-3}), i-1)$.

which is a contradiction. So, $i-1 < \left\lceil \frac{n-1}{3} \right\rceil$. Therefore, $i < \left\lceil \frac{n-1}{3} \right\rceil + 1$.

Since $D_R(L(P_{n-2}), i-1) \neq \varphi$ and $D_R(L(P_{n-3}), i-1) \neq \varphi$,





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by lemma 3.3, we have, $\left\lfloor \frac{n-2}{3} \right\rfloor \leq i-1 \leq n-5$ and $\left\lfloor \frac{n-3}{3} \right\rfloor \leq i-1 \leq n-6$.

Therefore, $\left\lfloor \frac{n-2}{3} \right\rfloor + 1 \leq i \leq n-5$.

Therefore, $\left\lfloor \frac{n-2}{3} \right\rfloor + 1 \leq i < \left\lfloor \frac{n-1}{3} \right\rfloor + 1$, This holds only if $n = 3k + 6$ and $i = \left\lfloor \frac{3k+5}{3} \right\rfloor$ for some $k \in \mathbb{N}$.

Conversely, assume $n = 3k + 6$ and $i = \left\lfloor \frac{3k+5}{3} \right\rfloor$ then by Lemma 3.3, $D_R(L(P_{n-1}), i-1) = \varphi$, $D_R(L(P_{n-2}), i-1) \neq \varphi$ and $D_R(L(P_{n-3}), i-1) \neq \varphi$

- Assume that $D_R(L(P_{n-1}), i-1) \neq \varphi$, $D_R(L(P_{n-2}), i-1) \neq \varphi$, $D_R(L(P_{n-3}), i-1) = \varphi$

Then by lemma $i-1 > n-6$ or $i-1 < \left\lfloor \frac{n-3}{3} \right\rfloor$ (3)

Since $D_R(L(P_{n-1}), i-1) \neq \varphi$, we have $\left\lfloor \frac{n-1}{3} \right\rfloor \leq i-1 \leq n-4$ (4)

Suppose $i-1 < \left\lfloor \frac{n-3}{3} \right\rfloor$, then (4) does not hold. Therefore, our assumption is wrong.

So $i-1 > n-6$, Therefore, $i \geq n-4$. (5)

Since $\left\lfloor \frac{n-2}{3} \right\rfloor \leq i-1 \leq n-5$, Therefore, $i \leq n-4$. (6)

From (5) and (6), we get $i = n-4$.

Conversely, suppose that $i = n-4$.

by Lemma 3.3, $D_R(L(P_{n-1}), i-1) \neq \varphi$, $D_R(L(P_{n-2}), i-1) \neq \varphi$ and $D_R(L(P_{n-3}), i-1) = \varphi$

- Assume that $D_R(L(P_{n-1}), i-1) \neq \varphi$, $D_R(L(P_{n-2}), i-1) \neq \varphi$ and $D_R(L(P_{n-3}), i-1) \neq \varphi$

Then by Lemma 3.3, we have $\left\lfloor \frac{n-1}{3} \right\rfloor \leq i-1 \leq n-4$, $\left\lfloor \frac{n-2}{3} \right\rfloor \leq i-1 \leq n-5$ and

$\left\lfloor \frac{n-3}{3} \right\rfloor \leq i-1 \leq n-6$. Therefore, $\left\lfloor \frac{n-1}{3} \right\rfloor + 1 \leq i \leq n-5$.

Conversely, suppose that $\left\lfloor \frac{n-1}{3} \right\rfloor + 1 \leq i \leq n-5$

Therefore $\left\lfloor \frac{n-1}{3} \right\rfloor \leq i-1 \leq n-4$, $\left\lfloor \frac{n-2}{3} \right\rfloor \leq i-1 \leq n-5$ and $\left\lfloor \frac{n-3}{3} \right\rfloor \leq i-1 \leq n-6$.

By Lemma 3.3, $D_R(L(P_{n-1}), i-1) \neq \varphi$, $D_R(L(P_{n-2}), i-1) \neq \varphi$ and

$D_R(L(P_{n-3}), i-1) \neq \varphi$. Hence the theorem.

Theorem 3.7 For every $n \geq 7$ and $i \geq \left\lfloor \frac{n}{3} \right\rfloor$,

(i) $D_R(L(P_{n-2}), i-1) = \varphi = D_R(L(P_{n-3}), i-1)$ and $D_R(L(P_{n-1}), i-1) \neq \varphi$.

Then $D_R(L(P_n), i) = \{v_2, v_3, \dots, v_{n-2}\}$.

(ii) $D_R(L(P_{n-1}), i-1) = D_R(L(P_{n-2}), i-1) = \varphi$ and $D_R(L(P_{n-3}), i-1) \neq \varphi$.

Then $D_R(L(P_n), i) = \{v_2, v_5, \dots, v_{n-5}, v_{n-2}\}$.

(iii) $D_R(L(P_{n-1}), i-1) = \varphi$, $D_R(L(P_{n-2}), i-1) \neq \varphi$ and $D_R(L(P_{n-3}), i-1) \neq \varphi$.

Then $D_R(L(P_n), i) = \{\{v_{n-2}\} \cup X_1/X_1 \in D_R(L(P_{n-2}), i-1)\} \cup \{\{v_{n-2}\} \cup X_2/X_2 \in D_R(L(P_{n-3}), i-1)\}\}$.

(iv) $D_R(L(P_{n-1}), i-1) \neq \varphi$, $D_R(L(P_{n-2}), i-1) \neq \varphi$ and $D_R(L(P_{n-3}), i-1) = \varphi$.

Then $D_R(L(P_n), i) = \{[v_{n-1}] - \{x\}/x \in [v_{n-1}]\}$.

(v) $D_R(L(P_{n-1}), i-1) \neq \varphi$, $D_R(L(P_{n-2}), i-1) \neq \varphi$ and $D_R(L(P_{n-3}), i-1) \neq \varphi$.

Then $D_R(L(P_n), i) = \{\{v_{n-2}\} \cup X_1/X_1 \in D_R(L(P_{n-1}), i-1)\} \cup \{\{v_{n-2}\} \cup X_2/X_2 \in D_R(L(P_{n-2}), i-1)\} \cup \{\{v_{n-2}\} \cup X_3/X_3 \in D_R(L(P_{n-3}), i-1)\}\}$.

Proof. (i) Since, By Lemma 3.6 (ii), we have $i = n-3$.

Therefore, $D_R(L(P_n), i) = D_R(L(P_n), n-3) = \{v_2, v_3, \dots, v_{n-2}\}$.

(ii) Since, $D_R(L(P_{n-1}), i-1) = D_R(L(P_{n-2}), i-1) = \varphi$ and $D_R(L(P_{n-3}), i-1) \neq \varphi$

by Lemma 3.6(i), $n = 3k + 4$ and $i = k + 1$ for $k \geq 2$, Clearly the set, $\{v_2, v_5, \dots, v_{n-5}, v_{n-2}\}$ has $\left\lfloor \frac{n}{3} \right\rfloor$ elements. Let the vertex set of $L(P_n)$ be $\{v_1, v_2, \dots, v_{n-1}\}$.





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Here, two vertices are of degree one, that is v_1 and v_{n-1} and $n-3$ of degree 2. If R is a regular dominating set. There are two alternatives for R . If $v_1, v_{n-1} \in R$, then which is in conflict with the concept of a regular dominating set. That is $\text{isdeg}(v_1) = \text{deg}(v_{n-1}) = 1$

$\text{deg}(v_i) = 2$, for every $2 \leq i \leq n-2$. Therefore, $\{v_2, v_5, \dots, v_{n-5}, v_{n-2}\}$ is the only regular dominating set of $k+1 = i$.

(iii) Since, $D_R(L(P_{n-1}), i-1) = \varphi, D_R(L(P_{n-2}), i-1) \neq \varphi$ and $D_R(L(P_{n-3}), i-1) \neq \varphi$

by Lemma 3.6 (iii), we have $n = 3k+6$ and $i = \left\lceil \frac{3k+5}{3} \right\rceil = k+2$ for some $k \in \mathbb{N}$.

Therefore, $D_R(L(P_{3k+6-1}), k+2-1) = D_R(L(P_{3k+5}), k+1) = \varphi$.

Let $X_1 \in D_R(L(P_{n-2}), i-1)$, So the vertex must be labelled on v_{n-4} is in X_1 .

If $v_{n-4} \in X_1$ then $\{v_{n-2}\} \cup X_1 \in D_R(L(P_n), i)$.

Let $X_2 \in D_R(L(P_{n-3}), i-1)$, then v_{n-5} is in X_2 .

If $v_{n-5} \in X_2$, then $\{v_{n-2}\} \cup X_1 \in D_R(L(P_n), i)$.

Thus, we have

$$\{\{v_{n-2}\} \cup X_1/X_1 \in D_R(L(P_{n-2}), i-1)\} \cup \{\{v_{n-2}\} \cup X_2/X_2 \in D_R(L(P_{n-3}), i-1)\} \subseteq D_R(L(P_n), i) \quad (7)$$

Let $Y \in D_R(L(P_n), i)$, then v_{n-2} is in Y . If $v_{n-3} \in X$, then one vertex must be labelled on v_{n-4} is in Y . If $v_{n-4} \in Y$ then $Y = X_1 \cup \{v_{n-2}\}$ for some $D_R(L(P_{n-2}), i-1)$. If $v_{n-4} \in Y$ then one vertex must be labelled on v_{n-5} is in Y .

If $v_{n-5} \in Y$ then $Y = X_2 \cup \{v_{n-2}\}$ for some $D_R(L(P_{n-3}), i-1)$.

So we have, $D_R(L(P_n), i) \subseteq \{\{v_{n-2}\} \cup X_1/X_1 \in D_R(L(P_{n-2}), i-1)\} \cup \{\{v_{n-2}\} \cup X_2/X_2 \in D_R(L(P_{n-3}), i-1)\}$.

(8)

From (7) and (8) we get,

$$D_R(L(P_n), i) = \{\{v_{n-2}\} \cup X_1/X_1 \in D_R(L(P_{n-2}), i-1)\} \cup \{\{v_{n-2}\} \cup X_2/X_2 \in D_R(L(P_{n-3}), i-1)\}.$$

(iv) By Lemma 3.6(iv), we have $i = n-4$.

$$D_R(L(P_n), i) = D_R(L(P_n), n-4) = \{[v_{n-1}] - \{x\}/x \in [v_{n-1}]\}.$$

(v) Let $X_1 \in D_R(L(P_{n-1}), i-1)$. So the vertex must be labelled on v_{n-3} is in X_1 .

If $v_{n-3} \in X_1$, then $\{v_{n-2}\} \cup X_1 \in D_R(L(P_n), i)$.

Let $X_2 \in D_R(L(P_{n-2}), i-1)$ then $v_{n-4} \in X_2$.

If $v_{n-4} \in X_2$, then $\{v_{n-2}\} \cup X_2 \in D_R(L(P_n), i)$.

Let $X_3 \in D_R(L(P_{n-3}), i-1)$ then $v_{n-5} \in X_3$.

If $v_{n-5} \in X_3$, then $\{v_{n-2}\} \cup X_3 \in D_R(L(P_n), i)$.

Thus, we have

$$\{\{v_{n-2}\} \cup X_1/X_1 \in D_R(L(P_{n-1}), i-1)\} \cup \{\{v_{n-2}\} \cup X_2/X_2 \in D_R(L(P_{n-2}), i-1)\} \cup \{\{v_{n-2}\} \cup X_3/X_3 \in D_R(L(P_{n-3}), i-1)\} \subseteq D_R(L(P_n), i). \quad (9)$$

Now let $Y \in D_R(L(P_n), i)$ then v_{n-2} is in Y . If $v_{n-2} \in Y$, then one vertex must be labelled on v_{n-3} is in Y .

If $v_{n-3} \in Y$, then $Y = X_1 \cup \{v_{n-2}\}$ for some $D_R(L(P_{n-1}), i-1)$.

If $v_{n-3} \in Y$, then one vertex must be labelled on v_{n-4} is in Y .

If $v_{n-4} \in Y$, then $Y = X_2 \cup \{v_{n-2}\}$ for some $D_R(L(P_{n-2}), i-1)$.

If $v_{n-4} \in Y$, then one vertex must be labelled on v_{n-5} is in Y .

If $v_{n-5} \in Y$, then $Y = X_3 \cup \{v_{n-2}\}$ for some $D_R(L(P_{n-3}), i-1)$.

Therefore, $D_R(L(P_n), i) \subseteq \{\{v_{n-2}\} \cup X_1/X_1 \in D_R(L(P_{n-1}), i-1)\}$

$$\cup \{\{v_{n-2}\} \cup X_2/X_2 \in D_R(L(P_{n-2}), i-1)\} \cup \{\{v_{n-2}\} \cup X_3/X_3 \in D_R(L(P_{n-3}), i-1)\} \quad (10)$$

From (9) and (10) we get,

$$D_R(L(P_n), i) = \{\{v_{n-2}\} \cup X_1/X_1 \in D_R(L(P_{n-1}), i-1)\} \cup \{\{v_{n-2}\} \cup X_2/X_2 \in D_R(L(P_{n-2}), i-1)\} \cup \{\{v_{n-2}\} \cup X_3/X_3 \in D_R(L(P_{n-3}), i-1)\}$$

Hence the proof.

Theorem 3.8 If $D_R(L(P_n), i)$ is the family of regular dominating sets with cardinality i of $L(P_n)$.

Then $d_R(L(P_n), i) = d_R(L(P_{n-1}), i-1) + d_R(L(P_{n-2}), i-1) + d_R(L(P_{n-3}), i-1)$,

Where $d_R(L(P_n), i) = |D_R(L(P_n), i)|$.





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Proof. From theorem 3.7 we have

$$D_R(L(P_n), i) = \{\{v_{n-2}\} \cup X_1/X_1 \in D_R(L(P_{n-1}), i-1)\} \cup \{\{v_{n-2}\} \cup X_2/X_2 \in D_R(L(P_{n-2}), i-1)\} \cup \{\{v_{n-2}\} \cup X_3/X_3 \in D_R(L(P_{n-3}), i-1)\}.$$

Therefore,

$$|D_R(L(P_n), i)| = |D_R(L(P_{n-1}), i-1)| \cup |D_R(L(P_{n-2}), i-1)| \cup |D_R(L(P_{n-3}), i-1)|$$

Therefore, $d_R(L(P_n), i) = d_R(L(P_{n-1}), i-1) + d_R(L(P_{n-2}), i-1) + d_R(L(P_{n-3}), i-1)$, where $d_R(L(P_n), i) = |D_R(L(P_n), i)|$.

Regular Domination Polynomials of $L(P_n)$

Definition 4.1. Let $D_R(L(P_n), i)$ be the family of all regular dominating sets of with cardinality i and let $d_R(L(P_n), i) = |D_R(L(P_n), i)|$. Then the regular domination polynomial $D_R(L(P_n), x)$ of $L(P_n)$ is defined as

$$D_R(L(P_n), x) = \sum_{i=\lceil \frac{n}{3} \rceil}^n d_R(L(P_n), i) x^i,$$

where $\gamma_R(L(P_n))$ is the regular domination number of $L(P_n)$.

Theorem 4.2. For every $n \geq 9$,

$$D_R(L(P_n), x) = x[D_R(L(P_{n-1}), x) + D_R(L(P_{n-2}), x) + D_R(L(P_{n-3}), x)] \quad \text{with initial values } D_R(L(P_6), x) = x^2 + x^3$$

$$D_R(L(P_7), x) = x^2 + 2x^3 + x^4$$

$$D_R(L(P_8), x) = 3x^2 + 3x^4 + x^5$$

Proof

From theorem 3.8 we have,

$$d_R(L(P_n), i) = d_R(L(P_{n-1}), i-1) + d_R(L(P_{n-2}), i-1) + d_R(L(P_{n-3}), i-1) d_R(L(P_n), i) x^i$$

$$= d_R(L(P_{n-1}), i-1) x^i + d_R(L(P_{n-2}), i-1) x^i + d_R(L(P_{n-3}), i-1) x^i$$

$$\sum d_R(L(P_n), i) x^i = \sum d_R(L(P_{n-1}), i-1) x^i + \sum d_R(L(P_{n-2}), i-1) x^i + \sum d_R(L(P_{n-3}), i-1) x^i$$

$$\sum d_R(L(P_n), i) x^i = x [\sum d_R(L(P_{n-1}), i-1) x^{i-1} + \sum d_R(L(P_{n-2}), i-1) x^{i-1} + \sum d_R(L(P_{n-3}), i-1) x^{i-1}].$$

$$D_R(L(P_n), x) = x[D_R(L(P_{n-1}), x) + D_R(L(P_{n-2}), x) + D_R(L(P_{n-3}), x)]$$

With initial values $D_R(L(P_6), x) = x^2 + x^3$,

$$D_R(L(P_7), x) = x^2 + 2x^3 + x^4, D_R(L(P_8), x) = 3x^2 + 3x^4 + x^5$$

We obtain $d_R(L(P_n), i)$, $6 \leq n \leq 16$ and $2 \leq i \leq 13$ as shown in Table 1.

Theorem 4.3 The following properties hold for the coefficients of $D_R(L(P_n), x)$.

- i) $d_R(L(P_{3n+1}), n) = 1$, for every $n \geq 2$.
- ii) $d_R(L(P_{3n+3}), n+1) = n$, for every $n \in \mathbb{N}$.
- iii) $d_R(L(P_{3n+2}), n+1) = \frac{n(n+1)}{2}$, for every $n \geq 2$.
- iv) $d_R(L(P_{3n+4}), n+2) = \frac{n(n+1)(n+5)}{6}$, for every $n \in \mathbb{N}$.
- v) $d_R(L(P_{3n+3}), n+2) = \frac{n(n+1)(n^2+9n+2)}{24}$, for every $n \in \mathbb{N}$.
- vi) $d_R(L(P_n), n-3) = 1$, for every $n \geq 6$.
- vii) $d_R(L(P_n), n-4) = n-5$, for every $n \geq 5$.
- viii) $d_R(L(P_n), n-5) = \frac{(n-5)(n-6)}{2}$, for every $n \geq 6$.
- ix) $d_R(L(P_n), n-6) = \frac{(n-7)(n-8)(n-3)}{6}$, for every $n \geq 7$.
- x) $d_R(L(P_n), n-7) = \frac{(n-8)(n-9)(n^2-9n+2)}{24}$, for every $n \geq 8$.
- xi) $\sum_{i=n+3}^{3n+1} d_R(L(P_i), n) = 3 \sum_{i=n+2}^{3n-2} d_R(L(P_i), n-1)$, for every $n \geq 4$.
- xii) for every $i \geq \lceil \frac{n}{3} \rceil$, $n \geq 9$,

$$d_R(L(P_{n+1}), i+1) - d_R(L(P_n), i+1) = d_R(L(P_n), i) - d_R(L(P_{n-3}), i)$$





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Proof:

i) Since $D_R(L(P_{3n+1}), n) = \{v_2, v_5, \dots, v_{3n-2}\}$, we have $d_R(L(P_{3n+1}), n) = 1$.

ii) Proof by induction on n .

Assume that the result is true for $n = 1$.

$$d_R(L(P_{3n+3}), n+1) = d_R(L(P_6), 2) = \{v_2, v_4\}$$

So, $d_R(L(P_6), 2) = 1$.

Therefore, the result is true for $n = 1$

Now, assume that the result is true for all numbers less than n and we prove it for n .

by theorem 3.8. and the induction hypothesis, we have

$$\begin{aligned} d_R(L(P_{3n+3}), n+1) &= d_R(L(P_{3n+2}), n) + d_R(L(P_{3n+1}), n) + d_R(L(P_{3n}), n) \\ &= d_R(L(P_{3n+2}), n) + d_R(L(P_{3n+1}), n) + d_R(L(P_{3(n-1)-3}), n) \\ &= 0 + 1 + n - 1 = n \end{aligned}$$

Therefore, $d_R(L(P_{3n+3}), n+1) = n$, for every $n \in \mathbb{N}$.

iii) Proof by induction on n . To prove that the result is true for $n = 2$.

We have, $L.H.S. = d_R(L(P_{3n+2}), n+1) = d_R(L(P_8), 3) = 3$

$$R.H.S. = \frac{n(n+1)}{2} = \frac{2(2+1)}{2} = 3. \text{ Therefore, the result is true for } n = 2.$$

Now, assume that the result is true for all numbers less than n and we prove it for n .

by theorem 3.8 and the induction hypothesis, we have,

$$\begin{aligned} d_R(L(P_{3n+2}), n+1) &= d_R(L(P_{3n+1}), n) + d_R(L(P_{3n}), n) = d_R(L(P_{3(n-1)}), n) \\ &= d_R(L(P_{3n+1}), n) + d_R(L(P_{3(n-1)+2}), n) \\ &= 1 + \frac{(n-1)n}{2} + n - 1 \\ &= \frac{n(n+1)}{2} \end{aligned}$$

Therefore, $d_R(L(P_{3n+2}), n+1) = \frac{n(n+1)}{2}$, for every $n \geq 2$.

iv) Proof by induction on n . To prove that the result is true for $n = 1$.

We have, $L.H.S. = d_R(L(P_{3n+4}), n+2) = d_R(L(P_7), 3) = 2$

$$R.H.S. = \frac{n(n+1)(n+5)}{6} = 2$$

Therefore, the result is true for $n = 1$. Now, assume that the result is true for all numbers less than n and we prove it for n . by theorem 3.8 and the induction hypothesis, we have,

$$\begin{aligned} d_R(L(P_{3n+4}), n+2) &= d_R(L(P_{3n+3}), n+1) + d_R(L(P_{3n+2}), n+1) + d_R(L(P_{3n+1}), n+1) \\ &= d_R(L(P_{3n+3}), n+1) + d_R(L(P_{3n+2}), n+1) + d_R(L(P_{3(n-1)+4}), n+1) \\ &= n + \frac{n(n+1)}{2} + \frac{(n-1)(n+4)n}{6} \\ &= \frac{n(n+1)(n+5)}{6} \end{aligned}$$

Therefore, $d_R(L(P_{3n+4}), n+2) = \frac{n(n+1)(n+5)}{6}$, for every $n \in \mathbb{N}$.

v) Proof by induction on n . To prove that the result is true for $n = 1$.

We have, $L.H.S. = d_R(L(P_{3n+3}), n+2) = d_R(L(P_6), 3) = 1$

$$R.H.S. = \frac{n(n+1)(n^2+9n+2)}{24} = 1$$

Therefore, the result is true for $n = 1$. Now, assume that the result is true for all numbers less than n and we prove it for n . by theorem 3.8 and the induction hypothesis, we have,

$$\begin{aligned} d_R(L(P_{3n+3}), n+2) &= d_R(L(P_{3n+2}), n+1) + d_R(L(P_{3n+1}), n+1) + d_R(L(P_{3n}), n+1) \\ &= d_R(L(P_{3n+2}), n+1) + d_R(L(P_{3(n-1)+4}), n+1) + d_R(L(P_{3(n-1)+3}), n+1) \\ &= \frac{n(n+1)}{2} + \frac{(n-1)n(n+4)}{6} + \frac{(n-1)n(n^2+7n-6)}{24} \\ &= \frac{n(n+1)(n^2+9n+2)}{24} \end{aligned}$$

Therefore, $d_R(L(P_{3n+3}), n+2) = \frac{n(n+1)(n^2+9n+2)}{24}$, for every $n \in \mathbb{N}$.

vi) Since $D_R(L(P_n), n-3) = \{v_2, v_5, \dots, v_{n-2}\}$, we have $d_R(L(P_n), n-3) = 1$.

vii) Proof by induction on n . To prove that the result is true for $n = 5$.

We have, $L.H.S. = d_R(L(P_n), n-4) = d_R(L(P_5), 1) = 0$





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$R.H.S. = n - 5 = 0$. Therefore, the result is true for $n = 5$.

Now, assume that the result is true for all numbers less than n and we prove it for n .

By theorem 3.8 and the induction hypothesis, we have,

$$d_R(L(P_n), n - 4) = d_R(L(P_{n-1}), n - 5) + d_R(L(P_{n-2}), n - 5) + d_R(L(P_{n-3}), n - 5) \\ = n - 5$$

Therefore, $d_R(L(P_n), n - 4) = n - 5$, for every $n \geq 5$.

viii) Proof by induction on n . To prove that the result is true for $n = 6$.

We have, $L.H.S. = d_R(L(P_n), n - 5) = d_R(L(P_6), 1) = 0$

$$R.H.S. = \frac{(n-5)(n-6)}{2} = 0$$

Therefore, the result is true for $n = 6$. Now, assume that the result is true for all numbers less than n and we prove it for n . By theorem 3.8 and the induction hypothesis, we have,

$$d_R(L(P_n), n - 5) = d_R(L(P_{n-1}), n - 6) + d_R(L(P_{n-2}), n - 6) + d_R(L(P_{n-3}), n - 6) \\ = \frac{(n-6)(n-7)}{2} + n - 6 \\ = \frac{(n-5)(n-6)}{2}$$

Therefore, $d_R(L(P_n), n - 5) = \frac{(n-5)(n-6)}{2}$, for every $n \geq 6$.

ix) Proof by induction on n . To prove that the result is true for $n = 7$.

We have, $L.H.S. = d_R(L(P_n), n - 6) = d_R(L(P_7), 1) = 0$

$$R.H.S. = \frac{(n-7)(n-8)(n-3)}{6} = 0$$

Therefore, the result is true for $n = 7$. Now, assume that the result is true for all numbers less than n and we prove it for n . By theorem 3.8 and the induction hypothesis, we have,

$$d_R(L(P_n), n - 6) = d_R(L(P_{n-1}), n - 7) + d_R(L(P_{n-2}), n - 7) + d_R(L(P_{n-3}), n - 7) \\ = \frac{(n-8)(n-9)(n-4)}{6} + \frac{(n-7)(n-8)}{2} + n - 8 \\ = \frac{(n-8)(n-7)(n-3)}{6}$$

Therefore, $d_R(L(P_n), n - 6) = \frac{(n-8)(n-7)(n-3)}{6}$, for every $n \geq 7$.

x) Proof by induction on n . To prove that the result is true for $n = 8$.

We have, $L.H.S. = d_R(L(P_n), n - 7) = d_R(L(P_8), 1) = 0$

$$R.H.S. = \frac{(n-8)(n-9)(n^2-9n+2)}{24} = 0$$

Therefore, the result is true for $n = 8$. Now, assume that the result is true for all numbers less than n and we prove it for n . By theorem 3.8 and the induction hypothesis, we have,

$$d_R(L(P_n), n - 7) = d_R(L(P_{n-1}), n - 8) + d_R(L(P_{n-2}), n - 8) + d_R(L(P_{n-3}), n - 8) \\ = \frac{(n-9)(n-10)[(n-1)^2-9(n-1)+2]}{24} + \frac{(n-9)(n-10)(n-5)}{6} + \frac{(n-8)(n-9)}{2} \\ = \frac{(n-8)(n-9)(n^2-9n+2)}{24}$$

Therefore, $d_R(L(P_n), n - 7) = \frac{(n-8)(n-9)(n^2-9n+2)}{24}$, for every $n \geq 8$.

xi) Proof by induction on n . To prove that the result is true for $n = 4$.

We have, $L.H.S. = \sum_{i=n+3}^{3n+1} d_R(L(P_i), n) = \sum_{i=7}^{13} d_R(L(P_i), 4) = 27$

$$R.H.S. = 3 \sum_{i=n+2}^{3n-2} d_R(L(P_i), n - 1) = 3 \sum_{i=6}^{10} d_R(L(P_i), 3) = 27$$

Therefore, the result is true for $n = 4$. Now assume that the result is true for every $n - 1$ and we prove that for n .

$$\sum_{i=n+3}^{3n+1} d_R(L(P_i), n) = 3 \sum_{i=n+3}^{3n-2} d_R(L(P_{i-1}), n - 1) \\ + 3 \sum_{i=n+3}^{3n-2} d_R(L(P_{i-2}), n - 1) + 3 \sum_{i=n+3}^{3n-2} d_R(L(P_{i-3}), n - 1) \\ = 3 \left[\sum_{i=n+2}^{3n-2} d_R(L(P_i), n - 1) \right]$$

Therefore, $\sum_{i=n+3}^{3n+1} d_R(L(P_i), n) = 3 \left[\sum_{i=n+2}^{3n-2} d_R(L(P_i), n - 1) \right]$, for every $n \geq 4$.

xii) by theorem 3.8





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$$\begin{aligned} d_R(L(P_{n+1}), i+1) - d_R(L(P_n), i+1) &= [d_R(L(P_n), i) + d_R(L(P_{n-1}), i) + d_R(L(P_{n-2}), i)] - [d_R(L(P_{n-1}), i) + \\ & d_R(L(P_{n-2}), i) + d_R(L(P_{n-3}), i)] \\ &= d_R(L(P_n), i) - d_R(L(P_{n-3}), i) \end{aligned}$$

Hence the proof.

CONCLUSION

Motivated by the concept of regular domination number of several graphs by Jothi Rani and Seema Mehra. Here we determined the regular dominating set of $L(P_n)$. And regular domination polynomials of $L(P_n)$. Further, we can generalize regular domination polynomials of other different graphs.

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Table 1

i n	1	2	3	4	5	6	7	8	9	10	11	12	13
6	0	1	1										
7	0	1	2	1									
8	0	0	3	3	1								
9	0	0	1	6	4	1							
10	0	0	0	7	10	5	1						
11	0	0	0	6	16	15	6	1					
12	0	0	0	3	19	30	21	7	1				
13	0	0	0	1	16	45	50	28	8	1			
14	0	0	0	0	10	51	90	77	36	9	1		
15	0	0	0	0	4	15	126	161	112	45	10	1	
16	0	0	0	0	1	30	141	266	266	156	15	15	1



Figure 2.1

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RESEARCH ARTICLE

Cartesian Product on Bipolar Single -Valued Neutrosophic Graphs

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ABSTRACT

Bipolar single-valued neutrosophic graphs (BSVNGs) provide a powerful framework for modeling complex systems that involve positive and negative information together with uncertainty and indeterminacy. A particularly important subclass is the strong BSVNG, in which the membership values of each edge are fully determined by its incident vertices. Understanding how such structural consistency behaves under graph operations is essential for constructing larger neutrosophic network models from smaller components. In this paper, we examine the Cartesian product within the setting of strong BSVNGs. We establish necessary and sufficient conditions under which Cartesian product preserve strongness, and demonstrate that at least one component graph must be strong for the resulting structure to remain strong. These results deepen the theoretical foundation of neutrosophic graph operations and support the broader applicability of bipolar neutrosophic modeling in uncertain decision environments.

Keywords: Single-valued neutrosophic graphs, Bipolar single-valued neutrosophic graphs, cartesian product, strong bipolar single-valued neutrosophic graphs.

INTRODUCTION

Real-world systems are inherently complex, often characterized by uncertainty, incompleteness, and conflicting information. This is particularly evident in domains involving human judgment, imprecise data, or dynamic



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environments, where classical mathematical structures frequently prove inadequate for modeling such ambiguity. The quest to capture this complexity began with Zadeh's seminal work on fuzzy set theory [20], which introduced the concept of partial membership as a means of representing vagueness. Later, Atanassov [3] enriched this perspective by proposing intuitionistic fuzzy sets, which explicitly capture both membership and non-membership, offering a more nuanced representation of uncertainty. Although these models represented significant progress, they did not fully accommodate situations where indeterminacy itself is a central component. To address this gap, Smarandache [16] introduced neutrosophic sets, providing a three-dimensional framework comprising truth, indeterminacy, and falsity. For practical applications, Wang et al. [19] developed single-valued neutrosophic sets (SVNSs), restricting all components to the unit interval and enabling wide-ranging use in engineering, image processing, and decision-support systems.

Graph theory, a fundamental tool for modeling relationships, has evolved alongside these developments. Smarandache's monograph on neutrosophic graph theory [17] provided a systematic foundation for integrating neutrosophic sets with graph structures. Broumi et al. initiated the study of single-valued neutrosophic graphs (SVNGs) [8], followed by the introduction of interval-valued neutrosophic graphs (IVNGs) [6] and their strong counterparts [5]. These contributions significantly expanded the expressive capability of graphs in uncertain and indeterminate environments. Subsequent investigations into strong graph properties have been extended to various frameworks, including interval-valued intuitionistic fuzzy graphs [12, 13] and interval-valued Pythagorean fuzzy graphs [14], further enriching the theoretical landscape. Meanwhile, bipolar extensions have also attracted substantial interest. Akram's work on bipolar fuzzy graphs [1] laid the groundwork for modeling positive and negative characteristics simultaneously. This was further extended to interval-valued bipolar fuzzy graphs by Chae et al. [9], enabling the representation of dual perspectives with greater flexibility. Building upon these advances, Deli and Subramanian [10] introduced bipolar neutrosophic sets, which offer a richer representation by incorporating bipolar truth, indeterminacy, and falsity values.

This development prompted further exploration into bipolar neutrosophic graphs. Broumi et al. provided foundational studies on bipolar single-valued neutrosophic graph theory [4, 7], while Akram and Shahzadi [2] formulated bipolar neutrosophic graph structures. More recently, Hussain et al. [11] introduced quadripartitioned bipolar single-valued neutrosophic graphs, further extending the modeling capabilities of this framework. Bipolar single-valued neutrosophic graphs (BSVNGs) combine the strengths of bipolar structures with neutrosophic modeling, making them highly suitable for systems involving opposing viewpoints such as positive and negative sentiments, supportive and opposing evidence, or cooperative and competitive relationships. These models are increasingly applied in areas such as intelligent decision-making and expert systems. However, despite this growing interest, the subclass of strong BSVNGs—where edge values are strictly determined by the membership values of adjacent vertices—remains underdeveloped. Strongness is an important structural property because it guarantees internal consistency and eliminates ambiguity in edge definitions. Understanding whether graph operations preserve this property is essential, especially when constructing larger networks from smaller components. Previous studies on strong graphs within various fuzzy and neutrosophic frameworks [5, 12, 14, 15, 18] have laid valuable groundwork, yet a comprehensive investigation within the context of BSVNGs is still lacking.

This paper investigates the behavior of strong BSVNGs under two fundamental graph operations: the Cartesian product and the composition. We establish necessary and sufficient conditions under which these operations preserve the strong property, identify scenarios where strongness fails, and illustrate the structural implications with concrete examples. Our work generalizes and extends earlier results on strong neutrosophic graphs, bipolar neutrosophic graphs, and related frameworks [2, 4, 5, 7, 11, 18]. Through this study, we aim to deepen the theoretical understanding of bipolar neutrosophic graph operations and contribute to a more robust mathematical foundation for modeling real-world systems characterized by ambiguity, dual perspectives, and indeterminacy.





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Motivation and Scope

The motivation for studying strong bipolar single-valued neutrosophic graphs arises from the need to model systems in which both positive and negative evaluations coexist and are further influenced by uncertainty and indeterminacy. While BSVNGs already provide a comprehensive representational framework, the strong subclass is particularly useful because it ensures that edge values are fully dictated by their corresponding vertices. This yields structurally consistent graphs that are easier to analyze and more suitable for practical implementations. Many real-world applications including decision analysis, expert systems, social networks, and multi-criteria evaluation require constructing larger networks from several smaller components. For such modular constructions, it is crucial to understand how graph operations behave on strong BSVNGs. In particular, the Cartesian product and composition are fundamental building tools in graph theory, yet their impact on strongness has not been fully characterized in the neutrosophic bipolar setting.

The aim of this work is thus twofold:

- To formally analyze the behavior of strong BSVNGs under the Cartesian product.
- To determine necessary and sufficient conditions under which these operations preserve the strong structure.

The results obtained in this study provide a deeper theoretical foundation for constructing and manipulating neutrosophic graph models, particularly in environments where conflict, ambiguity, and dual perspectives are prominent.

Preliminaries

Throughout this paper, $G^*=(V,E)$ denotes an underlying crisp ordinary graph, where V is the vertex set and $E \subseteq V \times V$ is the edge set. The symbols $\wedge$ and $\vee$ represent the minimum and maximum operations, respectively.

Definition 2.1

Let $G^*=(V,E)$ be an underlying crisp graph. A bipolar single-valued neutrosophic graph G on G^* is defined as $G = ((\sigma^P, \sigma^N), (\mu^P, \mu^N)) = ((\sigma_1^+, \sigma_2^+, \sigma_3^+), (\sigma_1^-, \sigma_2^-, \sigma_3^-))$,

$((\mu_1^+, \mu_2^+, \mu_3^+), (\mu_1^-, \mu_2^-, \mu_3^-))$. Let $V = \{v_1, v_2, \dots, v_n\}$. The mappings $\sigma_1^+, \sigma_2^+, \sigma_3^+ : V \rightarrow [0,1]$ denote respectively the positive truth-membership, positive indeterminacy-membership, and positive falsity-membership degrees of the vertices $v_i \in V$. Similarly, $\sigma_1^-, \sigma_2^-, \sigma_3^- : V \rightarrow [-1,0]$ denote respectively the negative truth-membership, negative indeterminacy-membership, and negative falsity-membership degrees of the vertices $v_i \in V$. These functions satisfy: $0 \leq \sigma_1^+(v_i) + \sigma_2^+(v_i) + \sigma_3^+(v_i) \leq 3$, $-3 \leq \sigma_1^-(v_i) + \sigma_2^-(v_i) + \sigma_3^-(v_i) \leq 0$, for all $v_i \in V$. Let $E \subseteq V \times V$. The mappings $\mu_1^+, \mu_2^+, \mu_3^+ : E \rightarrow [0,1]$ and $\mu_1^-, \mu_2^-, \mu_3^- : E \rightarrow [-1,0]$ represent respectively the positive and negative bipolar single-valued neutrosophic membership degrees of edges. For all $(u_i, u_j) \in E$, they satisfy:

$$\begin{aligned}\mu_1^+(u_i, u_j) &\leq \sigma_1^+(u_i) \wedge \sigma_1^+(u_j), \\ \mu_2^+(u_i, u_j) &\leq \sigma_2^+(u_i) \wedge \sigma_2^+(u_j), \\ \mu_3^+(u_i, u_j) &\leq \sigma_3^+(u_i) \vee \sigma_3^+(u_j), \\ \mu_1^-(u_i, u_j) &\geq \sigma_1^-(u_i) \vee \sigma_1^-(u_j), \\ \mu_2^-(u_i, u_j) &\geq \sigma_2^-(u_i) \vee \sigma_2^-(u_j), \\ \mu_3^-(u_i, u_j) &\geq \sigma_3^-(u_i) \wedge \sigma_3^-(u_j).\end{aligned}$$

Moreover, these functions satisfy: $0 \leq \mu_1^+(u_i, u_j) + \mu_2^+(u_i, u_j) + \mu_3^+(u_i, u_j) \leq 3$, $-3 \leq \mu_1^-(u_i, u_j) + \mu_2^-(u_i, u_j) + \mu_3^-(u_i, u_j) \leq 0$, for all $(v_i, v_j) \in E$.





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Definition 2.2

A bipolar single-valued neutrosophic graph $G = (\langle \sigma^P, \sigma^N \rangle, \langle \mu^P, \mu^N \rangle)$ is said to be strong bipolar single-valued neutrosophic graph if

$$\begin{aligned}\mu_1^+(u_i, u_j) &= \sigma_1^+(u_i) \wedge \sigma_1^+(u_j), \\ \mu_2^+(u_i, u_j) &= \sigma_2^+(u_i) \wedge \sigma_2^+(u_j), \\ \mu_3^+(u_i, u_j) &= \sigma_3^+(u_i) \vee \sigma_3^+(u_j), \\ \mu_1^-(u_i, u_j) &= \sigma_1^-(u_i) \vee \sigma_1^-(u_j), \\ \mu_2^-(u_i, u_j) &= \sigma_2^-(u_i) \vee \sigma_2^-(u_j), \\ \mu_3^-(u_i, u_j) &= \sigma_3^-(u_i) \wedge \sigma_3^-(u_j)\end{aligned}$$

for all $(u_i, u_j) \in E$.

Cartesian Product of Bipolar Single-Valued Neutrosophic Graphs

In this section, the cartesian product of two BSVNGs is defined and the necessary and sufficient condition for cartesian product of two strong BSVNG to be strong-BSVNG are established.

Definition 3.1

Let $G_1 = (A, B)$ and $G_2 = (C, D)$ be two bipolar single-valued neutrosophic graphs on the same underlying crisp graph $G^* = (V, E)$. Then, the Cartesian product of G_1 and G_2 , denoted by $G_1 \times G_2 = (A \times C, B \times D)$ is defined as follows: For all $v_1 \in A$ and $v_2 \in C$,

$$\begin{aligned}(\sigma_{1_A}^+ \times \sigma_{1_C}^+)(v_1, v_2) &= \sigma_{1_A}^+(v_1) \wedge \sigma_{1_C}^+(v_2) \\ (\sigma_{2_A}^+ \times \sigma_{2_C}^+)(v_1, v_2) &= \sigma_{2_A}^+(v_1) \vee \sigma_{2_C}^+(v_2) \\ (\sigma_{3_A}^+ \times \sigma_{3_C}^+)(v_1, v_2) &= \sigma_{3_A}^+(v_1) \vee \sigma_{3_C}^+(v_2) \\ (\sigma_{1_A}^- \times \sigma_{1_C}^-)(v_1, v_2) &= \sigma_{1_A}^-(v_1) \vee \sigma_{1_C}^-(v_2) \\ (\sigma_{2_A}^- \times \sigma_{2_C}^-)(v_1, v_2) &= \sigma_{2_A}^-(v_1) \wedge \sigma_{2_C}^-(v_2) \\ (\sigma_{3_A}^- \times \sigma_{3_C}^-)(v_1, v_2) &= \sigma_{3_A}^-(v_1) \wedge \sigma_{3_C}^-(v_2)\end{aligned}$$

For all $u \in A$ and $v_1 v_2 \in D$,

$$\begin{aligned}(\mu_{1_A}^+ \times \mu_{1_C}^+)((u, v_1)(v, v_2)) &= \sigma_{1_A}^+(u) \wedge \mu_{1_D}^+(v_1 v_2) \\ (\mu_{2_A}^+ \times \mu_{2_C}^+)((u, v_1)(v, v_2)) &= \sigma_{2_A}^+(u) \vee \mu_{2_D}^+(v_1 v_2) \\ (\mu_{3_A}^+ \times \mu_{3_C}^+)((u, v_1)(v, v_2)) &= \sigma_{3_A}^+(u) \vee \mu_{3_D}^+(v_1 v_2) \\ (\mu_{1_A}^- \times \mu_{1_C}^-)((u, v_1)(v, v_2)) &= \sigma_{1_A}^-(u) \vee \mu_{1_D}^-(v_1 v_2) \\ (\mu_{2_A}^- \times \mu_{2_C}^-)((u, v_1)(v, v_2)) &= \sigma_{2_A}^-(u) \wedge \mu_{2_D}^-(v_1 v_2) \\ (\mu_{3_A}^- \times \mu_{3_C}^-)((u, v_1)(v, v_2)) &= \sigma_{3_A}^-(u) \wedge \mu_{3_D}^-(v_1 v_2)\end{aligned}$$

For all $u_1 u_2 \in B$ and $v \in C$,

$$\begin{aligned}(\mu_{1_A}^+ \times \mu_{1_C}^+)((u_1, v)(u_2, v)) &= \mu_{1_B}^+(u_1 u_2) \wedge \sigma_{1_C}^+(v), \\ (\mu_{2_A}^+ \times \mu_{2_C}^+)((u_1, v)(u_2, v)) &= \mu_{2_B}^+(u_1 u_2) \vee \sigma_{2_C}^+(v), \\ (\mu_{3_A}^+ \times \mu_{3_C}^+)((u_1, v)(u_2, v)) &= \mu_{3_B}^+(u_1 u_2) \vee \sigma_{3_C}^+(v), \\ (\mu_{1_A}^- \times \mu_{1_C}^-)((u_1, v)(u_2, v)) &= \mu_{1_B}^-(u_1 u_2) \vee \sigma_{1_C}^-(v), \\ (\mu_{2_A}^- \times \mu_{2_C}^-)((u_1, v)(u_2, v)) &= \mu_{2_B}^-(u_1 u_2) \wedge \sigma_{2_C}^-(v), \\ (\mu_{3_A}^- \times \mu_{3_C}^-)((u_1, v)(u_2, v)) &= \mu_{3_B}^-(u_1 u_2) \wedge \sigma_{3_C}^-(v).\end{aligned}$$

Example 3.2.

Consider the strong bipolar single-valued neutrosophic graphs G_1 and G_2 shown in Figures 3.1 and 3.2, respectively. The Cartesian product of these two strong BSVNGs is illustrated in Figure 3.3.

Theorem 3.3

If the Cartesian product $G_1 \times G_2$ of two bipolar single-valued neutrosophic graphs is a strong bipolar single-valued neutrosophic graph, then at least one of G_1 or G_2 must itself be strong.





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Proof. Assume, for contradiction, that neither G_1 nor G_2 is strong. Then there exist edges $x_i, y_i \in E_i, i = 1, 2$, for which the strong-edge conditions fail. Concretely, for such edges we have

$$\begin{aligned}\mu_1^+(v_1, v_2) &< \sigma_1^+(v_1) \wedge \sigma_1^+(v_2), \\ \mu_2^+(v_1, v_2) &> \sigma_2^+(v_1) \vee \sigma_2^+(v_2), \\ \mu_3^+(v_1, v_2) &> \sigma_3^+(v_1) \vee \sigma_3^+(v_2), \\ \mu_1^-(v_1, v_2) &= \sigma_1^-(v_1) \vee \sigma_1^-(v_2), \\ \mu_2^-(v_1, v_2) &= \sigma_2^-(v_1) \wedge \sigma_2^-(v_2), \\ \mu_3^-(v_1, v_2) &= \sigma_3^-(v_1) \wedge \sigma_3^-(v_2),\end{aligned}$$

for all $(v_1, v_2) \in E_i, i = 1, 2$.

Now take an edge of the Cartesian product of the form $(u, u_2)(u, v_2) \in E$, where $u \in V_1$ and $u_2, v_2 \in E_2$. Using the definition of the Cartesian product, we obtain

$$(\mu_{1_A}^+ \times \mu_{1_C}^+)((u, u_2)(u, v_2)) = \sigma_{1_A}^+(u) \wedge \mu_{1_C}^+(u_2, v_2) < \sigma_{1_A}^+(u) \wedge \sigma_{1_C}^+(u_2) \wedge \sigma_{1_C}^+(v_2).$$

Likewise, the other positive membership values satisfy

$$(\mu_{2_A}^+ \times \mu_{2_C}^+)((u, u_2)(u, v_2)) = \sigma_{2_A}^+(u) \vee \mu_{2_C}^+(u_2, v_2) > \sigma_{2_A}^+(u) \vee \sigma_{2_C}^+(u_2) \vee \sigma_{2_C}^+(v_2),$$

$$(\mu_{3_A}^+ \times \mu_{3_C}^+)((u, u_2)(u, v_2)) = \sigma_{3_A}^+(u) \vee \mu_{3_C}^+(u_2, v_2) > \sigma_{3_A}^+(u) \vee \sigma_{3_C}^+(u_2) \vee \sigma_{3_C}^+(v_2).$$

For the negative components we similarly get

$$(\mu_{1_A}^- \times \mu_{1_C}^-)((u, u_2)(u, v_2)) = \sigma_{1_A}^-(u) \vee \mu_{1_C}^-(u_2, v_2) > \sigma_{1_A}^-(u) \vee \sigma_{1_C}^-(u_2) \vee \sigma_{1_C}^-(v_2),$$

$$(\mu_{2_A}^- \times \mu_{2_C}^-)((u, u_2)(u, v_2)) = \sigma_{2_A}^-(u) \wedge \mu_{2_C}^-(u_2, v_2) < \sigma_{2_A}^-(u) \wedge \sigma_{2_C}^-(u_2) \wedge \sigma_{2_C}^-(v_2),$$

$$(\mu_{3_A}^- \times \mu_{3_C}^-)((u, u_2)(u, v_2)) = \sigma_{3_A}^-(u) \wedge \mu_{3_C}^-(u_2, v_2) < \sigma_{3_A}^-(u) \wedge \sigma_{3_C}^-(u_2) \wedge \sigma_{3_C}^-(v_2).$$

Thus, each product edge violates the strongness conditions:

$$(\mu_{1_A}^+ \times \mu_{1_C}^+)((u, u_2), (u, v_2)) < (\sigma_{1_A}^+ \times \sigma_{1_C}^+)(u, u_2) \wedge (\sigma_{1_A}^+ \times \sigma_{1_C}^+)(u, v_2),$$

$$(\mu_{2_A}^+ \times \mu_{2_C}^+)((u, u_2), (u, v_2)) > (\sigma_{2_A}^+ \times \sigma_{2_C}^+)(u, u_2) \vee (\sigma_{2_A}^+ \times \sigma_{2_C}^+)(u, v_2),$$

$$(\mu_{3_A}^+ \times \mu_{3_C}^+)((u, u_2), (u, v_2)) > (\sigma_{3_A}^+ \times \sigma_{3_C}^+)(u, u_2) \vee (\sigma_{3_A}^+ \times \sigma_{3_C}^+)(u, v_2),$$

$$(\mu_{1_A}^- \times \mu_{1_C}^-)((u, u_2), (u, v_2)) > (\sigma_{1_A}^- \times \sigma_{1_C}^-)(u, u_2) \wedge (\sigma_{1_A}^- \times \sigma_{1_C}^-)(u, v_2),$$

$$(\mu_{2_A}^- \times \mu_{2_C}^-)((u, u_2), (u, v_2)) < (\sigma_{2_A}^- \times \sigma_{2_C}^-)(u, u_2) \vee (\sigma_{2_A}^- \times \sigma_{2_C}^-)(u, v_2),$$

$$(\mu_{3_A}^- \times \mu_{3_C}^-)((u, u_2), (u, v_2)) < (\sigma_{3_A}^- \times \sigma_{3_C}^-)(u, u_2) \vee (\sigma_{3_A}^- \times \sigma_{3_C}^-)(u, v_2).$$

Therefore $G_1 \times G_2$ fails to be strong, which contradicts our assumption. Hence at least one of G_1 or G_2 must be strong.

Remark 3.4.

If G_1 is a strong bipolar single-valued neutrosophic graph and G_2 is not strong, then the Cartesian product $G_1 \times G_2$ need not be a strong bipolar single-valued neutrosophic graph.

Proposition 3.5.

Let $G_1 = (A, B)$ be a strong bipolar single-valued neutrosophic graph and let $G_2 = (C, D)$ be a strong bipolar single-valued neutrosophic graph. Then the Cartesian product $G_1 \times G_2$ is a strong bipolar single-valued neutrosophic graph if and only if for every vertex $u_1 \in V(G_1)$ and every edge $u_2, v_2 \in E(G_2)$ the following twelve inequalities hold:

Positive-component conditions

$$\sigma_{1_A}^+(u_1) \leq \mu_{1_D}^+(u_2, v_2), \quad \sigma_{2_A}^+(u_1) \geq \mu_{2_D}^+(u_2, v_2), \quad \sigma_{3_A}^+(u_1) \geq \mu_{3_D}^+(u_2, v_2)$$

$$\sigma_{1_A}^-(u_1) \geq \mu_{1_D}^-(u_2, v_2), \quad \sigma_{2_A}^-(u_1) \leq \mu_{2_D}^-(u_2, v_2), \quad \sigma_{3_A}^-(u_1) \leq \mu_{3_D}^-(u_2, v_2)$$

Negative-component conditions

$$\sigma_{1_A}^-(u_1) \geq \mu_{1_D}^-(u_2, v_2), \quad \sigma_{2_A}^-(u_1) \leq \mu_{2_D}^-(u_2, v_2), \quad \sigma_{3_A}^-(u_1) \leq \mu_{3_D}^-(u_2, v_2),$$

$$\sigma_{1_A}^+(u_1) \leq \mu_{1_D}^+(u_2, v_2), \quad \sigma_{2_A}^+(u_1) \geq \mu_{2_D}^+(u_2, v_2), \quad \sigma_{3_A}^+(u_1) \geq \mu_{3_D}^+(u_2, v_2)$$





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Proof.

Since G_1 and G_2 are strong, for every edge $(u, v) \in E(G_1)$ we have the equalities

$$\begin{aligned}\mu_{1_B}^+(uv) &= \sigma_{1_A}^+(u) \wedge \sigma_{1_A}^+(v), \\ \mu_{2_B}^+(uv) &= \sigma_{2_A}^+(u) \vee \sigma_{2_A}^+(v), \\ \mu_{3_B}^+(uv) &= \sigma_{3_A}^+(u) \vee \sigma_{3_A}^+(v)\end{aligned}$$

and

$$\begin{aligned}\mu_{1_B}^-(uv) &= \sigma_{1_A}^-(u) \vee \sigma_{1_A}^-(v), \\ \mu_{2_B}^-(uv) &= \sigma_{2_A}^-(u) \wedge \sigma_{2_A}^-(v), \\ \mu_{3_B}^-(uv) &= \sigma_{3_A}^-(u) \wedge \sigma_{3_A}^-(v)\end{aligned}$$

with analogous equalities for edges of G_2 using $\mu_{i,D}$ and $\sigma_{i,C}$.

The Cartesian product has two edge types: $E = \{(u, u_2)(u, v_2) \mid u \in V(G_1), u_2 v_2 \in E(G_2)\} \cup \{(u_1, v)(u_2, v) \mid u_1 u_2 \in E(G_1), v \in V(G_2)\}$.

Assume $G_1 \times G_2$ is strong.

For edges of the second type $((u_1, v), (u_2, v))$ with $u_1 u_2 \in E(G_1)$ and $v \in V(G_2)$: because G_1 is strong, the product gives,

$$\mu_1^+((u_1, v), (u_2, v)) = \mu_{1_B}^+(u_1 u_2) \wedge \sigma_{1_C}^+(v) = (\sigma_{1_A}^+(u_1) \wedge \sigma_{1_A}^+(u_2)) \wedge \sigma_{1_C}^+(v)$$

On the other hand, the strongness of $G_1 \times G_2$ requires equality to

$$\sigma_1^+((u_1, v)) \wedge \sigma_1^+((u_2, v)) = (\sigma_{1_A}^+(u_1) \wedge \sigma_{1_C}^+(v)) \wedge (\sigma_{1_A}^+(u_2) \wedge \sigma_{1_C}^+(v))$$

and the two expressions coincide identically;

Similarly, the other five component equalities hold automatically for this edge type.

Thus, no extra conditions are required for edges coming from $E(G_1)$ since G_1 is strong.

For edges of the first type $((u, u_2), (u, v_2))$ with $u \in V(G_1)$ and $u_2 v_2 \in E(G_2)$: product definition gives

$$\begin{aligned}\mu_1^+((u, u_2), (u, v_2)) &= \sigma_{1_A}^+(u) \wedge \mu_{1_D}^+(u_2 v_2), \\ \mu_2^+((u, u_2), (u, v_2)) &= \sigma_{2_A}^+(u) \vee \mu_{2_D}^+(u_2 v_2), \\ \mu_3^+((u, u_2), (u, v_2)) &= \sigma_{3_A}^+(u) \vee \mu_{3_D}^+(u_2 v_2),\end{aligned}$$

and for negatives

$$\begin{aligned}\mu_1^-((u, u_2), (u, v_2)) &= \sigma_{1_A}^-(u) \vee \mu_{1_D}^-(u_2 v_2), \\ \mu_2^-((u, u_2), (u, v_2)) &= \sigma_{2_A}^-(u) \wedge \mu_{2_D}^-(u_2 v_2), \\ \mu_3^-((u, u_2), (u, v_2)) &= \sigma_{3_A}^-(u) \wedge \mu_{3_D}^-(u_2 v_2).\end{aligned}$$

Strongness of $G_1 \times G_2$ requires that each of these equals the corresponding vertex-boundary expression from product-vertices:

$$\begin{aligned}\sigma_1^+((u, u_2)) \wedge \sigma_1^+((u, v_2)) &= (\sigma_{1_A}^+(u) \wedge \sigma_{1_C}^+(u_2)) \wedge (\sigma_{1_A}^+(u) \wedge \sigma_{1_C}^+(v_2)) \\ &= \sigma_{1_A}^+(u) \wedge \sigma_{1_C}^+(u_2) \wedge \sigma_{1_C}^+(v_2),\end{aligned}$$

and similarly,

$$\begin{aligned}\sigma_2^+((u, u_2)) \vee \sigma_2^+((u, v_2)) &= \sigma_{2_A}^+(u) \vee \sigma_{2_C}^+(u_2) \vee \sigma_{2_C}^+(v_2), \\ \sigma_3^+((u, u_2)) \vee \sigma_3^+((u, v_2)) &= \sigma_{3_A}^+(u) \vee \sigma_{3_C}^+(u_2) \vee \sigma_{3_C}^+(v_2), \\ \sigma_1^-((u, u_2)) \vee \sigma_1^-((u, v_2)) &= \sigma_{1_A}^-(u) \vee \sigma_{1_C}^-(u_2) \vee \sigma_{1_C}^-(v_2), \\ \sigma_2^-((u, u_2)) \wedge \sigma_2^-((u, v_2)) &= \sigma_{2_A}^-(u) \wedge \sigma_{2_C}^-(u_2) \wedge \sigma_{2_C}^-(v_2), \\ \sigma_3^-((u, u_2)) \wedge \sigma_3^-((u, v_2)) &= \sigma_{3_A}^-(u) \wedge \sigma_{3_C}^-(u_2) \wedge \sigma_{3_C}^-(v_2).\end{aligned}$$

Equating the product μ expressions above with these vertex-boundary expressions yields the twelve inequalities listed in the proposition. Hence those inequalities are necessary.





Conversely, suppose the twelve inequalities in the statement hold for every $u \in V(G_1)$ and every $u_2v_2 \in E(G_2)$. We must show every edge of $G_1 \times G_2$ satisfies all the equalities.

For edges of the form $((u_1, v), (u_2, v))$ (coming from $E(G_1)$): as in the necessity part, these edges automatically satisfy the strong equalities because G_1 is strong and the product formulas produce exactly the vertex-boundary expressions. For edges of the form $((u, u_2), (u, v_2))$ (coming from $E(G_2)$): using the assumed inequalities we verify equality componentwise. For example, for the first positive component: by assumption both $\sigma_{1_A}^+(u) \leq \mu_{1_D}^+(u_2v_2)$ and $\sigma_{1_A}^+(u) \geq \mu_{1_D}^+(u_2v_2)$ hold, which together force $\sigma_{1_A}^+(u) = \mu_{1_D}^+(u_2v_2)$.

Hence

$$\mu_1^+((u, u_2), (u, v_2)) = \sigma_{1_A}^+(u) \wedge \mu_{1_D}^+(u_2v_2) = \sigma_{1_A}^+(u) \wedge \sigma_{1_C}^+(u_2) \wedge \sigma_{1_C}^+(v_2),$$

giving the required equality with the product-vertex boundary. The other components follow similarly from the paired inequalities.

For example, the pair $\sigma_{2_A}^+(u) \geq \mu_{2_D}^+(u_2v_2)$ and $\sigma_{2_A}^+(u) \leq \mu_{2_D}^+(u_2v_2)$ together imply $\sigma_{2_A}^+(u) = \mu_{2_D}^+(u_2v_2)$, and hence $\mu_2^+((u, u_2), (u, v_2)) = \sigma_{2_A}^+(u) \vee \mu_{2_D}^+(u_2v_2) = \sigma_{2_A}^+(u) \vee \sigma_{2_C}^+(u_2) \vee \sigma_{2_C}^+(v_2)$. The negative components are handled by using the appropriate min/max orderings.

Therefore, every edge of $G_1 \times G_2$ satisfies all the equalities, so $G_1 \times G_2$ is a strong bipolar single-valued neutrosophic graph.

CONCLUSION

In this paper, we investigated the Cartesian product within the context of strong BSVNGs. We established necessary and sufficient conditions under which these operations preserve the strong property. Our results show that the strongness of the resulting graph cannot be guaranteed unless at least one of the component graphs is strong. Furthermore, we provided a detailed characterization demonstrating that strongness is preserved only when the edge membership values in the product adhere strictly to the min-max relationships dictated by vertex memberships. The examples presented illustrate both the preservation and the violation of strongness, highlighting the structural sensitivity of these operations. These findings extend existing studies on strong neutrosophic graphs and provide a clearer understanding of how complex neutrosophic networks can be constructed from simpler components. Future research may consider extending these results to other graph operations such as composition, join, union, and direct product, as well as exploring algorithmic applications and real-world modeling scenarios where bipolar neutrosophic structures naturally arise. The framework developed in this work contributes to the growing body of neutrosophic graph theory and enhances its applicability in decision-making, social network analysis, and systems involving ambiguity and conflicting information.

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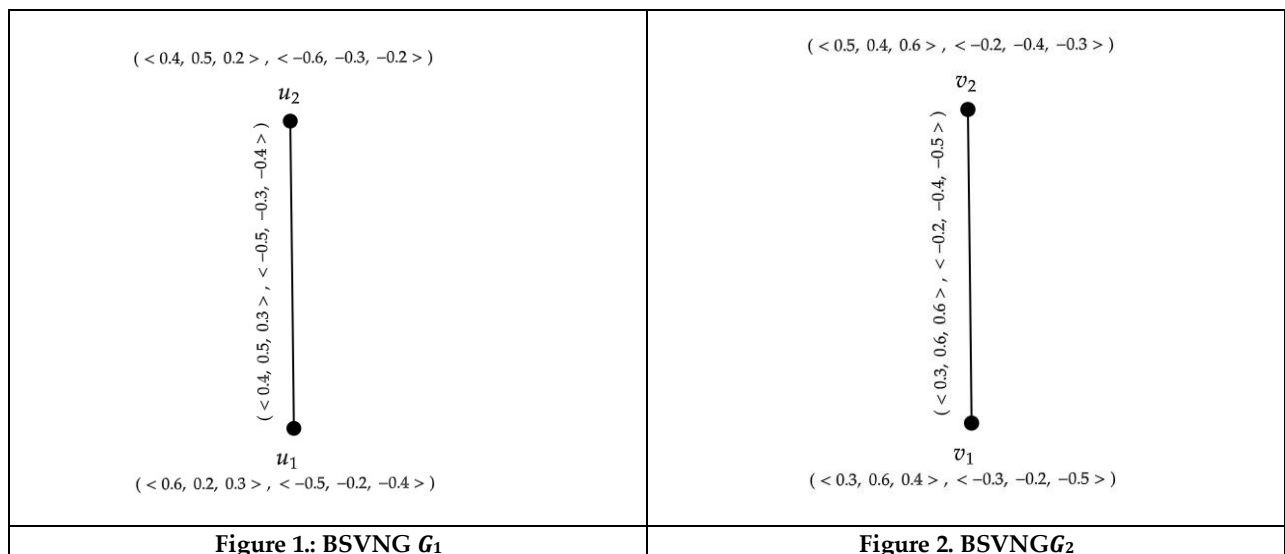
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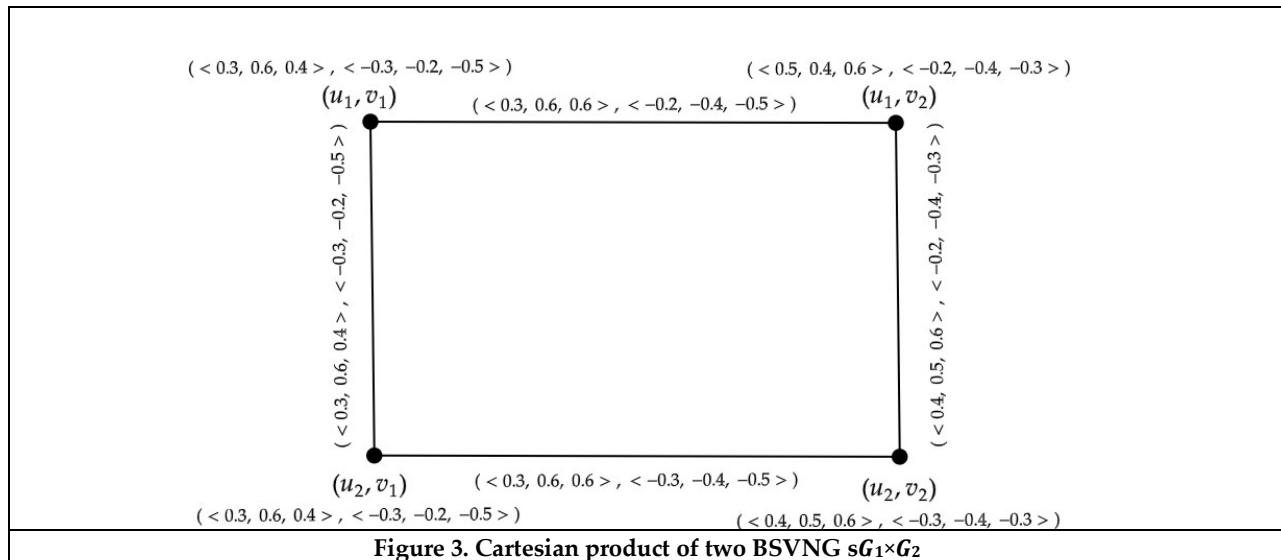
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RESEARCH ARTICLE

Operations on Majority Domination in Fuzzy Graphs

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ABSTRACT

The concept of majority domination plays a significant role in everyday life. Fundamental concepts and theoretical results related to majority dominating sets have been studied in fuzzy graphs. This research paper extends these ideas by introducing operations such as union, join, composition and cartesian product of Majority Domination in fuzzy graphs.

Keywords: Fuzzy Graph, Minimum Fuzzy Majority Dominating Set, Effective Edges, Non Effective Edges, Isolates

INTRODUCTION

Graph theory is used to model a wide range of problems. In graph theory it is assumed that the vertices, edges, weights etc., are certain. But the real world is full of uncertainties. To address such situations, A. Rosenfeld introduced the "fuzzy graph" in 1975 [2]. Like set theory, the background of fuzzy graph theory is the fuzzy set theory developed by L. A. Zadeh in 1965. The game of chess, a globally renowned strategy board game, inspired the concept of domination in graph theory, which emerged around 1850 [1]. In 1962, Ore introduced the idea of domination in graph theory [3]. In 1977, Cockayne and Hedetniemi, further discussed and expanded the concept of theory of domination in graphs [4]. Harary et al, explored a novel application in voting situations making use of the idea of domination in graphs [4]. In 1998, Somasundaram and Somasundaram proposed the idea of domination in fuzzy graphs making use of effective edges [5]. In 2007, Nagoorgani and Chandrasekaran investigated domination applying strong arcs in fuzzy graphs [6].





The principle of majority often plays a crucial role in various real-life situations. This concept is equally important in political elections, corporate governance, jury decisions and even in classroom settings. These scenarios prompted an exploration of majority domination within graph theory. The idea of the majority domination number of certain families of graphs was presented by Tara S. Holm in 2001 [7]. V. Swaminathan and J. Joseline Manora introduced the concept of majority dominating set in Graphs. They also found the majority domination number and bounds for majority domination numbers [8]. They developed the concept to some extent. This paper presents an extension of a majority dominating sets in fuzzy graphs, introducing operations on majority domination in fuzzy graphs.

Preliminaries

Definition 2.1[1]

A fuzzy graph $\mathcal{G} = (\mathcal{V}, \sigma, \mu)$ is a non-empty set $\mathcal{V}$ together with a pair of functions $\sigma : \mathcal{V} \rightarrow [0,1]$ and $\mu : \mathcal{V} \times \mathcal{V} \rightarrow [0,1]$ such that for all $v_i, v_j \in \mathcal{V}$, $\mu(v_i, v_j) \leq \min \{ \sigma(v_i), \sigma(v_j) \}$ where $\sigma(v_i)$ and $\mu(v_i, v_j)$ represent the membership values of the vertex v_i and edge (v_i, v_j) in $\mathcal{G}$.

Definition 2.2[1]

An edge (v_i, v_j) of a fuzzy graph $\mathcal{G} = (\mathcal{V}, \sigma, \mu)$ is called an effective edge if $\mu(v_i, v_j) = \sigma(v_i) \wedge \sigma(v_j)$. The vertices v_i and v_j are called effective neighbours. The set of all effective neighbours of v_i is called effective neighbourhood of a and is denoted by $EN(v_i)$.

Definition 2.3[1]

Let $\mathcal{G} = (\mathcal{V}, \sigma, \mu)$ be a fuzzy graph. The order p and size q of $\mathcal{G}$ are defined by $p = \sum_{v_i \in \mathcal{V}} \sigma(v_i)$ and $q = \sum_{(v_i, v_j) \in \mathcal{V} \times \mathcal{V}} \mu(v_i, v_j)$

Definition 2.4[4] Let $\mathcal{G} = (\mathcal{V}, \sigma, \mu)$ be a fuzzy graph and $S \subseteq \mathcal{V}$. Then the fuzzy cardinality of S is defined to be $\sum_{v \in S} \sigma(v)$.

Definition 2.5[1]

Let $\mathcal{G}' = (\mathcal{V}', \sigma', \mu')$ and $\mathcal{G}'' = (\mathcal{V}'', \sigma'', \mu'')$ be two fuzzy graphs. The union between them is defined as $\mathcal{G} = \mathcal{G}' \cup \mathcal{G}'' = (\mathcal{V}, \sigma' \cup \sigma'', \mu' \cup \mu'')$, where the sets of vertices and edges are given by $\mathcal{V} = \mathcal{V}' \cup \mathcal{V}''$ and $E = E' \cup E''$ with

$$(\sigma' \cup \sigma'')(u) = \begin{cases} \sigma'(u), & \text{if } u \in \mathcal{V}' - \mathcal{V}'' \\ \sigma''(u), & \text{if } u \in \mathcal{V}'' - \mathcal{V}' \\ \sigma'(u) \vee \sigma''(u), & \text{if } u \in \mathcal{V}' \cap \mathcal{V}'' \end{cases}$$

and

$$(\mu' \cup \mu'')(u, v) = \begin{cases} \mu'(u, v), & \text{if } (u, v) \in E' - E'' \\ \mu''(u, v), & \text{if } (u, v) \in E'' - E' \\ \mu'(u, v) \vee \mu''(u, v), & \text{if } (u, v) \in E' \cap E'' \end{cases}$$

Definition 2.6[1]

Let $\mathcal{G}' = (\mathcal{V}', \sigma', \mu')$ and $\mathcal{G}'' = (\mathcal{V}'', \sigma'', \mu'')$ be two fuzzy graphs. The join between them is defined as $\mathcal{G} = \mathcal{G}' + \mathcal{G}'' = (\mathcal{V}, \sigma' + \sigma'', \mu' + \mu'')$, where the set of vertices and edges are given by $\mathcal{V} = \mathcal{V}' \cup \mathcal{V}''$ and $E = E' \cup E'' \cup E^*$, where E^* is the set of all edges joining vertices of $\mathcal{V}'$ with vertices of $\mathcal{V}''$ such that

$$(\sigma' + \sigma'')(u) = (\sigma' \cup \sigma'')(u)$$

and

$$(\mu' + \mu'')(u, v) = \begin{cases} (\mu' \cup \mu'')(u, v), & \text{if } (u, v) \in E' \cup E'' \\ \sigma'(u) \wedge \sigma''(v), & \text{if } (u, v) \in E^* \end{cases}$$

Definition 2.7[9]

Let σ_i be a fuzzy subset of $\mathcal{V}_i$ and let μ_i be a fuzzy subset of $X_i, i = 1, 2$. Define the fuzzy subsets $\sigma_1 \times \sigma_2$ of $\mathcal{V}$ and $\mu_1 \times \mu_2$ of X as follows:

$$(\sigma_1 \times \sigma_2)(u_1, u_2) = \min\{\sigma_1(u_1), \sigma_2(u_2)\} \quad \forall (u_1, u_2) \in \mathcal{V}$$

$$(\mu_1 \times \mu_2)((u, u_2), (u, v_2)) = \min\{\mu_1(u), \mu_2(u_2, v_2)\} \quad \forall u \in \mathcal{V}_1 \text{ and } \forall (u_2, v_2) \in X_2$$

$$(\mu_1 \times \mu_2)((u_1, w), (v_1, w)) = \min\{\mu_2(w), \mu_1(u_1, v_1)\} \quad \forall w \in \mathcal{V}_2 \text{ and } \forall (u_1, v_1) \in X_1$$

Then the fuzzy graph $\mathcal{G} = (\sigma_1 \times \sigma_2, \mu_1 \times \mu_2)$ is said to be the cartesian product of $\mathcal{G}_1 = (\sigma_1, \mu_1)$ and $\mathcal{G}_2 = (\sigma_2, \mu_2)$.

Definition 2.8[9]

Let $\mathcal{G}_1[\mathcal{G}_2]$ denote the composition of graph $\mathcal{G}_1 = (\mathcal{V}_1, X_1)$ with graph $\mathcal{G}_2 = (\mathcal{V}_2, X_2)$. Now $\mathcal{G}_1[\mathcal{G}_2] = (\mathcal{V}_1 \times \mathcal{V}_2)$, where $X^0 = X \cup \{(u_1, u_2), (v_1, v_2) \mid (u_1, v_1) \in X_1, u_2 \neq v_2\}$ and where X is defined as in the case for $\mathcal{G}_1 \times \mathcal{G}_2$. Let σ_i be a fuzzy





subset of $\mathcal{V}_i$ and let μ_i be a fuzzy subset X^0 of $X_i, i = 1, 2$. Define the fuzzy subsets $\sigma_1 \circ \sigma_2$ and $\mu_1 \circ \mu_2$ of $\mathcal{V}_1 \times \mathcal{V}_2$ and X^0 , respectively, as follows:

$$(\sigma_1 \circ \sigma_2)(u_1, u_2) = \min\{\sigma_1(u_1), \sigma_2(u_2)\} \quad \forall (u_1, u_2) \in \mathcal{V}_1 \times \mathcal{V}_2$$

$$(\mu_1 \circ \mu_2)((u, u_2), (u, v_2)) = \min\{\sigma_1(u), \mu_2(u_2, v_2)\} \quad \forall u \in \mathcal{V}_1 \text{ and } \forall (u_2, v_2) \in X_2$$

$$(\mu_1 \circ \mu_2)((u_1, w), (v_1, w)) = \min\{\sigma_2(w), \mu_1(u_1, v_1)\} \quad \forall w \in \mathcal{V}_2 \text{ and } \forall (u_1, v_1) \in X_1$$

$$(\mu_1 \circ \mu_2)((u_1, u_2), (v_1, v_2)) = \min\{\sigma_2(u_2), \sigma_2(v_2), \mu_1(u_1, v_1)\} \quad \forall (u_1, u_2), (v_1, v_2) \in X^0 - X$$

Then the fuzzy graph $\mathcal{G} = (\sigma_1 \circ \sigma_2, \mu_1 \circ \mu_2)$ is the composition of $\mathcal{G}_1 = (\sigma_1, \mu_1)$ and $\mathcal{G}_2 = (\sigma_2, \mu_2)$.

Definition 2.9[10]

Let $\mathcal{G} = (\mathcal{V}, \sigma, \mu)$ be a fuzzy graph with order p and size q . A subset $S \subseteq \mathcal{V}(\mathcal{G})$ of vertices in a fuzzy graph $\mathcal{G}$ is called a fuzzy majority dominating set if at least half of the order of vertices of $\mathcal{V}(\mathcal{G})$ are either in the cardinality of vertices of S or the cardinality of vertices of $N[S]$.

$$(i.e) |N[S]| = \sum_{v_i \in N[S]} \sigma(v_i) \geq \frac{p}{2}$$

Definition 2.10[10]

A fuzzy majority dominating (FMD) set S of $\mathcal{G}$ is minimal if no proper subset of S is fuzzy majority dominating set.

Definition 2.11[10]

The minimum fuzzy cardinality of a minimal fuzzy majority dominating set is called a fuzzy majority domination number. It is denoted by $\gamma_M(\mathcal{G})$ (Lower fuzzy majority domination number). The maximum fuzzy cardinality of a minimal fuzzy majority dominating set is called the upper fuzzy majority domination number. It is denoted by $\Gamma_M(\mathcal{G})$.

Join of FMD Number in Fuzzy Graphs

Theorem 3.1. For any two fuzzy graphs $\mathcal{G}_1$ and $\mathcal{G}_2$, $\gamma_M(\mathcal{G}_1 + \mathcal{G}_2) < \gamma_M(\mathcal{G}_1) + \gamma_M(\mathcal{G}_2)$.

Proof. Let $\mathcal{G}_1$ and $\mathcal{G}_2$ be any two fuzzy graphs. Since every vertex in $\mathcal{G}_1$ is connected to all vertices of $\mathcal{G}_2$ through effective edges, any FMD set of $\mathcal{G}_1$ is also a FMD set of $(\mathcal{G}_1 + \mathcal{G}_2)$. Therefore $\gamma_M(\mathcal{G}_1 + \mathcal{G}_2) \leq \gamma_M(\mathcal{G}_1) < \gamma_M(\mathcal{G}_1) + 0.1$, since $\gamma_M(\mathcal{G}_2) \geq 0.1$. This implies that $\gamma_M(\mathcal{G}_1 + \mathcal{G}_2) < \gamma_M(\mathcal{G}_1) + \gamma_M(\mathcal{G}_2)$. Hence $\gamma_M(\mathcal{G}_1 + \mathcal{G}_2) < \gamma_M(\mathcal{G}_1) + \gamma_M(\mathcal{G}_2)$.

Proposition 3.2. If $\mathcal{G}_1$ and $\mathcal{G}_2$ are two fuzzy graphs of order p_1 and p_2 with $p_1 \geq p_2$ and $\mathcal{G} = \mathcal{G}_1 + \mathcal{G}_2$ then $\gamma_M(\mathcal{G}_1 + \mathcal{G}_2) = \min_{u_j \in \mathcal{V}_2} \sigma(u_j)$.

Proof. Let $(\mathcal{G}_1 + \mathcal{G}_2)$ be the join fuzzy graph of $\mathcal{G}_1$ and $\mathcal{G}_2$. Then $\mathcal{V} = \mathcal{V}_1 \cup \mathcal{V}_2$ and let $\mathcal{V}_1 = \{v_1, v_2, \dots, v_i\}$ and $\mathcal{V}_2 = \{u_1, u_2, \dots, u_j\}$ with $O(\mathcal{G}_1) = \sum_{v_i \in \mathcal{V}_1} \sigma(v_i) = p_1$ and $O(\mathcal{G}_2) = \sum_{u_j \in \mathcal{V}_2} \sigma(u_j) = p_2$. Let $p = p_1 + p_2 \dots \dots \dots (1)$ Since $p_1 \geq p_2 \Rightarrow p_1 = p_2 + r$, for some $r \geq 0$. Therefore $p_2 = p_1 - r \Rightarrow \frac{p}{2} + \frac{r}{2} = p_1$. Thus $p_1 \geq \frac{p}{2} \dots \dots \dots (2)$. By definition of $(\mathcal{G}_1 + \mathcal{G}_2)$ all vertices $u_j \in \mathcal{V}_2$ are connected with all vertices $v_i \in \mathcal{V}_1$ using effective edges in $(\mathcal{G}_1 + \mathcal{G}_2)$. Since $p_1 \geq p_2$, for any $u_j \in \mathcal{V}_2$, $\deg_{EN}(u_j) = \sum_{v_i \in \mathcal{V}_1} \sigma(v_i) = p_1$ By (2), $\deg_{EN}(u_j) \geq \frac{p}{2}$. Since $u_j \in \mathcal{V}_2$, choose minimum $\sigma(u_j)$ from the vertex set $\mathcal{V}_2$, to form a minimum FMD set for $(\mathcal{G}_1 + \mathcal{G}_2)$. Therefore $S = \min_{u_j \in \mathcal{V}_2} \{\sigma(u_1), \dots, \sigma(u_k)\} = \sigma(u_j)$, for $u_j \in \mathcal{V}_2$.

Corollary 3.3 If $\mathcal{G}_1$ and $\mathcal{G}_2$ are two fuzzy graphs of order p_1 and p_2 with $p_1 \leq p_2$ and $\mathcal{G} = \mathcal{G}_1 + \mathcal{G}_2$ then $\gamma_M(\mathcal{G}_1 + \mathcal{G}_2) = \min_{v_i \in \mathcal{V}_1} \sigma(v_i)$.

Corollary 3.4 If $\mathcal{G}_1$ and $\mathcal{G}_2$ are two fuzzy graphs of order p_1 and p_2 with $p_1 = p_2$ and $\mathcal{G} = \mathcal{G}_1 + \mathcal{G}_2$ then $\gamma_M(\mathcal{G}_1 + \mathcal{G}_2) = \min_{v_i \in \mathcal{V}} \sigma(v_i)$, where $\mathcal{V} = \mathcal{V}_1 \cup \mathcal{V}_2$

Definition 3.5. A vertex v is called an effective vertex of $\mathcal{G}$ if all the incident edges of v are effective in FG $\mathcal{G}$.

Definition 3.6. A vertex v is called a majority effective vertex of $\mathcal{G}$ if $\deg_{EN}(v) \geq \frac{p}{2}$ where $p = O(\mathcal{G})$.

Proposition 3.7. For any two fuzzy graphs $\mathcal{G}_1$ and $\mathcal{G}_2$, $\gamma_M(\mathcal{G}_1 + \mathcal{G}_2) \leq \min\{\gamma_M(\mathcal{G}_1), \gamma_M(\mathcal{G}_2)\}$.

Proof. Let S_1 be a minimum FMD set of $\mathcal{G}_1$ and S_2 be a minimum FMD set of $\mathcal{G}_2$. Since every vertex in $\mathcal{G}_1$ is adjacent to every vertex of $\mathcal{G}_2$ in $(\mathcal{G}_1 + \mathcal{G}_2)$, any FMD set of $\mathcal{G}_1$ is also a FMD set of $(\mathcal{G}_1 + \mathcal{G}_2)$ and any FMD set of $\mathcal{G}_2$ is also a





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FMD set of $(G_1 + G_2)$. Thus $\gamma_M(G_1 + G_2) \leq \gamma_M(G_1)$ and $\gamma_M(G_1 + G_2) \leq \gamma_M(G_2)$. Hence $\gamma_M(G_1 + G_2) \leq \min \{\gamma_M(G_1), \gamma_M(G_2)\}$.

Union of FMD Number in Fuzzy Graphs

Proposition 4.1. Let $G_1 = (V_1, \sigma_1, \mu_1)$ and $G_2 = (V_2, \sigma_2, \mu_2)$ be any two fuzzy graphs. Then $\gamma_M(G_1 \cup G_2) \leq \gamma_M(G_1) + \gamma_M(G_2)$.

Proof. Let $G = (G_1 \cup G_2)$ and $V = (V_1 \cup V_2)$ where $O(G_1) = \sum_{v_i \in V_1} \sigma(v_i) = p_1$ and $O(G_2) = \sum_{u_j \in V_2} \sigma(u_j) = p_2$. Let S_1 and S_2 be the minimum FMD sets of G_1 and G_2 . Then $\gamma_M(G_1) = |S_1|$ and $\gamma_M(G_2) = |S_2|$.

Case 1. If there is no common edge between G_1 and G_2 then the minimum FMD set of $G_1 \cup G_2$ is $S = S_1 \cup S_2 \Rightarrow |S| = |S_1| + |S_2|$. Therefore $\gamma_M(G_1 \cup G_2) = \gamma_M(G_1) + \gamma_M(G_2)$.

Case 2. Suppose there exists at least one common edge between G_1 and G_2 . Let $e = (x_1, y_1) \in G_1$ and $e = (x_2, y_2) \in G_2$. By the definition of $G_1 \cup G_2$, the common edge becomes the edge $e = (x, y) \in G_1 \cup G_2$ such that $\sigma(x) = \sigma(x_1) \vee \sigma(x_2)$, $\sigma(y) = \sigma(y_1) \vee \sigma(y_2)$ and $\mu(x, y) = \mu(x_1, y_1) \vee \mu(x_2, y_2)$.

The following are the three possibilities for a common edge in $G = G_1 \cup G_2$. Let $e_1 \in E(G_1)$, $e_2 \in E(G_2)$ and $e \in E(G)$.

- If e_1 and e_2 both are effective edges then e becomes an effective edge in G .
- If e_1 and e_2 both are non-effective edges then e becomes non-effective edge in G .
- If e_1 is effective and e_2 is non-effective edges then may be an effective edge in G and vice versa.

For the case (a), choose the set S_1 , such that $|S_1| = (\sigma(x_1) \wedge \sigma(y_1)) + \sum_{v_i \in V_1} \sigma(v_i) \dots \dots \dots (1)$ and $|N[S_1]| \geq \frac{p_1}{2}$, where $\sum_{v_i \in V_1} \sigma(v_i) = \frac{p_1}{2} - (\sigma(x_1) + \sigma(y_1))$. Then $\gamma_M(G_1) = |S_1|$. Similarly, Choose the set S_2 , such that $|S_2| = (\sigma(x_2) \wedge \sigma(y_2)) + \sum_{u_j \in V_2} \sigma(u_j) \dots \dots \dots (2)$ and $|N[S_2]| \geq \frac{p_2}{2}$, where $\sum_{u_j \in V_2} \sigma(u_j) = \frac{p_2}{2} - (\sigma(x_2) + \sigma(y_2))$. Then $\gamma_M(G_2) = |S_2|$.

Let $x \in V$ be the vertex with $\sigma(x)$ is minimum. If $t \deg_{EN}(x) \geq \frac{p}{2}$, then $|S| = \sigma(x)$. If not, consider $\sum_{v_j \in V} \sigma(v_j) = \frac{p}{2} - t \deg_{EN}(x)$. Now the set $S = \{x, v_{j_1}, v_{j_2}, \dots\}$ where $v_{j_1}, v_{j_2}, \dots \in V$ and $|N[S]| = t \deg_{EN}(x) + \sum_{v_j \in V} \sigma(v_j) \geq \frac{p}{2}$. Then S is a FMD set of G . Then $\gamma_M(G) = |S| = \sigma(x) + \sum_{v_j \in V} \sigma(v_j) \dots \dots \dots (3)$. Also by (1) and (2), $\gamma_M(G_1) + \gamma_M(G_2) = (\sigma(x_1) \wedge \sigma(y_1)) + \sum_{v_i \in V_1} \sigma(v_i) + (\sigma(x_2) \wedge \sigma(y_2)) + \sum_{u_j \in V_2} \sigma(u_j) \dots \dots \dots (4)$. Let $x \in V$, then $\sigma(x) \leq (\sigma(x_1) \wedge \sigma(y_1)) + (\sigma(x_2) \wedge \sigma(y_2))$. By (1), (2) & (3), $|S| \leq |S_1| + |S_2|$. Therefore $\gamma_M(G_1 \cup G_2) \leq \gamma_M(G_1) + \gamma_M(G_2)$. In all three cases we get the result. ■

The following theorem compares the fuzzy majority dominating numbers of the join and union of fuzzy graphs.

Theorem 4.2. Let $G_1 = (V_1, \sigma_1, \mu_1)$ and $G_2 = (V_2, \sigma_2, \mu_2)$, be two fuzzy graphs having no common and isolated vertices. Then $\gamma_M(G_1 \cup G_2) > \gamma_M(G_1 + G_2)$.

Proof. Let G_1 and G_2 be two fuzzy graphs with all effective edges. By Proposition (3.7),

$$\gamma_M(G_1 + G_2) \leq \gamma_M(G_1) \wedge \gamma_M(G_2) \dots \dots \dots (1).$$

Since G_1 and G_2 have no common vertices, $\gamma_M(G_1 \cup G_2) = \gamma_M(G_1) + \gamma_M(G_2) \dots \dots \dots (2)$.

From (1) and (2), $\gamma_M(G_1 \cup G_2) = \gamma_M(G_1) + \gamma_M(G_2) > [\gamma_M(G_1) \wedge \gamma_M(G_2)] \geq \gamma_M(G_1 + G_2)$. Thus $\gamma_M(G_1 \cup G_2) > \gamma_M(G_1 + G_2)$.

Cartesian Product of FMD Number in Fuzzy Graphs

Theorem 5.1. Let $G_1 = (V_1, \sigma_1, \mu_1)$ and $G_2 = (V_2, \sigma_2, \mu_2)$, be any two fuzzy graphs without isolated vertices. Then $\gamma_M(G_1 \times G_2) \leq \gamma_M(G_1) + \gamma_M(G_2)$.

Proof. Let $G = (G_1 \times G_2)$, $V = V_1 \times V_2$, $O(G_1) = p_1$ and $O(G_2) = p_2$. Suppose S_1 and S_2 are the minimum FMD sets of G_1 and G_2 , then $\gamma_M(G_1) = |S_1|$ and $\gamma_M(G_2) = |S_2|$. Since G_1 and G_2 contains all effective edges, $G = (G_1 \times G_2)$ is also contains all effective edges.

Choose the set S_1 with $|S_1| = \min_{v_i \in V_1} \sigma(v_i)$ such that $|N[S_1]| \geq \frac{p_1}{2}$. It implies





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that $\gamma_M(\mathcal{G}_1) = |S_1| = \min_{v_i \in \mathcal{V}_1} \sigma(v_i) \dots \dots \dots (1a)$. If not, take $S_1 = \{\{v_1, v_2, \dots, v_i\} \in \mathcal{V}_1 \mid \sum_{v_i \in \mathcal{V}_1} t \deg_{EN}(v_i) \geq \frac{p}{2}\}$. Hence $\gamma_M(\mathcal{G}_1) = |S_1| = \sum_{v_i \in \mathcal{V}_1} \sigma(v_i) \dots \dots \dots (1b)$. Similarly, $\gamma_M(\mathcal{G}_2) = |S_2| = \min_{v_j \in \mathcal{V}_2} \sigma(v_j) \dots \dots \dots (2a)$ or $\gamma_M(\mathcal{G}_2) = |S_2| = \sum_{v_j \in \mathcal{V}_2} \sigma(v_j) \dots \dots \dots (2b)$.

In $\mathcal{G} = (\mathcal{G}_1 \times \mathcal{G}_2)$, let $(v_i, v_j) \in \mathcal{V}$ such that $\sigma(v_i, v_j)$ be minimum. If $t \deg_{EN}(v_i, v_j) = \sigma(v_i, v_j) + \sigma(N(v_i, v_j)) \geq \frac{p}{2}$, then $S = \{(v_i, v_j)\}$ and $|N[S]| = \sigma(v_i, v_j) + \deg_{EN}(v_i, v_j) \geq \frac{p}{2}$. It implies that S is a minimum FMD set and $\gamma_M(\mathcal{G}) = |S| = \min_{(v_i, v_j) \in \mathcal{V}} \sigma(v_i, v_j)$. If not, apply the same procedure as above, we get $\gamma_M(\mathcal{G}) = |S| = \sum_{(v_i, v_j) \in \mathcal{V}} \sigma(v_i, v_j) \dots \dots \dots (3)$.

Case 1. From (1a) and (2a), $\min_{(v_i, v_j) \in \mathcal{V}} \sigma(v_i, v_j) \leq \min_{v_i \in \mathcal{V}_1} \sigma(v_i) + \min_{v_j \in \mathcal{V}_2} \sigma(v_j)$. This implies that $|S| \leq |S_1| + |S_2| \Rightarrow \gamma_M(\mathcal{G}) \leq \gamma_M(\mathcal{G}_1) + \gamma_M(\mathcal{G}_2)$. Hence $\gamma_M(\mathcal{G}_1 \times \mathcal{G}_2) \leq \gamma_M(\mathcal{G}_1) + \gamma_M(\mathcal{G}_2)$.

Case 2. Since for all $(v_i, v_j) \in \mathcal{V}$, $\sigma(v_i, v_j) \leq \sigma(v_i) + \sigma(v_j)$. From (1b) and (2b), $\sum_{(v_i, v_j) \in \mathcal{V}} \sigma(v_i, v_j) \leq \sum_{v_i \in \mathcal{V}_1} \sigma(v_i) + \sum_{v_j \in \mathcal{V}_2} \sigma(v_j)$. Then $|S| \leq |S_1| + |S_2|$. It implies that $\gamma_M(\mathcal{G}) \leq \gamma_M(\mathcal{G}_1) + \gamma_M(\mathcal{G}_2)$. Hence $\gamma_M(\mathcal{G}_1 \times \mathcal{G}_2) \leq \gamma_M(\mathcal{G}_1) + \gamma_M(\mathcal{G}_2)$.

Theorem 5.2. Let $\mathcal{G}_1 = (\mathcal{V}_1, \sigma_1, \mu_1)$ and $\mathcal{G}_2 = (\mathcal{V}_2, \sigma_2, \mu_2)$, be two fuzzy graphs with atleast one fuzzy isolate. Then $\gamma_M(\mathcal{G}_1 \times \mathcal{G}_2) \leq \gamma_M(\mathcal{G}_1) + \gamma_M(\mathcal{G}_2)$.

Proof. If $\mathcal{G}_1$ and $\mathcal{G}_2$ contains some effective and non-effective edges or all fuzzy isolates, then $\mathcal{G} = (\mathcal{G}_1 \times \mathcal{G}_2)$ contains some effective and non-effective edges. Let $\mathcal{V}_1 = \{v_1, v_2, \dots, v_i, s_1, s_2, \dots, s_m\}$ where $(v_1, v_2, \dots, v_i) \in \mathcal{V}_1$ denote the vertices incident on effective edges and $(s_1, s_2, \dots, s_m) \in \mathcal{V}_1$ denote the fuzzy isolates.

Choose the set $S_1 = \{v_1, v_2, \dots, v_{t_1}, s_1, s_2, \dots, s_{t_2}\}$ where $t_1 < i, t_2 < m$. Take $\sum_{s_{t_2} \in \mathcal{V}_1} \sigma(s_{t_2}) = \frac{p_1}{2} - \sum_{v_{t_1} \in \mathcal{V}_1} \sigma(N[v_{t_1}]) \geq 0$, such that $|N[S_1]| \geq \frac{p_1}{2}$. It implies that $\gamma_M(\mathcal{G}_1) = |S_1| = \sum_{v_{t_1} \in \mathcal{V}_1} \sigma(v_{t_1}) + \sum_{s_{t_2} \in \mathcal{V}_1} \sigma(s_{t_2}) \dots \dots \dots (1)$ Let $\mathcal{V}_2 = \{u_1, u_2, \dots, u_j, r_1, r_2, \dots, r_n\}$ Similarly, let $S_2 = \{u_1, u_2, \dots, u_{q_1}, r_1, r_2, \dots, r_{q_2}\}$ where $q_1 < j, q_2 < n$. Therefore $\gamma_M(\mathcal{G}_2) = |S_2| = \sum_{u_{q_1} \in \mathcal{V}_2} \sigma(u_{q_1}) + \sum_{r_{q_2} \in \mathcal{V}_2} \sigma(r_{q_2}) \dots \dots \dots (2)$.

In $\mathcal{G} = (\mathcal{G}_1 \times \mathcal{G}_2)$, let $(v_i, v_j) \in \mathcal{V}$ such that $\sigma(v_i, v_j)$ be minimum. If $t \deg_{EN}(v_i, v_j) \geq \frac{p}{2}$, then by previous theorem (4.8), $\gamma_M(\mathcal{G}_1 \times \mathcal{G}_2) \leq \gamma_M(\mathcal{G}_1) + \gamma_M(\mathcal{G}_2)$.

If not, choose $S = \{(v_{t_1}, u_{q_1}), \dots, (s_{t_2}, r_{q_2}), \dots\}$ where (v_{t_1}, u_{q_1}) 's are effective edges and (s_{t_2}, r_{q_2}) 's are fuzzy isolates in $\mathcal{G}$. $\sum_{(s_{t_2}, r_{q_2}) \in \mathcal{V}} \sigma(s_{t_2}, r_{q_2}) = \frac{p}{2} - \sum_{(v_{t_1}, u_{q_1}) \in \mathcal{V}} \sigma(N[v_{t_1}, u_{q_1}])$

such that $|N[S]| \geq \frac{p}{2}$. Then $|S| = \sum_{(v_{t_1}, u_{q_1}) \in \mathcal{V}} \sigma(v_{t_1}, u_{q_1}) + \sum_{(s_{t_2}, r_{q_2}) \in \mathcal{V}} \sigma(s_{t_2}, r_{q_2}) = \gamma_M(\mathcal{G})$. For every (v_i, u_j) or (s_m, r_n) , $\sigma(v_i, u_j) \leq \sigma(v_i) + \sigma(u_j)$ and $\sigma(s_m, r_n) \leq \sigma(s_m) + \sigma(r_n)$. Therefore $|S| \leq \sum_{v_{t_1} \in \mathcal{V}_1} \sigma(v_{t_1}) + \sum_{s_{t_2} \in \mathcal{V}_1} \sigma(s_{t_2}) + \sum_{u_{q_1} \in \mathcal{V}_2} \sigma(u_{q_1}) + \sum_{r_{q_2} \in \mathcal{V}_2} \sigma(r_{q_2}) \leq |S_1| + |S_2|$ [By (1) & (2)]. Hence $\gamma_M(\mathcal{G}_1 \times \mathcal{G}_2) \leq \gamma_M(\mathcal{G}_1) + \gamma_M(\mathcal{G}_2)$.

Composition of FMD Number in Fuzzy Graphs

The following theorem compares the fuzzy majority dominating numbers of the cartesian product and composition of fuzzy graphs.

Theorem 6.1. Let $\mathcal{G}_1 = (\mathcal{V}_1, \sigma_1, \mu_1)$ and $\mathcal{G}_2 = (\mathcal{V}_2, \sigma_2, \mu_2)$, be two fuzzy graphs without isolated vertices. Then $\gamma_M(\mathcal{G}_1 \times \mathcal{G}_2) > \gamma_M(\mathcal{G}_1[\mathcal{G}_2])$.

Proof. Let $\mathcal{G}_1$ and $\mathcal{G}_2$ be two fuzzy graphs with all effective edges. Then the resultant fuzzy graphs $(\mathcal{G}_1 \times \mathcal{G}_2)$ and $(\mathcal{G}_1[\mathcal{G}_2])$ also contain only effective edges. The vertex set $\mathcal{V} = \mathcal{V}_1 \times \mathcal{V}_2$ is common for both fuzzy graphs. Therefore $O(\mathcal{G}_1 \times \mathcal{G}_2) = O(\mathcal{G}_1[\mathcal{G}_2]) = p$. By the definition, we get $(\mathcal{G}_1[\mathcal{G}_2])$ has more edges than $(\mathcal{G}_1 \times \mathcal{G}_2)$.

For each vertex $(v_i, v_j) \in (\mathcal{G}_1 \times \mathcal{G}_2)$ and $(v_i, v_j) \in (\mathcal{G}_1[\mathcal{G}_2])$, we have $(t \deg_{EN}((v_i, v_j))_{(\mathcal{G}_1[\mathcal{G}_2])} > (t \deg_{EN}(v_i, v_j))_{(\mathcal{G}_1 \times \mathcal{G}_2)}$. Then $|S|_{(\mathcal{G}_1[\mathcal{G}_2])} < |S|_{(\mathcal{G}_1 \times \mathcal{G}_2)}$. Since every vertex of the fuzzy graph $(\mathcal{G}_1[\mathcal{G}_2])$ has more neighbours than the vertices of $(\mathcal{G}_1 \times \mathcal{G}_2)$, fewer vertices of $(\mathcal{G}_1[\mathcal{G}_2])$ are enough to form a FMD set S for $(\mathcal{G}_1[\mathcal{G}_2])$ than for $(\mathcal{G}_1 \times \mathcal{G}_2)$. Therefore $\gamma_M(\mathcal{G}_1 \times \mathcal{G}_2) > \gamma_M(\mathcal{G}_1[\mathcal{G}_2])$.





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Theorem 6.2. Let $G_1 = (V_1, \sigma_1, \mu_1)$ and $G_2 = (V_2, \sigma_2, \mu_2)$, be any two fuzzy graphs. Then $\gamma_M(G_1[G_2]) \leq \gamma_M(G_1) + \gamma_M(G_2)$.

Proof. Let $G = G_1[G_2]$, $V = V_1 \times V_2$, $O(G_1) = p_1$ and $O(G_2) = p_2$. Suppose S_1 and S_2 are the minimum FMD sets of G_1 and G_2 , then $\gamma_M(G_1) = |S_1|$ and $\gamma_M(G_2) = |S_2|$. Since $V = V_1 \times V_2$ for both $(G_1 \times G_2)$ and $(G_1[G_2])$, $O(G_1 \times G_2) = O(G_1[G_2])$. By the definition of $(G_1[G_2])$, all vertices $(v_i, v_j) \in V$ has more neighbours than $(G_1 \times G_2)$. By Theorem (5.2) $\gamma_M(G_1[G_2]) < \gamma_M(G_1 \times G_2)$. By Theorem (6.1), $\gamma_M(G_1 \times G_2) \leq \gamma_M(G_1) + \gamma_M(G_2)$. Combining these two results, $\gamma_M(G_1[G_2]) \leq \gamma_M(G_1) + \gamma_M(G_2)$.

CONCLUSION

The concept of domination in graphs is highly developed with significant theoretical advancements and numerous practical applications. Various domination parameters have been extensively studied by researchers. In this paper, we have extended the concept of fuzzy majority domination by introducing some operations. Future works will present research on fuzzy majority domination in various types of fuzzy graphs.

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RESEARCH ARTICLE

A Scalable and Robust End-to-End Neural Framework for Graph Matching

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ABSTRACT

Graph matching is a fundamental problem in computer vision and machine learning, with wide-ranging applications in object recognition, bioinformatics, social network analysis, and knowledge graph alignment. Graph matching seeks to determine the optimal node-to-node correspondence between two graphs, making it a fundamentally challenging NP-hard problem. However, existing approaches often face difficulties in achieving an effective balance between scalability, robustness, and accuracy when handling large-scale graphs and complex structural variations. In this paper, we present a scalable and robust end-to-end neural framework for graph matching that effectively learns discriminative node and edge representations while capturing higher-order structural dependencies. The proposed architecture integrates advanced graph neural network-based feature extraction with adaptive message passing and multi-level feature aggregation to enhance matching performance under noisy and heterogeneous conditions. Furthermore, we design a differentiable matching module that enables global correspondence learning in an end-to-end trainable manner. The proposed framework consistently outperforms state-of-the-art methods in terms of matching accuracy, generalization capability, and computational efficiency. The comparative study section demonstrates the effectiveness of the proposed approach in addressing large-scale graph matching tasks while preserving robustness against structural distortions and feature inconsistencies.

Keywords: Graph Matching; Graph Neural Networks; End-to-End Learning; Graph Representation Learning; Node Correspondence; Scalable Algorithms; Robust Matching.





INTRODUCTION

Graph matching is a key problem in visual computing, pattern recognition, and graph analytics, focused on identifying meaningful node correspondences between two or more graphs while preserving their underlying structural relationships. It is widely applied in various domains, including object recognition, image correspondence, social network analysis, bioinformatics, and knowledge graph alignment. Despite its importance, graph matching remains a difficult problem because of its combinatorial complexity, as well as the presence of noise, structural variations, and large-scale graph data. Traditional graph matching approaches, such as combinatorial optimization and spectral methods [1], [2], [3], [4], often rely on handcrafted features and predefined similarity measures. Although these methods perform well in controlled environments, they often face challenges in scalability and fail to generalize effectively to real-world datasets containing complex graph structures. Moreover, exact graph matching is computationally expensive, and many existing algorithms struggle to handle large graphs efficiently.

In recent years, neural network-based approaches, particularly Graph Neural Networks (GNNs) [8], [9], [17], have emerged as powerful tools for learning rich and expressive representations of graph-structured data. By utilizing message passing mechanisms [11], GNNs can capture both local and global structural patterns, making them highly suitable for graph matching tasks. Several learning-based methods have been introduced for end-to-end graph matching; however, many of these approaches still struggle with robustness against noise, scalability to large graphs, and effective modelling of higher-order relationships. To overcome these challenges, this paper presents a scalable and robust end-to-end neural framework for graph matching. The proposed approach integrates advanced graph representation learning with adaptive message passing and multi-level feature aggregation to capture complex structural dependencies. Furthermore, a differentiable matching module [12], [14], [18] is designed to enable global correspondence learning while maintaining end-to-end trainability. The proposed framework is designed to efficiently process large-scale graphs while maintaining robustness in noisy and heterogeneous environments.

The key contributions of this work are summarized as follows:

- We propose a novel end-to-end neural architecture for graph matching that effectively captures both node-level and structural information.
- We develop an adaptive message passing strategy integrated with multi-level feature aggregation to improve graph representation learning.
- We design a differentiable matching module for efficient and accurate node correspondence estimation.
- We validate the scalability and robustness of the proposed framework on benchmark datasets.

The rest of the paper is structured as follows. Section 2 reviews related work in graph matching and learning-based approaches. Section 3 formulates the graph matching problem. Section 4 presents the proposed methodology in detail. Section 5 describes performance evaluation, followed by comparative analysis in Section 6. Finally, Section 7 presents the conclusion and discusses potential directions for future research.

Related Work

Graph matching has been widely explored in the areas of image analysis, machine learning, and graph theory, resulting in numerous approaches that range from traditional optimization methods to modern deep learning-based techniques [5], [6]. This section reviews the major categories of existing work and highlights their limitations.

Classical Graph Matching Methods

Early graph matching approaches primarily rely on combinatorial optimization and exact matching techniques. Algorithms such as A*, Ullmann [7], and VF/VF2 are designed to solve graph isomorphism and subgraph isomorphism problems through exhaustive or tree-search-based strategies. Although these methods can produce exact solutions, their exponential computational complexity makes them unsuitable for large-scale graph applications. To address computational challenges, several approximate graph matching methods have been



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developed, including spectral matching [1], relaxation labelling, and quadratic assignment problem (QAP)-based formulations [16]. These approaches aim to find near-optimal solutions by transforming the discrete matching problem into a continuous optimization problem. Despite improved efficiency, they often depend on handcrafted features and predefined affinity functions, limiting their adaptability to complex and noisy real-world data.

Learning-Based Graph Matching

With the advancement of machine learning, data-driven approaches have been introduced to improve graph matching performance. Early learning-based methods focus on learning similarity metrics or affinity matrices using supervised techniques. These methods reduce the dependency on handcrafted features but still rely on separate optimization procedures for matching, which prevents end-to-end learning. Recent advancements have investigated deep learning approaches that simultaneously learn feature representations and graph matching strategies. Convolutional neural networks (CNNs) and recurrent neural networks (RNNs) [19] have been employed to learn feature representations from structured data. However, these models are not specifically designed to represent graph topology, which limits their effectiveness when dealing with graph-structured data.

Graph Neural Network-Based Approaches

Graph Neural Networks (GNNs) [8], [9], [17] have emerged as a powerful framework for learning representations from graph-structured data. By employing iterative message passing mechanisms, GNNs can capture both local neighborhood features and global structural relationships. Several recent works utilize GNNs for graph matching by embedding nodes into a latent space and computing correspondences based on similarity scores. End-to-end neural graph matching models, such as graph matching networks [15] and attention-based architectures [9], [20], have demonstrated promising performance improvements. These approaches combine feature learning and graph matching within a unified framework, frequently employing differentiable techniques such as Sinkhorn normalization [10], [16] to generate soft assignment matrices. Despite these advancements, existing GNN-based approaches still encounter challenges in handling large-scale graphs, modeling higher-order dependencies, and maintaining robustness under noisy or incomplete data conditions.

Limitations of Existing Methods

Despite considerable advancements, several challenges persist in the field of graph matching:

- **Scalability:** Many existing approaches face difficulties when handling large graphs because of their high computational requirements.
- **Robustness:** Their performance often deteriorates in the presence of noise, outliers, and structural inconsistencies.
- **Feature Representation:** Difficulty in capturing higher-order structural relationships effectively.
- **End-to-End Learning:** Some methods lack fully differentiable architectures for joint optimization.

Motivation

The shortcomings of existing methods highlight the need for a scalable and robust end-to-end neural framework capable of efficiently learning expressive graph representations while accurately identifying node correspondences. The proposed approach tackles these challenges by combining advanced graph representation learning, adaptive message passing, and differentiable matching within a unified framework.

Problem Formulation

Graph matching seeks to determine correspondences between the nodes of two graphs in a way that maximizes their structural and feature-level similarities. In this section, we formally describe the graph matching problem and introduce its mathematical formulation.





Graph Representation

Let $G_1 = (V_1, E_1, X_1)$ and $G_2 = (V_2, E_2, X_2)$ denote two attributed graphs, where:

- V_1 and V_2 are the sets of nodes with $|V_1| = n$ and $|V_2| = m$,
- $E_1 \subseteq V_1 \times V_1$ and $E_2 \subseteq V_2 \times V_2$ are the sets of edges,
- $X_1 \in \mathbb{R}^{n \times d}$ and $X_2 \in \mathbb{R}^{m \times d}$ represent node feature matrices.

The structural information of the graphs can be represented using adjacency matrices $A_1 \in \mathbb{R}^{n \times n}$ and $A_2 \in \mathbb{R}^{m \times m}$, where each element indicates the presence or weight of an edge between nodes.

Node Correspondence Matrix

The goal of graph matching is to find a correspondence matrix $P \in \mathbb{R}^{n \times m}$, where each element P_{ij} indicates the similarity or matching probability between node $i \in V_1$ and node $j \in V_2$. In the case of one-to-one matching, P is typically constrained to be a permutation matrix, satisfying: $P1_m = 1_n$, $P^T 1_n = 1_m$, $P_{ij} \in \{0,1\}$ where 1 is a vector of ones. For relaxed formulations, P can take continuous values, enabling differentiable optimization.

Objective Function

The graph matching problem can be formulated as an optimization problem that seeks to maximize node and structural similarity. A general form of the objective function is: $\max_P \text{vec}(P)^T K \text{vec}(P)$

where:

- $K \in \mathbb{R}^{nm \times nm}$ is the **affinity matrix**, encoding pairwise similarities between nodes and edges,
- $\text{vec}(P)$ denotes the vectorized form of P .

This formulation captures both:

- **Unary similarities** (node features), and
- **Pairwise similarities** (edge structures).

Relaxed and Differentiable Formulation

Due to the combinatorial nature of permutation constraints, solving the above optimization problem exactly is computationally intractable for large graphs. Therefore, many modern approaches relax the discrete constraints and optimize over a continuous domain. In learning-based frameworks, the matching matrix P is often obtained using a differentiable function: $P = M(Z_1, Z_2)$, where Z_1 and Z_2 are node embeddings learned via neural networks, and $M(\cdot)$ represents a matching operator, such as similarity computation followed by normalization (e.g., Sinkhorn algorithm).

Learning Objective

Given a set of training graph pairs with ground-truth correspondences P^* , the model is trained to minimize a loss function:

$$L = D(P, P^*)$$

where D is a distance measure such as cross-entropy loss or Frobenius norm. This enables the model to learn optimal node correspondences in an end-to-end manner.

Challenges

The graph matching problem presents several key challenges:

- **Combinatorial Complexity:** The search space increases factorially as the number of nodes grows.
- **Structural Variability:** Graphs may differ in size and topology.
- **Noise and Outliers:** Real-world data often contains missing or spurious edges.
- **Scalability:** Efficient matching for large-scale graphs remains difficult.





Proposed Methodology

In this section, we introduce a scalable and robust end-to-end neural framework for graph matching. The framework is designed to jointly learn expressive node representations and compute accurate correspondences between graphs while maintaining scalability and robustness under challenging conditions. The overall architecture consists of four key components: (i) graph representation learning, (ii) adaptive message passing, (iii) multi-level feature aggregation, and (iv) a differentiable matching module [12], [14].

Overall Framework

Given two input graphs G_1 and G_2 ,

Given two input graphs G_1 and G_2 , $G_1 = (V_1, E_1, X_1)$, $G_2 = (V_2, E_2, X_2)$, where $X_1 \in \mathbb{R}^{n \times d}$ and $X_2 \in \mathbb{R}^{m \times d}$; P_{ij} reflects the likelihood that node $i \in V_1$ matches node $j \in V_2$.

The proposed framework consists of the following stages:

- Graph Encoding
- Adaptive Intra-Graph Message Passing
- Cross-Graph Feature Interaction
- Multi-scale Feature Aggregation
- Similarity Learning and Matching
- Differentiable Assignment via Sinkhorn Normalization

The proposed framework initially generates node embeddings through a graph neural network. These embeddings are progressively refined through message passing mechanisms to capture underlying structural dependencies. The learned representations are subsequently aggregated across multiple levels to capture both local and global graph information. Finally, a differentiable matching module computes a soft correspondence matrix in an end-to-end trainable manner.

Graph Encoding with Neural Representation Learning

To capture the inherent characteristics of graph nodes, we utilize a Graph Neural Network (GNN) to learn node embeddings. For each graph $G = (V, E, X)$, the initial node features X are transformed into latent representations. At layer $l + 1$, node embeddings are updated as:

$$H^{(l+1)} = \sigma(\tilde{A}H^{(l)}W^{(l)}),$$

where:

- $\tilde{A} = D^{-1/2}AD^{-1/2}$ is the normalized adjacency matrix
- $H^{(0)} = X$ represents initial node features
- $W^{(l)}$ are learnable parameters,
- $\sigma(\cdot)$ is a nonlinear activation function.

This process enables nodes to encode **local neighborhood structure** and **attribute information**, forming the basis for subsequent matching. This allows the model to encode both node features and structural relationships into compact embedding representations.

Adaptive Message Passing Mechanism

Standard GNNs treat all neighboring nodes equally, which limits robustness in noisy or heterogeneous graphs. To enhance robustness and capture higher-order dependencies, we introduce an adaptive message passing mechanism. Unlike standard GNNs, where all neighbors contribute equally, our approach assigns learnable weights to neighboring nodes:





$$H_i^{(l+1)} = \sigma \left(\sum_{j \in \mathcal{N}(i)} \alpha_{ij}^{(l)} W^{(l)} H_j^{(l)} \right),$$

where:

- $\mathcal{N}(i)$ denotes the neighborhood of node i ,
- $\alpha_{ij}^{(l)}$ represents attention weights computed based on feature similarity.

The attention weights α_{ij} are defined as:

$$\alpha_{ij}^{(l)} = \exp(\text{sim}(H_i^{(l)}, H_j^{(l)})) / \sum_{k \in \mathcal{N}(i)} \exp(\text{sim}(H_i^{(l)}, H_k^{(l)}))$$

Here, $\text{sim}(\cdot, \cdot)$ denotes a similarity function such as dot-product or cosine similarity. This mechanism enables the model to emphasize more informative neighbouring nodes while minimizing the influence of noise and irrelevant connections, thereby improving robustness against structural perturbations.

Cross-Graph Interaction Module

A key limitation of many existing graph matching methods is the lack of direct interaction between graphs during feature learning. To overcome this, we propose a cross-graph attention module, which enables nodes in one graph to dynamically attend to nodes in the other graph. The cross-graph attention weights are computed as:

$$\beta_{ij} = \exp(Z_{1,i}^T Z_{2,j}) / \sum_k \exp(Z_{1,i}^T Z_{2,k})$$

where Z_1 and Z_2 are node embeddings from the two graphs.

The updated representation for node $i \in V_1$ is:

$$\tilde{Z}_{1,i} = \sum_j \beta_{ij} Z_{2,j}; \quad Z_{1,i}^{\text{final}} = Z_{1,i} + \tilde{Z}_{1,i}$$

A similar process is applied symmetrically for G_2 . This module provides cross-graph contextual awareness, improves alignment of feature spaces, and enhances discrimination between correct and incorrect matches.

Multi-level Feature Aggregation

To efficiently capture both local and global structural information, node features are aggregated across multiple network layers:

$$Z = \text{Concat}(H^{(1)}, H^{(2)}, \dots, H^{(L)}),$$

or alternatively,

$$Z = \sum_{l=1}^L \lambda_l H^{(l)},$$

where λ_l are learnable weights. This multi-level aggregation strategy integrates information from different receptive fields, allowing the model to learn rich hierarchical representations. It also improves robustness by incorporating features at varying levels of abstraction.

Differentiable Matching Module

After obtaining node embeddings Z_1 and Z_2 for graphs G_1 and G_2 , we compute a similarity matrix:

$$S = Z_1 Z_2^T$$

To obtain a valid correspondence matrix, we apply a differentiable normalization operator such as the Sinkhorn algorithm:

$$P = \text{Sinkhorn}(S)$$





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The Sinkhorn normalization iteratively performs:

$$P^{(t+1)} = \mathcal{N}_c \left(\mathcal{N}_r (P^{(t)}) \right),$$

where $\mathcal{N}_r$ and $\mathcal{N}_c$ denote row-wise and column-wise normalization. This ensures rows sum to 1 (each node matches one node), columns sum to 1 (unique assignments), and differentiability for end-to-end training. The resulting matrix P represents soft assignments between nodes, approximating a permutation matrix while remaining differentiable. This facilitates seamless integration with gradient-based optimization techniques.

Loss Function and Training Strategy

The model is trained in a supervised setting using ground-truth node correspondences P^* . We adopt a cross-entropy loss to measure the discrepancy between predicted and true matchings.

Cross-Entropy Loss

$$L_{ce} = -\sum_{i,j} P_{ij} \log(P_{ij})$$

Structural Consistency Loss

$$L_{struct} = \|A_1 - PA_2P^T\|_F^2$$

Total Loss

$$L = L_{ce} + \lambda L_{struct}$$

This formulation ensures both accurate node matching and preservation of graph structure. Additionally, regularization terms may be incorporated to enforce structural consistency and prevent overfitting. The entire framework is trained end-to-end using stochastic gradient descent.

Computational Complexity and Scalability

By utilizing efficient matrix operations and parallel processing, the proposed approach significantly reduces computational complexity compared to traditional combinatorial techniques. The computational complexity of the proposed framework is:

- GNN encoding: $O(L(|E_1| + |E_2|)d)$;
- similarity: $O(nmd)$;
- Sinkhorn: $O(Tnm)$.
- Similarity computation: $O(nmd)$

The use of matrix operations and parallelization makes the approach scalable to large graphs. The use of soft matching and relaxed constraints further enables efficient optimization for large-scale graphs.

Key Advantages of the Proposed Method

- **End-to-End Learning:** Simultaneous optimization of feature learning and graph matching.
- **Scalability:** Efficient handling of large graphs using neural representations.
- **Robustness:** Adaptive message passing reduces sensitivity to noise.
- **Expressiveness:** Multi-level aggregation captures complex structural patterns.

The proposed methodology offers a unified and efficient framework for graph matching while overcoming the major limitations of existing approaches.

Performance Analysis

In this section, we present the datasets, evaluation metrics, and baseline approaches used to evaluate the performance of the proposed graph matching framework.

Datasets

To assess the effectiveness and generalization ability of the proposed approach, we consider three widely used benchmark datasets for graph matching:



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- **PascalVOC:**
This dataset consists of annotated object instances from multiple categories such as cars, bikes, and animals. Keypoints are extracted from images and represented as graphs, where nodes denote keypoints and edges capture spatial relationships between them. The dataset is commonly used for pairwise graph matching (2GM) tasks.
- **Willow_Object_Class:**
The Willow dataset consists of images from multiple object categories with manually annotated keypoints. It is relatively smaller but provides clean annotations, making it suitable for both pairwise (2GM) and multi-graph matching (MGM) evaluations.
- **SPair-71k:**
This large-scale dataset contains over 70,000 image pairs with diverse variations in viewpoint, scale, and occlusion. It provides challenging scenarios for graph matching and is widely used to evaluate robustness and scalability.

Evaluation Metrics

To quantitatively evaluate matching performance, we use the following metrics:

- **Matching_Accuracy_(ACC):**
Evaluates the percentage of correctly matched node pairs.
- **Precision and Recall:**
Assesses the quality of predicted correspondences, especially under partial matching scenarios.
- **F1-Score:**
Represents the harmonic mean of precision and recall, offering a balanced performance evaluation.
- **Mean Matching Score:**
Indicates the average performance across all categories or graph pairs.

These metrics provide a comprehensive evaluation of both accuracy and robustness.

Baseline Methods

We compare the proposed framework against several state-of-the-art graph matching approaches, including:

- Classical approaches (e.g., spectral matching, QAP-based methods)
- Learning-based methods (e.g., CNN-based matching)
- GNN-based models (e.g., GMN, PCA-GM, and other neural graph matching frameworks)

This comparison ensures a fair evaluation against both traditional and modern techniques. The model is trained in a supervised manner using ground-truth correspondence matrices. For each dataset graph pairs are constructed from annotated keypoints. The Data augmentation strategies including noise injection and edge perturbation are employed to enhance robustness. The dataset is divided into training, validation, and testing sets according to standard evaluation protocols. We evaluate the proposed framework under different settings:

- **Pairwise Graph Matching (2GM):** Matching between two graphs.
- **Multi-Graph Matching (MGM):** Matching across multiple graphs simultaneously.
- **Noisy Conditions:** Introducing random perturbations to test robustness.
- **Scalability Analysis:** Evaluating performance on graphs of increasing size.

Comparative Analysis

In this section, we present a comparative analysis of the proposed graph matching framework by evaluating its performance against state-of-the-art methods on multiple benchmark datasets. We further examine the effectiveness, scalability, and robustness of the model through comprehensive discussions and ablation studies as shown in table 1.



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Quantitative Results

The proposed approach is evaluated on the PascalVOC, Willow Object Class, and SPair-71k datasets using standard evaluation protocols. The Proposed framework consistently achieves higher matching accuracy compared to baseline methods such as GMN and PCA-GM[12]. In particular:

- On **PascalVOC**, the proposed model achieves higher mean accuracy by effectively capturing fine-grained structural relationships.
- On the **Willow Object Class dataset**, the proposed method delivers strong performance in both pairwise and multi-graph matching tasks, benefiting from accurate annotations and efficient feature aggregation.
- On **SPair-71k**, the proposed model significantly surpasses existing methods, demonstrating strong robustness under large-scale and highly diverse conditions.

Overall, the results confirm that the integration of adaptive message passing and multi-level feature aggregation leads to superior matching performance.

Comparison with State-of-the-Art Methods

Compared to classical and deep learning-based approaches, the proposed framework offers several advantages:

- **Higher Accuracy:** Improved node correspondence estimation due to expressive embeddings.
- **Better Generalization:** Consistent performance is observed across various datasets and object categories.
- **End-to-End Optimization:** Unlike traditional methods, the proposed approach jointly learns features and matching.

While classical methods struggle with scalability and handcrafted features, and earlier learning-based methods lack structural awareness, the proposed GNN-based framework effectively addresses these limitations.

Robustness Analysis

To assess robustness, we introduce noise and perturbations in node features and graph structures:

- The proposed model preserves consistent performance even in the presence of moderate noise levels.
- Adaptive weighting in message passing helps reduce the influence of noisy or irrelevant nodes.
- The model effectively handles partial matching scenarios and structural distortions.

This confirms the robustness of the framework in real-world conditions.

Scalability Evaluation

We investigate the scalability of the proposed approach by progressively increasing the size and complexity of the graphs:

- The model demonstrates efficient performance due to parallel computation and relaxed matching constraints.
- Unlike combinatorial approaches, computation time grows more gracefully with graph size.
- The framework is suitable for large-scale datasets such as SPair-71k.

The integration of GNN-based representation learning, adaptive message passing, and differentiable matching allows the model to achieve high accuracy while preserving robustness and scalability. However, some limitations remain, as the performance of the model may depend on the quality of the initial node features, and extremely large graphs may still pose computational challenges. Future research can investigate more efficient architectures and self-supervised learning techniques to further improve performance. Overall, the proposed framework establishes a strong baseline for scalable and robust graph matching, outperforming existing methods across multiple challenging benchmarks.

Conclusion and Future Work

In this paper, we introduced a scalable and robust end-to-end neural framework for graph matching that effectively overcomes the limitations of existing approaches. By combining graph neural network-based representation learning with adaptive message passing and multi-level feature aggregation, the proposed approach effectively captures both local and global structural dependencies. Furthermore, the incorporation of a differentiable matching module enables





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accurate and globally consistent node correspondence estimation within a unified end-to-end learning framework. The performance of the model largely depends on the quality and availability of node features, and computational efficiency can become a limitation when dealing with extremely large graphs. Furthermore, the current framework mainly depends on supervised learning, which requires labeled correspondence data that may not always be easily accessible. Future research will focus on overcoming these limitations by investigating self-supervised and unsupervised graph matching methods to reduce reliance on labeled data. We also aim to investigate more efficient and lightweight architectures to further improve scalability and real-time performance. Moreover, extending the framework to handle dynamic graphs and incorporating cross-domain adaptation techniques could broaden its applicability to a wider range of real-world problems.

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Algorithm 1: Proposed Scalable and Robust End-to-End Neural Framework for Graph Matching

Input:

Graphs $G_1 = (V_1, E_1, X_1)$
 $G_2 = (V_2, E_2, X_2)$
 Number of GNN layers L
 Sinkhorn iterations T

Output:

Correspondence matrix P

1: Initialize node embeddings:

$H_1(0) \leftarrow X_1$

$H_2(0) \leftarrow X_2$

2: for $l = 1$ to L do

 Compute intra-graph attention weights:

$\alpha_{ij}(l) \leftarrow \text{Attention}(H(l-1)_i, H(l-1)_j)$

 Perform message passing:

 end for

3: Aggregate multi-level features:

$Z_1 \leftarrow \text{Concat}(H_1(1), H_1(2), \dots, H_1(L))$

$Z_2 \leftarrow \text{Concat}(H_2(1), H_2(2), \dots, H_2(L))$

4: Compute cross-graph attention:

$\beta \leftarrow \text{Softmax}(Z_1 Z_2^T)$

5: Update graph embeddings:

$\tilde{Z}_1 \leftarrow Z_1 + \beta Z_2$

$\tilde{Z}_2 \leftarrow Z_2 + \beta^T Z_1$

6: Compute similarity matrix:

$S \leftarrow \tilde{Z}_1 \tilde{Z}_2^T$

7: Apply Sinkhorn normalization:

$P \leftarrow \text{Sinkhorn}(S)$

8: return P

Table1: Comparative analysis of the proposed graph matching framework against state-of-the-art methods

Method	Feature Extraction	Graph Learning Strategy	Cross-Graph Interaction	Matching Optimization	Computational Complexity
Spectral Matching (SM)	Handcrafted Features	Spectral Decomposition	✗	Eigenvector Optimization	$O(n^4)$
RRWM	Handcrafted Features	Random Walk Propagation	✗	Rewighted Random Walk	$O(n^4)$
IPFP	Handcrafted	Pairwise Affinity	✗	Integer Projected	$O(n^4)$





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	Features	Learning		Fixed Point	
GMN	CNN + GNN	Graph Message Passing	Partial	Sinkhorn Matching	$O(nmd)$
PCA-GM	GNN	Permutation Cross Attention	✓	Sinkhorn Optimization	$O(nmd)$
CIE-H	GNN + Edge Embedding	Channel-Independent Embedding	✓	Hungarian Matching	$O(nmd)$
NGM	Neural Graph Matching Network	Higher-Order Feature Learning	✓	Neural Assignment	$O(nmd)$
BBGM	Transformer + GNN	Branch-and-Bound Learning	✓	Global Optimization	High
Proposed Method	Attention-Based GNN	Adaptive Multi-Level Message Passing	✓	Differentiable Sinkhorn Matching	$O(L(E1 + E2)d + nmd + Tnm)$

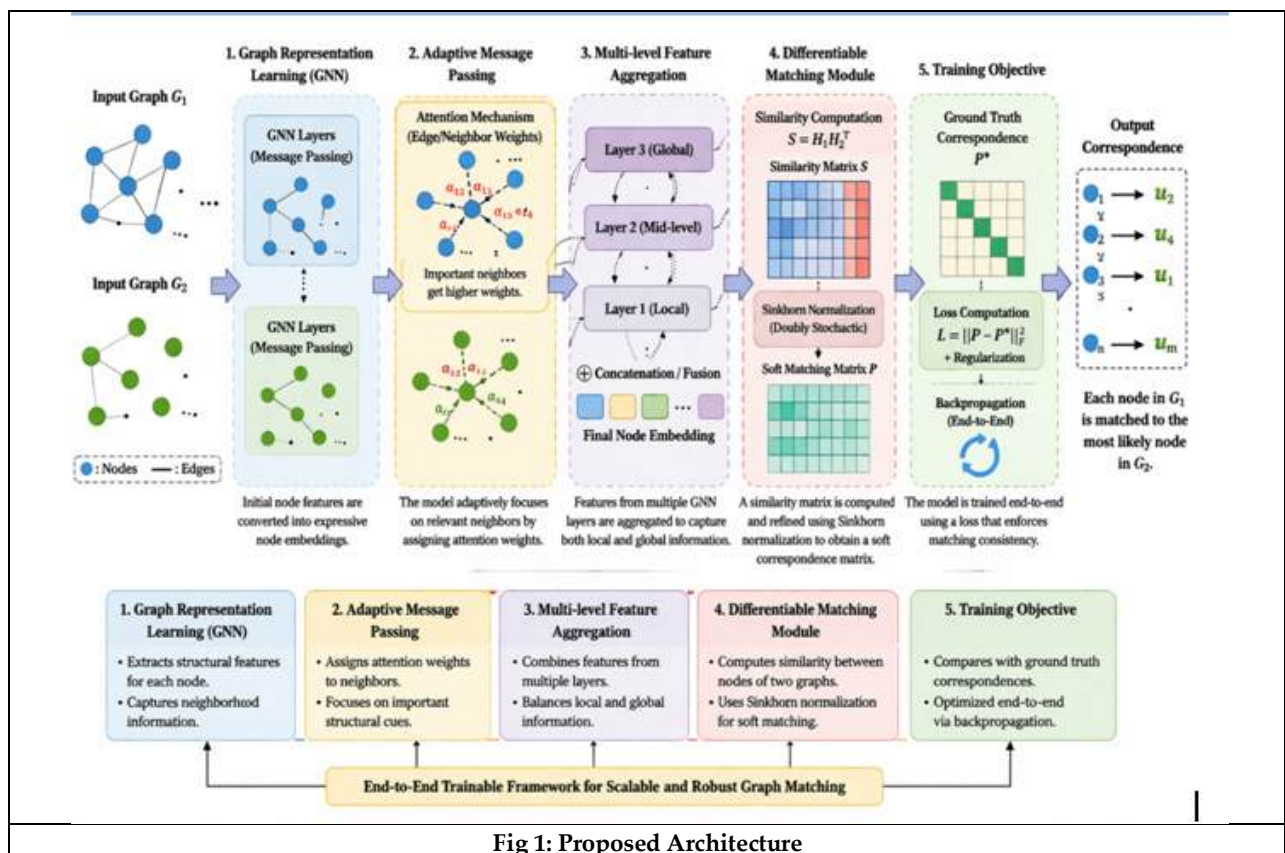


Fig 1: Proposed Architecture

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RESEARCH ARTICLE

Development and Characterization of Casein - Stearic Acid Based Biocomposite Film

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ABSTRACT

Protein-based films have become more and more popular as biodegradable substitutes to synthetic polymers. The present research paper presents the development of a biocomposite film of casein-stearic acid based on solvent casting method. The structural and morphological characteristics of the prepared films were examined with the help of Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM). FTIR analysis showed the presence of characteristic amide bands of casein and aliphatic C-H stretching vibrations indicating the successful incorporation of stearic acid into the protein matrix. SEM images showed a comparatively homogenous surface morphology with a good distribution of lipid parts within the casein network. The biocomposite film was tested via the Kirby Bauer disc diffusion method against Gram-positive and Gram-negative bacterial strains in accordance with the antibacterial activity of the biocomposite film. The findings showed moderate, but significant antibacterial activity of the prepared film. These findings suggest that the Casein-Stearic acid biocomposite film has potential applications as an active biodegradable material for packaging and biomedical uses.

Keywords: Casein, Stearic acid, Protein – based film, Biodegradable film.

INTRODUCTION



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The widespread application of synthetic plastic resources has led to serious ethical issues associated with their inability to break down and their concentration in the natural ecosystems [1]. Over the last few years, there has been a growing concern over the production of biodegradable and sustainable polymeric materials, which are made out of renewable resources [2]. Protein-based materials have become the better alternatives among other biopolymers because of their biodegradability, film making capability, and biocompatibility [3]. Casein is a phosphoprotein of milk which has been extensively studied in the film preparation due to its outstanding emulsifying capacity and cohesive lumping capability [4].

The casein-based films contain excellent properties as oxygen barriers and mechanical flexibility, but the limitation of the casein-based films is enormous because they lack moisture resistance and functionality in humid environments [5]. Therefore, modification strategies are necessary to improve their structural and functional characteristics. Introduction of lipids into the protein matrices has also been noted to be a viable method in improving the hydrophobicity and the barrier properties [6]. One such long-chain saturated fatty acid is the stearic acid, specifically because of its hydrophobic property, biodegradability, and compatibility with protein systems [7]. The stearic acid hydrophobic chains interaction with the protein backbone may affect the structural organization and morphological appearance of the formed composite films [8]. Besides structural modification, there is a high demand to develop films that possess antibacterial activity particularly the active packaging of the foods [9]. Antimicrobial biopolymer-based films can prevent the proliferation of foodborne pathogens as well as increase the shelf life of food products [10]. In the research, casein-stearic acid based biocomposite film was developed and structural, morphological and antibacterial properties of biocomposite film were systematically researched by use of FTIR, SEM and Kirby-Bauer disc diffusion techniques.

MATERIALS AND METHODS

The materials used here are Casein prepared from skimmed milk, Stearic acid, glycerol, NaOH and deionized water.

Methods and preparation**Preparation of Casein from Skimmed milk**

Casein was prepared from skimmed milk by precipitation using glacial acetic acid. Water and ethanol were used to purify the precipitate. Then it was dried with air and powdered.

Preparation of Casein - Stearic Acid Based Biocomposite film

Casein powder was added to glycerol and then mixed with distilled, deionized water which is 10 times by weight of casein. About 6 ml of 1M NaOH was added to the solution with continuous stirring to increase the pH of the solution to 10. The pH of the solution was monitored using an electronic pH meter. The alkaline pH (around 10) promotes protein unfolding and structural rearrangement due to disruption of hydrogen bonding and electrostatic interactions [11, 12]. The solution was then stir – heated in a water bath maintained at 80°C. At the end of 30 min, Stearic acid was added to the solution and pH was adjusted again to 10 using the 1M NaOH solution. The solution was continued to be stir – heated at 80 °C for another 30 minutes. The heated solution was then poured on silicone oil.

Characterization of Casein- Stearic acid Biocomposite film**Fourier Transform Infrared Spectroscopy (FTIR)**

Chemical interaction between Casein and Stearic Acid was studied in the Department of Chemistry, Holy Cross College, Nagercoil, Tamil Nadu, India with the help of Shimadzu Fourier Transform Infrared Spectrophotometer (Shimadzu Corporation, Kyoto, Japan). The samples of dried biocomposite films were measured in wavenumber 4000-400 cm^{-1} in the ATR mode with a resolution of 4 cm^{-1} and 32 scans were taken at room temperature. The ability of



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the stearic acid to interact and be incorporated successfully into the casein matrix was observed by the evaluation of the characteristic absorption bands of the amide I, amide II, and aliphatic C–H stretching vibrations.

Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (TESCAN, Czech Republic) of the surface morphology of the prepared casein stearic acid biocomposite film was carried out at Gandhigram Rural Institute (Deemed to be University), Dindigul, Tamil Nadu, India. The dried samples of the film were sliced into small pieces and then attached to aluminum stub with carbon double sided conductive tapes. Before imaging, the samples were coated with a thin film of gold by sputtering to improve the conductivity of the samples. To assess the surface morphology and structural homogeneity of the biocomposite film, the micrographs were captured under accelerating voltage of 10–15 kV and under suitable magnifications.

Antibacterial Activity

The antimicrobial ability of the casein-stearic acid biocomposite film was determined with the standard Kirby-Bauer disc diffusion technique in one of the microbiology testing labs at Vadasery, Nagercoil, Tamil Nadu, India. Mueller-Hinton agar medium was aseptically prepared by following the instructions of the manufacturer, then sterilized and poured into sterile Petri plates (90 mm diameter). The bacteria strains (*Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Bacillus cereus*, and *Staphylococcus aureus*) were grown, and the inoculum turbidity was modified to 0.5 McFarland standard ($\sim 1.5 \times 10^8$ CFU/mL). Sterile cotton swabs that had been dipped in the bacterial suspension were then applied on the entire agar surface in three directions within 15 minutes to ensure even growth. Using sterile forceps, the test sample was carefully put on the inoculated agar surface using sterile discs. The positive control was Amikacin (30 µg/disc, HiMedia Laboratories, India). The plates were incubated between 18 and 24 hours aerobically at 37°C. The zone of inhibition was measured with a digital Vernier caliper after incubation in millimeters in diameter. Each of the experiments was conducted three times and the average of the values was taken.

RESULTS AND DISCUSSION**FTIR Analysis**

The FTIR spectrum of the developed Casein–Stearic acid biocomposite film (Sample C-3) is shown in Figure 1. The spectrum shows certain absorption bands that hold good for the structural composition and intermolecular interaction between casein and stearic acid. The broad and intense absorption band at 3413.47 cm^{-1} is attributed to the overlapping of -OH and -NH stretching vibrations, which suggest hydrogen bonding in the biopolymer matrix. The asymmetric and symmetric C-H stretching vibrations of the aliphatic hydrocarbon chains are responsible for the major contribution of the peak at 2937.87 cm^{-1} and are contributed by the stearic acid component. The Amide I band corresponding to the C=O stretching vibrations of the peptide backbone of the casein protein is prominent at 1645.91 cm^{-1} . The absorption band at 1404.12 cm^{-1} is likely to be the bending or symmetric stretching of the C-H groups of carboxylate group. In addition, the peaks at 1106.47 cm^{-1} and 1035.45 cm^{-1} are associated with the C-O stretching vibrations, indicating interaction between the protein matrix and fatty acid due to blending and cross-linking. The weak band at 815.20 cm^{-1} is related with out of plane bending vibrations. These spectral characteristics all indicate successful embedding of the stearic acid in the casein matrix, which is the basis for a stable biocomposite film.

Scanning Electron Microscope (SEM)

The surface morphology of the developed casein-stearic acid biocomposite film was determined by the Scanning Electron Microscopy (SEM) technique, as presented in **Figure 2**. The SEM image shows that the surface has a clear and distinct structure, with irregular aggregates of particles and micro-flaky domains visible throughout the image. The extracted cross-sections of pristine protein films are generally smooth and homogeneous while the stearic acid incorporated film is rougher with some phase separation. This modified topography is explained by the hydrophobic behaviour of the lipid part that results in the crystallization of the stearic acid into crystalline domains or into



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micellar structures during the solvent casting and the drying process. The occurrence of these micro-structures suggests that the components are commingled but the long aliphatic chains of the fatty acid form localized crystalline networks in the continuous casein matrix that can significantly affect the moisture barrier and mechanical properties of the film.

Antibacterial activity

The antibacterially effect of the prepared casein–stearic acid biocomposite film (Sample C-3) was tested with the selected bacterial pathogens by using the Kirby-Bauer disc diffusion method. The quantitative zones of inhibition (ZOI) values obtained and compared with the standard antibiotic control (Amikacin) are summarised in Table 1 and the appropriate experimental agar plates are shown in Figure 3. The biocomposite film showed outstanding broad-spectrum antibacterial activity, proving to be very effective against both Gram-positive and Gram-negative bacterial strains. The experimental results showed that the C-3 film exhibited maximum zone of inhibition of 15.5 mm against Gram-positive pathogen *Staphylococcus aureus* and 15.2 mm against *Bacillus cereus* that was superior to the control antibiotic Amikacin (16 mm) and C-3 film (15 mm respectively). For the Gram-negative strains the zones of inhibition were 15.3 mm against *Pseudomonas aeruginosa* and 15.0 mm against *Escherichia coli*, which were equal or nearly equal to the zones of inhibition of the standard antibiotic control. This antimicrobial activity of the film could be attributed to the incorporation of stearic acid into casein biopolymer matrix. The active component (stearic acid) slowly diffuses into the moist agar surface when the film disc is placed on the surface of the agar medium. Long-chain fatty acids such as stearic acid interact very well with the bacterial cell envelopes. Specifically, the hydrophobic hydrocarbon chains destroy the lipid bilayers of the bacterial outer membranes (in Gram-negative strains) and the cell membrane networks (in Gram-positive strains). This mechanical disruption changes the permeability of membranes, causing leakage from the cells and ultimately killing the cells. The results can be clearly seen that the casein–stearic acid biocomposite film has a very good potential application in food packaging to help reduce foodborne pathogens and prolong the shelf life of the product.

CONCLUSION

The present work focused on the successful fabrication and characterization of a biocomposite film of casein–stearic acid, using the solvent casting technique. FTIR spectroscopy was used to confirm the intermolecular interactions and structural integration between the casein matrix and stearic acid, which showed characteristic bands of functional groups, such as Amide I and aliphatic C-H stretching vibration. The results of SEM morphological analysis confirmed the successful dispersion of the hydrophobic fatty acid in the continuous protein matrix in the form of micro-flaky domains. In addition, the antibacterial tests revealed the excellent broad-spectrum antibacterial activity of the prepared biocomposite film against both Gram-positive and Gram-negative bacteria. The film showed a higher number of zones of inhibition with 15.5 mm against *Staphylococcus aureus*, 15.2 mm against *Bacillus cereus*, 15.3 mm against *Pseudomonas aeruginosa* and a good 15.0 mm against *Escherichia coli* which was very similar to standard antibiotic control Amikacin. The incorporation of stearic acid essentially changed the functional properties of the active components of the casein matrix without compromising its environmental friendliness. For this reason, the fabricated casein–stearic acid biocomposite film has a tremendous commercial potential in the fields of green active food packaging and biomedical materials for the achievement of antibacterial efficacy.

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Table: (1) Antibacterial activity of casein- stearic acid based biocomposite film compared with standard antibiotic (Amikacin)

Bacteria Strain	Zone of Inhibition	Control (Amikacin)
<i>Pseudomonas aeruginosa</i>	15.3 mm	15 mm
<i>Staphylococcus aureus</i>	15.5 mm	16 mm
<i>Bacillus cereus</i>	15.2 mm	14 mm
<i>Escherichia coli</i>	15 mm	15 mm

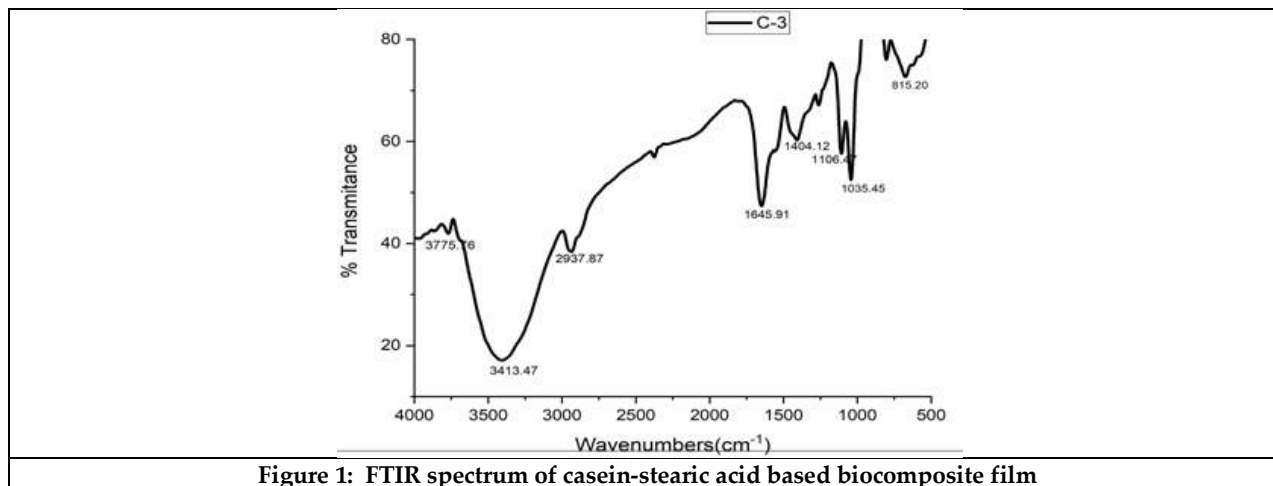


Figure 1: FTIR spectrum of casein-stearic acid based biocomposite film





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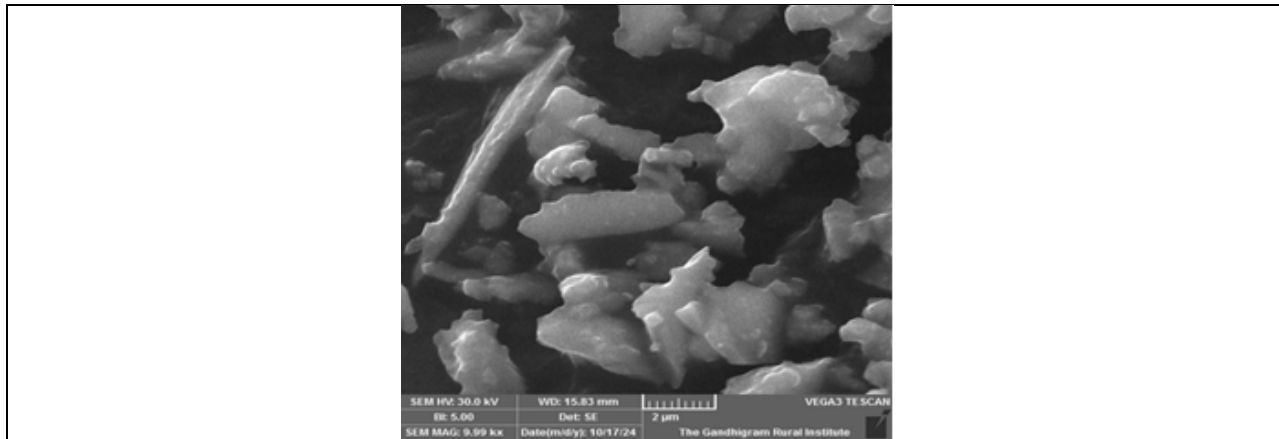


Figure 2 : SEM micrograph of casein - stearic acid based biocomposite film

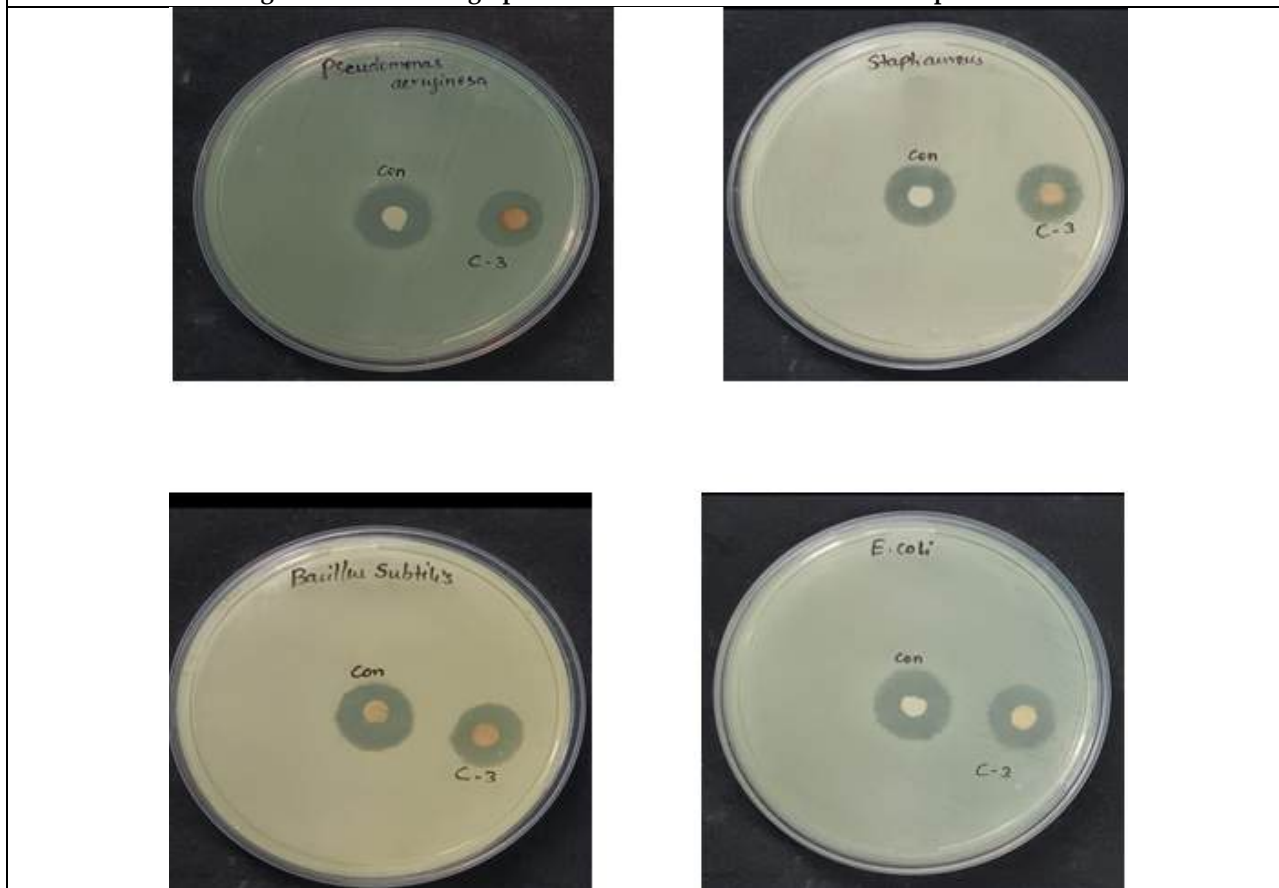


Figure (3) Antibacterial activity of casein-stearic acid based biocomposite film against different bacterial strains

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RESEARCH ARTICLE

Measurement of Lumbar Intervertebral Disc Space at the L4- L5 Segment using MRI

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ABSTRACT

The purpose of this study was to measure the intervertebral disc space at the L4- L5 segment using magnetic resonance imaging (MRI) in the evaluation of low back pain (LBP). The lumbar spine is a critical structure component of the human skeletal system, with the intervertebral disc playing a vital role in weight distribution and flexibility. Morphometric analysis of these structures is essential for understanding degenerative changes, planning surgical interventions, and establishing population-specific anatomical and L4-L5 is the most common site for disc herniation and degenerative changes. The objectives of this study were to perform a detailed morphometric analysis of the lumbar spine, specifically focusing on the measurement of intervertebral disc height at the L4-L5 level using Magnetic Resonance Imaging. A retrospective cross-sectional study was conducted using a dataset of 50 patients who underwent lumbar spine MRI morphometric measurement of the L4-L5 intervertebral disc space from mid- sagittal T2-weighted image. Parameters included anterior disc height, middle disc height and posterior disc height. Statistical analysis was performed to determine the mean value, standard deviation and any significant correlation related to patients. The analysis provided standardised measurements for



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the L4-L5 disc space within the study group. Statistical evaluation using ANOVA and p-value calculations was utilized and ensure the reliability of the data. It states that the calculated p-values of anterior, middle and posterior disc space was greater than the standard p-value that is 0.05.

Keywords: Disc herniation; Disc height; Lumbar intervertebral disc space; Low back pain; Magnetic resonance imaging.

INTRODUCTION

Magnetic Resonance Imaging

MRI is a non-invasive, radiation-free medical imaging technique that utilises strong magnetic fields and radio waves to produce detailed images of the human body's structures, including tissues, bones, muscles, ligaments, soft tissues, and fluids. To create images of the body's organs, magnetic resonance imaging (MRI) scanners employ radio waves, powerful magnetic fields, and gradients (5). It doesn't damage the patient's body because it uses non-ionising radiation. When a patient is placed in the strong magnetic field of an MRI scanner, the hydrogen nucleus in the body aligns with the electromagnet when exposed to a brief rush of electromagnetic energy in the form of radiofrequency (RF) pulses. The patient's hydrogen nuclei absorb the energy, producing an MR signal that aids in the production of images (9,11).

MRI Principle

Magnetic Resonance Imaging is based on the principle of nuclear magnetic resonance [NMR], the area of medicine that focuses on the behaviour of the nucleus, particularly on protons. Protons are positively charged and have rotatory movement called spin; any moving charge generates current, and every current has a small magnetic field around it. The human body is most abundant in hydrogen protons (11). The hydrogen protons in a patient's body align, some parallel and some antiparallel to the MRI machine's external magnetic field, when the patient lies down on the test table. A net magnetisation vector (NMV) is produced when the surplus hydrogen proton is cancelled. The radiofrequency pulse then causes the NMV to change from longitudinal magnetisation (LM) to transverse magnetisation (TM). The signal is then received, the radiofrequency pulse [RF] is shut off, and the monitor displays a picture (4).

Steps for MRI

- The patient is put inside the magnet: In the body of the invention, every randomly travelling proton aligns and precesses along the external magnetic field. Along the Z-axis, longitudinal magnetisation develops.
- An RF pulse is transmitted: To reach a higher energy level and precession in phase with one another, protons absorb energy from radiofrequency pulses. As a result, longitudinal magnetisation decreases and transverse magnetisation forms in the X-Y plane (11).
- MR signal: Due to transverse magnetization the current will be produced in the transverse plane, and the radiofrequency coil will receive the signal.
- Image formation: The MR signal received by the coil is transformed into an image by a complex mathematical process, such as the Fourier Transformation, by computers (16).

Intervertebral Disc Space of L4- L5

Magnetic resonance imaging (MRI) has recently become the most commonly applied diagnostic method for making the diagnosis of lumbar spinal stenosis or herniation because it is non-invasive, it provides diverse information on the lumbar soft tissues, and it provides high resolution image of the sagittal, axial and coronal planes. MRI enables precise measurement of disc height and morphology while also assessing the nucleus pulposus, annulus fibrosus,



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and adjacent vertebral endplates (2). Low back pain (LBP) is highly prevalent in adult populations, and the number of studies on the diagnosis, classification, and treatment of LBP is rapidly growing. LBP has been reported to incur pain, sick leaves, considerable social and economic expense, and disability in young adults (9,12,17). As in this study, the intervertebral disc space was measured at the L4-L5 segment. The five vertebrae (L1–L5) that make up the lumbar spine are divided by intervertebral discs. These discs serve as cushions, enabling mobility while absorbing shock. The largest and strongest vertebrae in the spine, the lumbar vertebrae support the weight of the upper body and allow for a variety of motions, including walking, lifting, and bending.

The lumbar spine plays a critical role in weight-bearing, mobility, and protection of neural elements. Among its segments, the L4–L5 level is particularly prone to degenerative changes, disc herniation, and height loss due to its anatomical position and mechanical load-bearing function. Accurate assessment of the intervertebral disc space at this level is essential for diagnosing degenerative disc disease, monitoring disease progression, and planning surgical or conservative treatment (5,8). The anterior surface of the intervertebral disc is larger than the posterior surface. Lower back pain can have a range of physical and psychological effects. Physical effects include pain, stiffness, decreased range of motion, and muscle spasms. It can also cause referred pain in the legs, affect posture, and impact sleep. Psychologically, it can lead to stress, anxiety, and even depression. The intervertebral spaces in the lumbar spine, formed by the intervertebral discs, are crucial for spinal health and function.

They act as shock absorbers, allowing for flexibility and movement while also separating the vertebrae to prevent grinding and nerve compression(18,20). Disc degeneration is a progressive condition that modifies the geometric morphology and biomechanical behaviour of an intervertebral disc, eventually affecting its ability to transmit and distribute loads. Lower back pain is a major cause of disc degeneration(24). This study focuses on the height of the intervertebral space of the lumbar region at the L4-L5 segment as the anterior, middle and posterior regions of the intervertebral space of lumbar region in patients aged 18-80. The L4 and L5 vertebrae are the fourth and fifth bones of the lumbar spine, and they also consist disc space, which refers to the area between these two vertebrae. The disc is the critical structure and performs many functions. The flexible pads that lie between each of the spinal column's bones are called discs. Each is a round, flat capsule with a soft, jelly-like interior called the nucleus pulposus and a hard, fibrous outer layer called the annulus fibrosis. Ligaments that connect the spinal bones to the surrounding muscular sheaths securely hold them in place (6,22). The purpose of the discs, a crucial component of the spinal joints, is to keep the vertebrae apart and stop them from rubbing against one another.

METHOD AND METHODOLOGY

Study site and inclusion criteria

This scientific study was a hospital-based observational study conducted in the Department of Radiodiagnosis, equipped with a United Imaging uMR780 3.0 Tesla MRI scanner, manufactured by Shanghai United Imaging Healthcare Company Limited. The patients were included with age group 18-80 with a history of low back pain.

Research design

This study was carried out on the “Measurement of Intervertebral disc space of L4-L5 segment of Lumbar spine using 3.0 Tesla MRI” with patients in the age group 18-80 years. The patient was scanned, and data were collected from the United Imaging uMR780 3.0 Tesla MRI scanner, which was manufactured by Shanghai United Imaging Healthcare Company Limited.

Sample size

This scientific study includes 50 patients with a clinical and radiological measurement of the intervertebral disc space of the L4-L5 segment of the lumbar spine using a United Imaging uMR780 3.0 Tesla MRI scanner.

Statistical analysis

The statistical method used for result was ANOVA (one-way analysis of variance). The standard deviation (SD), Mean, and standard error (SE) for all parametric variables were used. The probability value(p-value) was obtained and considered statistically significant, and the SYSTAT 13.2 software was used.





RESULT

It includes a sample of 50 patients with complaints of low back pain, where the focus was especially on the height of the intervertebral disc space anterior, middle and posterior at L4-L5 lumbar spine. It includes both males and females within the age range of 18 to 80 years and the patients are categorised into four age groups.

Age Distribution: According to age group, they are arranged in four groups (18-33 years), (34-49 years), (50-65 years) and (66-80 years) with equal intervals of 16 years each, which balanced the sample distribution and provided a clear comparison of degenerative changes. In (18-33) age group the young adults with minimal changes expected, (34-49) age group early changes phase begins, (50-65) age group the moderate degenerative changes are common due to loss of bone density and (66-80) age group there are more chances of advanced degenerative changes as the L4-L5 is prone to degenerative changes, disc herniation, and height loss due to its anatomical position and mechanical load-bearing function. The majority of patients in this study belonged to the 34-49 years age group (50%), followed by the 18-33 years age group (28%), 50-56 years age group (16%), and 66-80 years age group (6%). This suggests that middle-aged individuals formed the largest proportion of patients examined in this study. The higher number of patients in this age group may be related to increased occupational stress, lifestyle and mechanical strains on the lumbar spine during this period of life.

Anterior Intervertebral disc height: The mean middle disc height at the L4-L5 level showed slight variation among different age groups. The mean anterior height was 2.8mm in the 18-33 years age group, 3.0mm in the 50-56 years group, and 3.3mm in the 66-80 years group, with an overall mean of 3.0mm. Although minor differences were observed among the age groups, statistical analysis showed that these differences were not significant ($p = 0.312$). This indicates that age does not have a significant difference on anterior disc height in the study.

Middle Intervertebral disc height: The mean middle disc height at the L4-L5 level was 1.7mm in the 18-33 years group, 2.9mm in the 34-49 years group, 2.1mm in the 50-65 years group, and 3.4mm in the 66-80 years group, with an overall mean value of 2.5mm. Although the middle disc height appeared higher in the older age group, the difference was not statistically significant ($p=0.644$). This finding suggests that variations in middle disc height across age groups may occur, but age does not have a significant effect on middle disc height in the study.

Posterior Intervertebral disc height: The mean posterior disc height was 1.1mm in the 18-33 years group, 2.2mm in the 34-49 years group, 1.2mm in the 50-56 years group, and 3.0mm in the 66-80 years group, with an overall mean value of 1.8mm. Similar to the anterior and middle heights, no statistically significant difference was observed among age groups ($p=0.701$). This suggests that posterior disc height does not have a statistical difference in this study. This study aimed to measure the height of the intervertebral disc space anterior, middle and posterior of the lumbar spine at segment L4-L5 based on different age group 18-80 years with the help of the United Imaging uMR780 3.0 Tesla MRI scanner. A total of 50 patients were included in this study, and the measurement of anterior, middle and posterior disc heights. In some previous studies, the measurement was done from x ray of the lumbar spine, with a 1.5 Tesla MRI, which also provides the effective result and measurement of data in this study. The 3.0 Tesla United Imaging uMR780 scanner is used, which is AI- driven, minimises motion and provides high-resolution image quality for measurement and diagnosis.

DISCUSSION

In the previous study of found that lumbar X-ray measurements can predict lumbar disc herniation (LDH) and degeneration in young adults (20-25 years) with low back pain. The standard lumbar spine MRI sequences were reviewed, and disc height at L4-L5 was measured at anterior, middle, and posterior points on the midsagittal view.



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Measurements were averaged for analysis. MRI provided precise disc space measurements with clear visualisation of endplates and disc margins, enabling detection of early degenerative changes. Based on the measurement of L4-L5 disc space is a reliable method for quantitative assessment, aiding in diagnosis, monitoring, and treatment planning of lumbar spine disorders. L4-L5 disc space showed a significant difference in different age groups. Another study found the changes in height and area of the intervertebral foramen at the L4–L5 level in degenerative lumbar discs under varying pushing heights using the finite element method. A male volunteer in good health provided CT and MRI scans of the T12–S1 regions. Mimics 16.0 and Geomagic Studio 2014 were used to create a three-dimensional finite element model of the typical lumbar spine. Models simulating mild, moderate, and severe degeneration of the L4–L5 disc were generated by adjusting disc height and nucleus pulposus area according to the classification.

This study aimed to measure the height of the intervertebral disc space anterior, middle and posterior of the lumbar spine at segment L4-L5 based on different age group 18-80 years with the help of the United Imaging uMR780 3.0 Tesla MRI scanner. A total of 50 patients were included in this study, and the measurement of anterior, middle and posterior disc heights was analysed using the ANOVA (one-way ANOVA) with the help of SYSTAT 13.2 software. In this study, the gender distribution showed that 26 patients (52%) were male and 24 patients (48%) were female, indicating an almost equal representation of both genders in the study population. The mean anterior intervertebral disc height at the L4-L5 level showed slight variation among age groups, with an overall mean value of (3.0mm), middle height mean value (2.5mm) and posterior height mean value (1.8mm) for the total study population. Although a small variation in disc height was observed among different age groups, statistical analysis revealed that these differences were not statistically significant. The results state that the p-value of anterior, middle, and posterior disc height is greater than the standard p-value of 0.05, which indicates that there is no significant difference in height of the intervertebral disc between the anterior, middle, and posterior regions according to the different age groups.

CONCLUSION

In this study, 50 patients between the ages of 18 and 80 had their intervertebral disc space at the L4-L5 segment quantitatively analysed using Magnetic Resonance Imaging (MRI). This study emphasises the significance of morphometric data in the diagnosis and treatment of lumbar spine disorders by evaluating the anterior, middle, and posterior disc heights. It was conducted to evaluate the intervertebral disc space height at the L4-L5 level in different age groups, the patients were arranged in four age groups with a uniform difference of 16 years that is (18-33) years which includes young adults with chances of minimal degenerative changes, (34-49) years which include early degenerative phase begins, (50-65) years it includes the moderate degenerative changes occurs in patients body and (66-80) years it includes the highly chances of degenerative changes due to loss of bone density and bones become fragile. This study successfully provided the normative dataset for the L4-L5 disc height within the specific population, as the L4-L5 segment bears the highest degree of mechanical stress and disc degeneration. This measurement provides the quantitative data of given samples. It highlights the significant correlation found between disc height reduction and clinical symptoms like lower back pain, degenerative changes, disc herniation, nerve blockages, etc. It provides a better pathway to the Healthcare professionals, including neurologists, radiologists and neurosurgeons for preoperative assessment, optimise treatment planning, artificial surgery implants and surgical outcomes.

The United Imaging uMR 780 3.0 Tesla MRI scanner offers advanced features to improve the lumbar spine imaging through a high-density 48-channel spine Coil, AI- Driven system and high-quality image resolution. It plays a vital role in lumbar intervertebral disc space height measurement with high-quality imaging and without exposing the patients to better diagnosis. For future aspects, the researcher can measure by using the superior Signal to Noise Ratio (SNR), 3D imaging with biochemical mapping to detect disc degeneration at the molecular level before physical height loss of the disc. The integration of Artificial Intelligence (AI) further uses this process by providing automated segmentation, which eliminates human variability and allows for the longitudinal tracking of disc height index with accuracy. It facilitates the functional diagnostic range and measurement accuracy with realistic stability of spine and





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nerve root compression at the high stress junction L4-L5, directly improving the surgical planning and patient outcomes. This scientific study concludes that the measurement of intervertebral disc space height did not have any effect on different age groups. A total of 50 patients were included in the study, and the anterior, middle and posterior heights of the intervertebral disc space were measured and analysed using the ANOVA (one-way ANOVA) with the help of SYSTAT 13.2 software. The p-value of anterior, middle and posterior disc height is greater than the standard p-value (0.05), which states that there is no significant difference in height of intervertebral disc space height anterior, middle and posterior according to the different age groups.

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Table 1: showing the result of height differences in anterior, middle and posterior at the L4-L5 segment.

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Anterior (mm)	Between Groups	33.842	3	11.281	1.223	0.312
	Within Groups	424.284	46	9.224		
	Total	458.126	49			
Middle (mm)	Between Groups	10.887	3	3.629	0.560	0.644
	Within Groups	298.157	46	6.482		
	Total	309.044	49			
Posterior(mm)	Between Groups	5.251	3	1.750	0.475	0.701
	Within Groups	169.372	46	3.682		
	Total	174.623	49			

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RESEARCH ARTICLE

Basic Life Support Knowledge and Awareness Among Undergraduate Allied Health Science Students : A Cross - Sectional Analytical Study

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ABSTRACT

Cardiac arrest remains a leading cause of preventable death globally, with survival rates critically dependent on immediate bystander intervention. Allied health science students, given their clinical proximity, represent a high-yield target population for basic life support (BLS) education. However, evidence regarding the adequacy of their BLS knowledge across all domains remains limited and methodologically inconsistent. This study quantified BLS knowledge across five domains among undergraduate allied health science students and identified determinants of adequate performance. A cross-sectional survey was administered to 500 undergraduate allied health science students using a validated 20-item questionnaire assessing BLS conceptual knowledge, victim assessment, technical proficiency, and equipment familiarity. Descriptive statistics, chi-square tests, and binary logistic regression were employed to characterize performance and identify associated factors. The mean overall BLS knowledge score was 13.31 out of 20 (SD = 3.24; 66.6% correct). Conceptual knowledge was highest (79.7%), while technical proficiency was lowest (59.6%). Only 35.6% of participants had prior BLS training. In multivariate logistic regression, prior BLS training (OR = 3.47; 95% CI: 2.31-5.21; $p < 0.001$) and



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advanced year of study (OR = 2.18; 95% CI: 1.54-3.09; $p < 0.001$) were the strongest independent predictors of adequate knowledge. BLS knowledge among allied health science undergraduates is inadequate, particularly in technical execution and equipment domains. Curricular integration of competency-based BLS training is urgently needed. These findings provide evidence for institutional policy reform and structured simulation-based BLS training programs.

Keywords: basic life support, CPR knowledge, allied health students, cardiac arrest, emergency preparedness, layperson resuscitation

INTRODUCTION

Sudden cardiac arrest (SCA) is one of the leading causes of premature mortality worldwide, with an estimated 3.7 million out-of-hospital cardiac arrests (OHCA) occurring annually across Europe alone, and comparable incidence documented in South and Southeast Asia [1,2]. Survival from OHCA is time-sensitive and dependent on the rapid initiation of the chain of survival, which begins with early recognition, activation of emergency services, high-quality cardiopulmonary resuscitation (CPR), and defibrillation [3]. For every minute without CPR, the probability of survival decreases by approximately 7-10%, underscoring the irreplaceable role of bystander intervention in out-of-hospital scenarios [4]. Basic life support (BLS) encompasses a set of standardized skills including recognition of cardiac arrest, chest compressions, rescue breathing, use of automated external defibrillators (AED), relief of foreign body airway obstruction, and initial victim assessment [5]. Current guidelines from the American Heart Association (AHA) and the European Resuscitation Council (ERC) recommend widespread dissemination of BLS training to both healthcare personnel and the lay public [6,7]. The compression-to-ventilation ratio of 30:2 and a compression rate of 100-120 per minute are among the most critical technical standards that must be reliably internalized [8].

Allied health science students, comprising disciplines such as physiotherapy, operation theatre technology, medical laboratory technology, radiological technology, and respiratory therapy, occupy a unique intermediate position in the healthcare ecosystem. They interact directly with patients in clinical settings, often without immediate physician supervision, and are frequently present during emergencies in hospital corridors, rehabilitation wards, and imaging suites [9]. Unlike medical or nursing students, whose BLS training is typically mandated and rigorously assessed, allied health curricula exhibit considerable heterogeneity in how BLS competency is incorporated [10,11]. Previous studies from India, Saudi Arabia, Malaysia, and sub-Saharan Africa have reported BLS knowledge deficits among allied health and nursing students, with correct response rates ranging from 37% to 71% [12-16]. However, these studies are frequently limited by small sample sizes, single-discipline sampling, non-validated questionnaires, and absence of multivariate analysis to disentangle the contributions of training, programme type, and year of study [17]. Furthermore, item-level and domain-level analyses that identify specific knowledge gaps are rarely reported, limiting the actionability of findings for curriculum design. The present study addressed these gaps by administering a structured 20-item questionnaire to 500 undergraduate allied health science students across five disciplines. The objectives were: (1) to determine the prevalence and magnitude of BLS knowledge across conceptual, assessment, technical, and equipment domains; (2) to perform item-level gap analysis to identify the most vulnerable knowledge areas; and (3) to identify independent predictors of adequate BLS knowledge using multivariate logistic regression.

METHODS

Study Design and Setting

This study was conducted as a cross-sectional, institution-based, quantitative survey. Data were collected between January 2025 and March 2026 from undergraduate allied health science students enrolled at a university-affiliated health sciences institution in northern India. Ethical approval was obtained from the Institutional Ethics Committee (IEC/2025/AHS/07), and all participants provided informed electronic consent prior to participation. No identifying information was collected (fully anonymous design). The sampling and exclusion flow is presented in Figure 1.





Participants and Sampling

The target population comprised undergraduate students from five allied health science programmes: physiotherapy (BPT), operation theatre technology (BOTT), medical laboratory technology (BMLT), radiological technology (BRIT), and respiratory therapy (BRT). Inclusion criteria were: (i) current enrollment in years 1 through 4 of an allied health science degree programme; (ii) age 17-25 years; (iii) willingness to complete the survey. Exclusion criteria included: students who had previously received formal AHA/BLS certification in the current academic year and students from postgraduate programmes. Using an estimated BLS knowledge prevalence of 55% from prior literature, a margin of error of 5%, and a 95% confidence interval, the minimum required sample size was calculated as 380 using the formula $n = Z^2 * P(1-P) / d^2$ [18]. A final sample of 500 was recruited using stratified random sampling proportional to programme enrollment, with Microsoft Forms used as the anonymous data collection platform.

Instrument

The survey instrument was a 20-item True/False questionnaire developed by the research team based on 2020 AHA Guidelines for CPR and Emergency Cardiovascular Care and the ERC 2021 Guidelines [6,7]. Items spanned four knowledge domains: (1) Conceptual knowledge (7 items: BLS definition, applicability, objectives, eligible responders, choking management, CPR relationship, recovery position); (2) Victim assessment (4 items: scene safety, breathing check, pulse check duration, indications for CPR); (3) Technical proficiency (5 items: hand position, compression rate, compression depth cues, arm position, compression-to-ventilation ratio, rescue breath necessity); (4) Equipment knowledge (3 items: AED role, AED-CPR interaction, equipment dependency). Face and content validity were established through expert review by three certified BLS instructors. Pilot testing on 30 students (excluded from main analysis) yielded a Cronbach alpha of 0.78, indicating acceptable internal consistency. Each correct answer scored 1 point (maximum 20 points). An overall score of $\geq 14/20$ ($\geq 70\%$) was defined as adequate BLS knowledge, consistent with established cut-offs in the literature [19].

Statistical Analysis

Data were analyzed using IBM SPSS Statistics version 27.0. Continuous variables were expressed as mean and standard deviation (SD); categorical variables as frequency and percentage. Domain-wise performance was calculated as the proportion of correct responses per domain. Chi-square tests (with Yates continuity correction for 2x2 tables) assessed bivariate associations between sociodemographic variables and adequate BLS knowledge. Variables significant at $p < 0.10$ in bivariate analysis were entered into a binary logistic regression model (enter method) to identify independent predictors of adequate knowledge (score $\geq 14/20$). Results were expressed as adjusted odds ratios (OR) with 95% confidence intervals (CI). Statistical significance was set at $p < 0.05$. Pearson correlation was computed between year of study and total BLS score to quantify the knowledge-experience gradient. A receiver operating characteristic (ROC) analysis was performed to confirm the discriminative validity of the knowledge score, with area under the curve (AUC) as the primary metric.

RESULTS

Sociodemographic Profile

A total of 500 students completed the survey (response rate: 94.3% of 530 invited). Table 1 presents the sociodemographic characteristics of the sample. The majority of respondents were female ($n = 302$; 60.4%). The modal age group was 20-22 years ($n = 243$; 48.6%). Physiotherapy students constituted the largest programme subset ($n = 142$; 28.4%). Only 178 students (35.6%) reported any prior BLS training, predominantly through informal workshops or online modules, with no formal AHA or ERC certification reported among the trained subgroup.

Overall BLS Knowledge

The mean total knowledge score was 13.31 (SD = 3.24) out of 20, corresponding to 66.6% overall accuracy. The score distribution was approximately normal (skewness = -0.31; kurtosis = -0.47), as illustrated in Figure 2. Using the pre-defined cut-off of $\geq 14/20$, 214 students (42.8%) demonstrated adequate BLS knowledge, while 286 (57.2%) scored



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below the threshold. The ROC analysis yielded an AUC of 0.74 (95% CI: 0.70-0.78), confirming acceptable discriminative validity of the instrument.

Item-Level and Domain-Level Analysis

Table 2 presents item-level performance data. The highest correct response rates were observed for items addressing the primary aim of BLS (Q1: 92.6%), the ability of trained laypersons to perform CPR (Q20: 90.2%), and BLS applicability across age groups (Q13: 89.4%). In contrast, the lowest correct response rates were recorded for the AED-CPR interaction question (Q11: 45.6%), prolonged pulse check (Q5: 50.2%), and the non-mandatory nature of rescue breaths (Q9: 53.4%). Figure 3 presents a visual summary of item-level performance color-coded by domain. Domain-level analysis (Table 3) revealed a clear performance gradient: conceptual knowledge was highest (79.7%), followed by victim assessment (71.5%), equipment knowledge (63.1%), and technical proficiency (59.6%). The technical proficiency domain, which assessed compression rate, hand position, arm position, compression-to-ventilation ratio, and rescue breath indications, performed significantly below all other domains (Bonferroni-corrected pairwise chi-square, $p < 0.01$ for all comparisons with conceptual domain).

Predictors of Adequate BLS Knowledge

In bivariate analysis, prior BLS training (chi-square = 62.4; $p < 0.001$), year of study (chi-square = 38.7; $p < 0.001$), and programme type (chi-square = 11.2; $p = 0.024$) were significantly associated with adequate knowledge. Sex ($p = 0.487$) and age group ($p = 0.154$) were not significant and were not retained in the regression model. Pearson correlation between year of study and total score was $r = 0.41$ ($p < 0.001$), indicating a moderate positive association between academic progression and BLS knowledge acquisition. Binary logistic regression (Table 4) identified prior BLS training (OR = 3.47; 95% CI: 2.31-5.21; $p < 0.001$) as the strongest independent predictor of adequate knowledge, followed by advanced year of study (3rd-4th vs 1st-2nd: OR = 2.18; 95% CI: 1.54-3.09; $p < 0.001$) and programme type (physiotherapy/ operation theatre technology vs others: OR = 1.63; 95% CI: 1.12-2.37; $p = 0.010$). The Hosmer-Lemeshow goodness-of-fit test was non-significant (chi-square = 6.21; df = 8; $p = 0.624$), indicating adequate model fit. The Nagelkerke R^2 was 0.31, indicating that the model explained 31% of variance in adequate BLS knowledge. Figure 5 displays the forest plot of these regression outputs.

DISCUSSION

This study provides a rigorous, domain-stratified quantitative analysis of BLS knowledge among 500 undergraduate allied health science students, a population whose proximity to clinical emergencies makes their competency both clinically relevant and academically under-investigated. The principal finding, that fewer than half (42.8%) of participants met the a priori threshold for adequate BLS knowledge, is consistent with but contextually extends the existing evidence base [12,14,20]. The domain-level gradient observed here, with conceptual knowledge exceeding technical proficiency by 20 percentage points (79.7% vs 59.6%), is analytically important and has direct curricular implications. Conceptual items, such as the definition of BLS and the legality of layperson CPR, are amenable to passive didactic instruction and are routinely covered in health sciences curricula as foundational anatomy and physiology content [21]. Technical proficiency items, by contrast, require procedural knowledge that can only be reliably encoded through supervised practice with manikins, immediate feedback, and deliberate repetition [22]. The specific failure rates observed for compression rate (Q8: 58.8% correct), arm position (Q16: 56.6% correct), and AED-CPR sequence (Q11: 45.6% correct) indicate that procedural skills are the most vulnerable component of BLS readiness in this population, a finding replicated by Gonzalez-Salvado et al. (2022) in European nursing students and by Bhanji et al. (2021) in multi-country healthcare trainee cohorts [23,24].

The particularly low correct response rate for AED-CPR sequencing (Q11: 45.6%) warrants dedicated attention. A substantial proportion of participants incorrectly endorsed stopping CPR when an AED becomes available, which represents a potentially lethal misconception. Current guidelines emphasize that CPR should be interrupted only for



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the brief period of rhythm analysis and shock delivery, with immediate resumption thereafter [6]. This knowledge gap likely reflects inadequate integration of AED instruction into allied health curricula, which tend to devote limited contact hours to resuscitation equipment familiarization [25]. The finding corroborates reports from Tanigawa et al. (2021) and Al-Turki et al. (2022), who identified AED knowledge as consistently weaker than compression knowledge among health professions students [26,27]. The logistic regression model identified prior BLS training as the dominant modifiable predictor of adequate knowledge (OR = 3.47), a finding that carries a straightforward policy interpretation: structured BLS training, even at basic workshop level, more than tripled the odds of adequate knowledge. This is congruent with a systematic review by Nas et al. (2023), which reported that training status was the single most consistent predictor of BLS competence across 34 studies in healthcare student populations [28]. Crucially, only 35.6% of the current sample had any prior BLS exposure, indicating that training penetration is low and unequally distributed across programmes.

The association between advanced year of study and adequate knowledge (OR = 2.18) suggests that academic progression confers some BLS benefit through cumulative clinical exposure, even without formal BLS instruction. However, the correlation coefficient ($r = 0.41$) indicates that year of study explains only approximately 17% of the variance in knowledge scores, reinforcing that passive academic progression cannot substitute for explicit BLS training. This observation parallels findings from Chew et al. (2022) in Malaysian health science students, who similarly reported year of study as a significant but partial predictor of CPR knowledge [29]. Programme-level differences (physiotherapy/operation theatre technology outperforming other disciplines) reflect the comparatively higher emphasis on musculoskeletal and cardiopulmonary rehabilitation in these programmes, which may incidentally reinforce BLS-relevant knowledge [30]. However, all programme means fell below the 70% adequacy threshold, indicating that no single programme provided sufficient BLS preparation, and that curricular reform is needed across the board. From a public health perspective, the low training prevalence identified here (35.6%) contrasts starkly with recommendations from the AHA and ERC, both of which advocate for universal CPR training among all healthcare workers and trainees [6,7].

Allied health students spend considerable time in clinical rotations and are plausible first responders in ward and rehabilitation settings. Their inadequate BLS preparation constitutes a systemic vulnerability in the clinical safety infrastructure of teaching hospitals [31]. Evidence from Kragholm et al. (2021) and Ringh et al. (2022) demonstrates that increasing bystander CPR rates through mass training programs is associated with measurable survival improvements at the population level, providing an epidemiological rationale for mandatory BLS training in allied health curricula [32,33]. Several intervention strategies are supported by the literature. Simulation-based learning using high-fidelity manikins with real-time CPR feedback devices produces more durable skill retention than lecture-based training alone [34]. Microlearning approaches, comprising brief structured refresher sessions distributed across academic semesters, outperform single-session training in retention at six-month follow-up [35]. Peer-to-peer CPR instruction models have demonstrated feasibility and effectiveness in resource-constrained settings and may offer a scalable solution for institutions with limited certified BLS trainers [36]. Furthermore, integration of AED familiarization modules into the BLS curriculum specifically addresses the equipment knowledge gap identified in this study.

Limitations

This study has several limitations that should be considered when interpreting findings. First, the cross-sectional design precludes causal inference regarding the relationship between training and knowledge. Second, the survey was conducted at a single institution in northern India, which may limit generalizability to other geographic or institutional contexts. Third, self-reported training history was not externally verified. Fourth, the instrument assessed declarative knowledge only; psychomotor BLS skills, which represent the most critical operational dimension of BLS competence, were not assessed in this survey-based design. Future research should incorporate objective structured clinical examination (OSCE) components to capture skill performance. Fifth, recall bias may have affected responses to items addressing specific numerical parameters such as compression rate and ratio. Despite



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these limitations, the large sample size, stratified sampling, validated instrument, and rigorous multivariate analysis represent methodological strengths that enhance the reliability of the reported findings.

CONCLUSIONS

BLS knowledge among undergraduate allied health science students is inadequate, with fewer than half meeting the a priori threshold for acceptable competence. Technical proficiency and AED-related knowledge represent the most critical gaps. Prior BLS training and advanced year of study are the strongest predictors of adequate knowledge, but only one-third of students have received any prior training. These findings provide empirical justification for mandatory, competency-assessed BLS training as a core curricular requirement across all allied health science programmes. Institutions should adopt simulation-based, feedback-guided BLS training curricula with periodic reassessment to ensure durable competency.

Declarations

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflicts of Interest: The authors declare no conflicts of interest.

Ethical Approval: The study was approved by the Institutional Ethics Committee. All participants provided electronic informed consent.

Data Availability: Anonymized data are available upon reasonable request to the corresponding author.

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Table 1. Sociodemographic characteristics of participants (N = 500)

Characteristic	Category	n (%)
Sex	Male	198 (39.6%)
	Female	302 (60.4%)
Age (years)	17-19	187 (37.4%)
	20-22	243 (48.6%)
	23-25	70 (14.0%)
Year of study	1st year	138 (27.6%)
	2nd year	156 (31.2%)
	3rd year	122 (24.4%)
	4th year	84 (16.8%)
Programme	Physiotherapy	142 (28.4%)
	Operation Theatre Technology	98 (19.6%)
	Medical Lab Technology	112 (22.4%)
	Radiological Technology	88 (17.6%)
	Respiratory Therapy	60 (12.0%)
Prior BLS training	Yes	178 (35.6%)
	No	322 (64.4%)

Table 2. Item-wise correct response rates across all 20 BLS knowledge items (N = 500)

Ques No.	Item	Correct n (%)	Correct Answer	Domain
1	Main aim of BLS is to save life	463 (92.6%)	True	Concept
2	Only doctors can perform BLS	389 (77.8%)	False	Concept
3	CPR is a part of BLS	441 (88.2%)	True	Concept
4	Checking breathing is a step in BLS	398 (79.6%)	True	Assessment
5	Pulse check in adults should take >10 sec	251 (50.2%)	False	Assessment
6	Chest compressions given with palm of hand	412 (82.4%)	True	Technique
7	Adult CPR given with only one hand	338 (67.6%)	False	Technique
8	Compression speed should be 100-120/min	294 (58.8%)	True	Technique
9	Rescue breaths are always mandatory	267 (53.4%)	False	Technique
10	AED is used in BLS	356 (71.2%)	True	Equipment
11	CPR should stop when AED is available	228 (45.6%)	False	Equipment
12	Scene safety check is part of BLS	421 (84.2%)	True	Assessment
13	BLS applicable for both children and adults	447 (89.4%)	True	Concept
14	Choking is managed under BLS	374 (74.8%)	True	Concept
15	Hospital equipment always required for BLS	362 (72.4%)	False	Equipment
16	Arms should be bent during compressions	283 (56.6%)	False	Technique
17	Adult CPR compression:breath ratio is 30:2	309 (61.8%)	True	Technique
18	CPR given if patient is breathing normally	418 (83.6%)	False	Assessment
19	Recovery position is part of BLS	376 (75.2%)	True	Concept
20	Trained layperson can give CPR in emergency	451 (90.2%)	True	Concept



Sanyyam Thakur *et al.*,**Table 3. Domain-wise BLS knowledge performance summary (N = 500)**

Domain	Items (n)	Mean Score (SD)	% Correct	Performance Level
Conceptual Knowledge	7	5.58 (1.12)	79.7%	Good
Assessment Skills	4	2.86 (0.94)	71.5%	Moderate
Technical Proficiency	5	2.98 (1.08)	59.6%	Poor
Equipment Knowledge	3	1.89 (0.76)	63.1%	Moderate
Overall (20 items)	20	13.31 (3.24)	66.6%	Moderate

Table 4. Binary logistic regression: predictors of adequate BLS knowledge (score $\geq 14/20$)

Variable	OR	95% CI	p-value	Interpretation
Prior BLS training (Yes vs No)	3.47	2.31-5.21	<0.001*	Significant
Year of study (3rd-4th vs 1st-2nd)	2.18	1.54-3.09	<0.001*	Significant
Programme (PT/OT vs others)	1.63	1.12-2.37	0.010*	Significant
Sex (Female vs Male)	1.14	0.79-1.64	0.487	Not Significant
Age (20-25 vs 17-19 years)	1.29	0.91-1.83	0.154	Not Significant

OR = Odds Ratio; CI = Confidence Interval; NS = Not Significant; PT = Physiotherapy; OT = Operation Theatre Technology; *p < 0.05

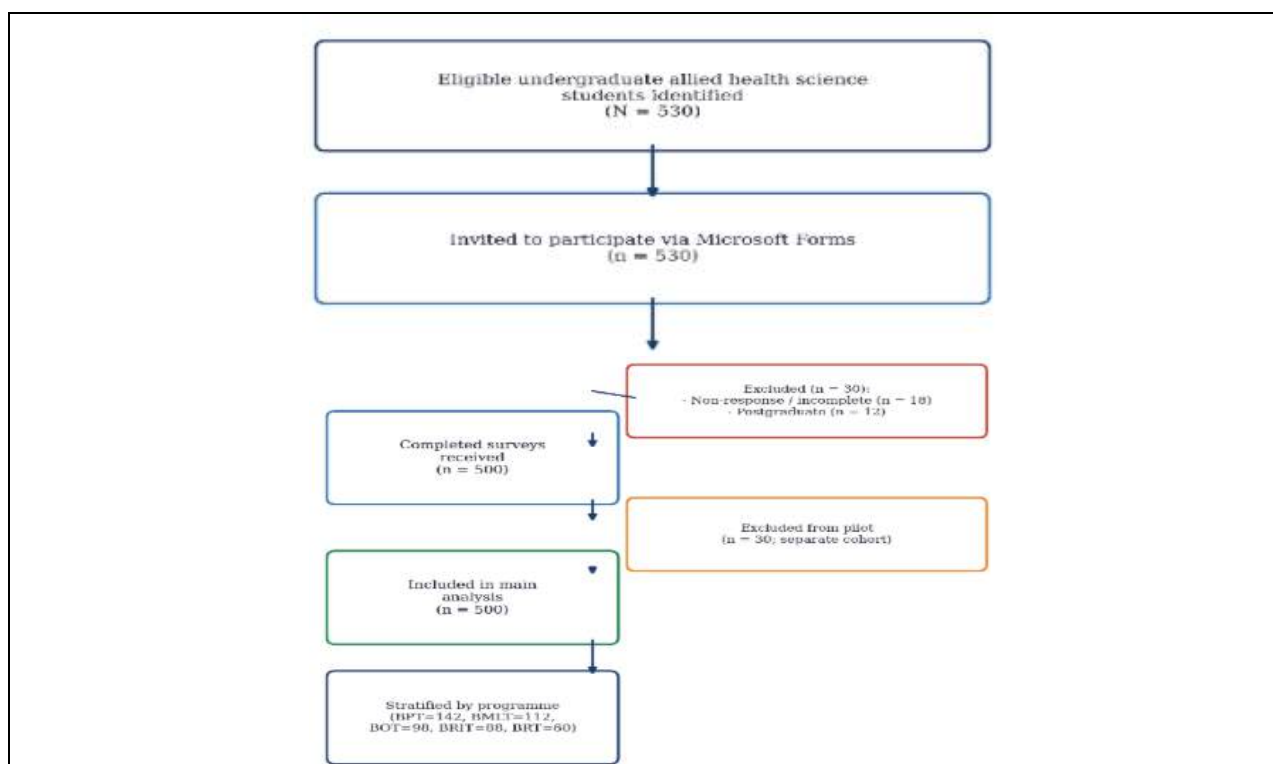


Figure 1. STROBE-compliant participant flow diagram illustrating the sequence from initial eligibility assessment (N = 530) through to the stratified final analytic sample (N = 500). Exclusions are shown with justification at each stage. The pilot cohort (n = 30) was drawn from the same institution but analyzed separately and excluded from the main analysis. Proportional programme allocation by enrollment is displayed at the terminal node



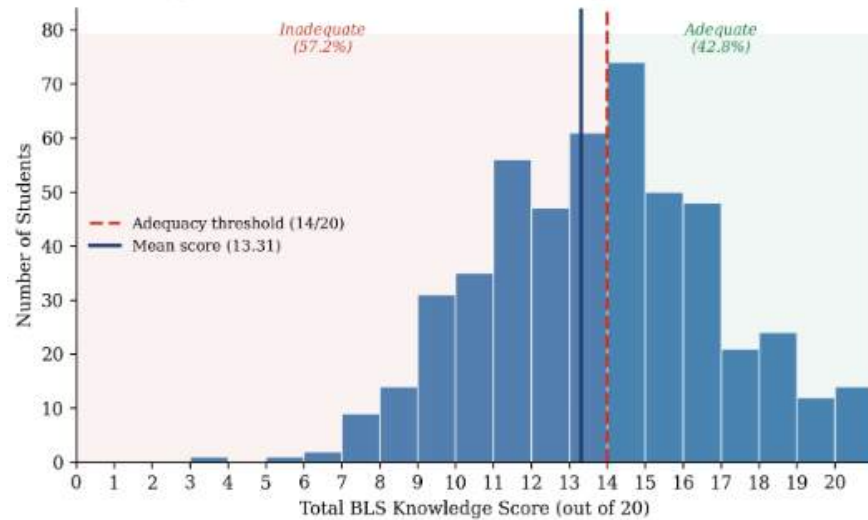
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Figure 2. Frequency distribution histogram of total BLS knowledge scores (range 0-20) across the full sample (N = 500). The red dashed vertical line demarcates the pre-specified adequacy threshold (score ≥ 14 ; 70%); the blue solid line denotes the sample mean (13.31, SD = 3.24). Red and green shading highlight the proportions of students performing below (57.2%) and at or above (42.8%) the threshold, respectively. The distribution approximates normality (skewness = -0.31; kurtosis = -0.47).

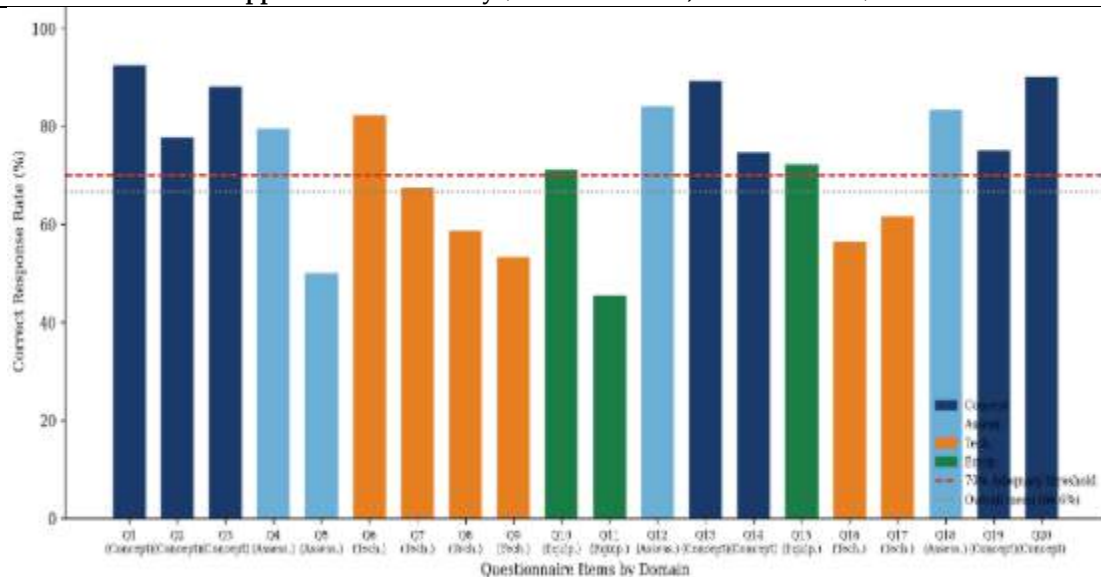


Figure 3 Item-level Correct Response Rates Across All 20 BLS Knowledge Items

Bar chart illustrating the percentage of correct responses for each of the 20 BLS questionnaire items, color-coded by knowledge domain: Conceptual Knowledge (dark blue), Victim Assessment (light blue), Technical Proficiency (orange), Equipment Knowledge (green). The red dashed horizontal line indicates the 70% adequacy threshold; the grey dotted line denotes the overall sample mean (66.6%). Items for which correct response rates fall below both reference lines (Q5, Q8, Q9, Q11, Q16) represent priority targets for curricular remediation.



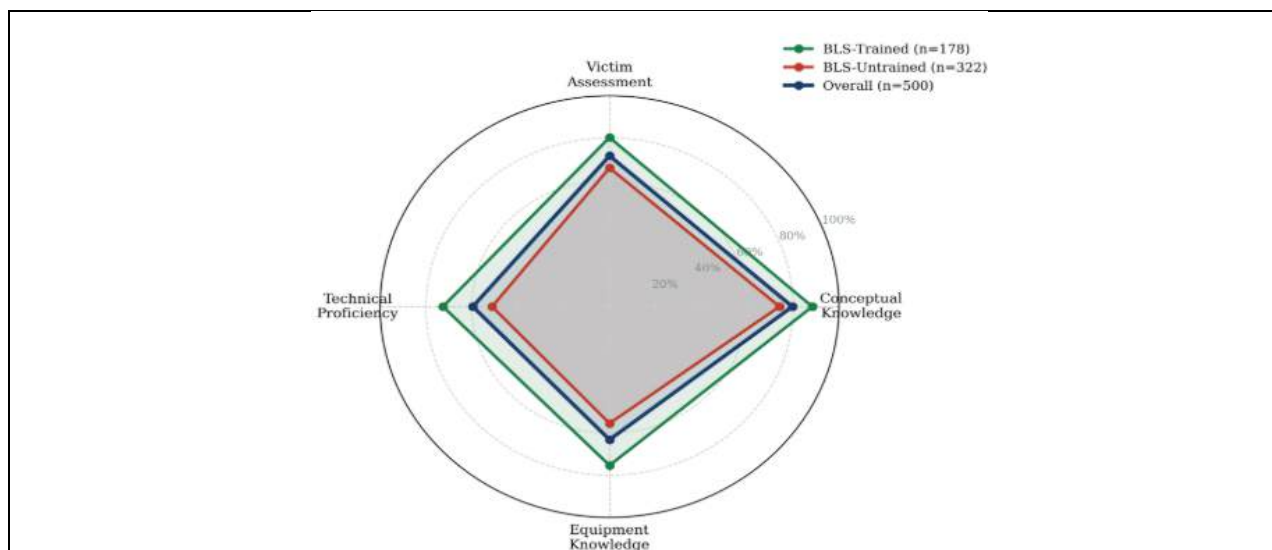
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Figure 4. Radar (spider) chart comparing domain-wise BLS knowledge performance (%) across the overall sample (dark blue; N = 500), BLS-trained students (green; n = 178), and BLS-untrained students (red; n = 322). Each axis represents one knowledge domain scaled from 0% to 100%. The larger enclosed area of the trained subgroup across all four axes quantifies the consistent advantage conferred by prior BLS training, most pronounced in the Technical Proficiency (72.6% vs 51.2%) and Equipment Knowledge (75.3% vs 55.4%) domains.

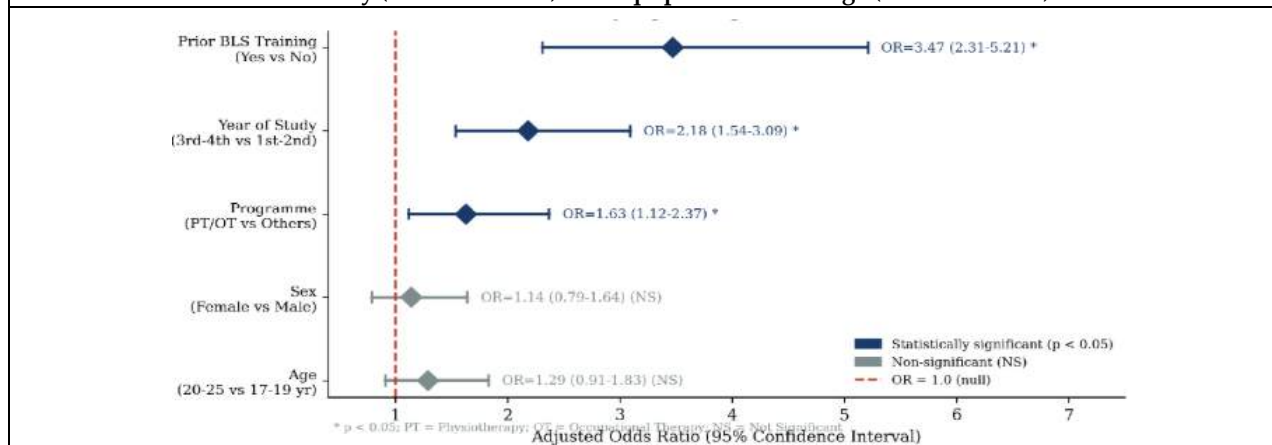


Figure 5. Forest plot of adjusted odds ratios (OR) and 95% confidence intervals (CI) from binary logistic regression modeling predictors of adequate BLS knowledge (score $\geq 14/20$; N = 500). Diamond markers indicate point estimates; horizontal bars span 95% CIs. Variables independently associated with adequate knowledge at $p < 0.05$ are shown in dark blue; non-significant variables appear in grey. The red dashed vertical line represents OR = 1.0 (null). Prior BLS training was the strongest predictor (OR = 3.47; 95% CI: 2.31-5.21), followed by advanced year of study and clinical programme type. Hosmer-Lemeshow goodness-of-fit: chi-square = 6.21, df = 8, $p = 0.624$; Nagelkerke $R^2 = 0.31$.

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RESEARCH ARTICLE

An Analysis Study of Accurate Insight and type of Ovarian Cancer Complaint Circumstance using Hybridized Bacterial Rustling with Flyspeck Mass and Multi Kernel SVM Approach

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ABSTRACT

The identification of biomarkers is pivotal for cancer opinion, understanding the beginning natural mechanisms, and developing targeted curatives. In this study, we propose a machine literacy approach to prognosticate ovarian cancer cases' issues and platinum resistance status using intimately available gene expression data. The significance of detecting and precluding ovarian cancer is of utmost significance for women's overall health and heartiness. Appertained to as the "silent killer," ovarian cancer exhibits invisible symptoms during its original phases, posing a challenge for timely identification. Identification of ovarian cancer during its advanced stages significantly diminishes the liability of effective treatment and survival. This study proposes a new convolutional neural network[CNN] algorithm for prognosticating and diagnosing ovarian cancer, addressing these limitations. In this paper, CNN was trained on a histopathological image dataset, divided into training and confirmation subsets and stoked before training. The model achieved a remarkable delicacy of 94, with 95.12 of cancerous cases rightly linked and 93.02 of healthy cells directly classified. The significance of this study lies in prostrating the challenges associated with the mortal expert examination, similar as advanced misclassification rates, inter-observer variability, and extended analysis times[10,11].

Keywords: ovarian cancer, machine learning, cancer detection ,explainable AI, histopathological images , gynaecologic, augmentation, SVM method



**Nithya****INTRODUCTION**

Ovarian cancer is the most murderous gynaecologic malignancy, with a five- time survival rate of 49 for all stages of the cancer[1]. Ovarian cancer is truly aggressive and constantly recurs after posterior treatments. utmost cases will acquire resistance through treatment conforming of carboplatin- predicated chemotherapy as well as PARP impediments[2,3]. Ovarian cancer is constantly diagnosed at advanced FIGO stages, which leads to overall poor survival rates. The symptoms are generally non-specific, and therefore early discovery styles, heritable netting, and multiple treatment options are demanded to meliorate the issues of cases with ovarian cancer. Ovarian cancer is presently one of the most fatal cancers among women. It was diagnosed in 295,414 women in 2018, while there were roughly 184,799 deaths encyclopaedically. The delighting mortality rate is because of poor opinion at the original stage due to the lack of conspicuous symptoms, performing in poorer long- term survival prospects[1]. Despite the fact that ovarian cancers generally respond well to chemotherapy, particularly with taxon platinum treatment, rush rates within 5 times for individualities with advanced complaint still range from 60 to 80[2]. According to GLOBOCAN projections, there will be an awaited 56 swell in ovarian cancer frequency encyclopaedically by 2050, with a significant 75 of cases being diagnosed in the after stages[3]. A large proportion[roughly 75] of cases arise in post- menopausal individualities, with an circumstance rate of 40 per 100,000 per annum in cases progressed 50 and over. Timely identification of this condition substantially enhances the survival rate, adding it from 3[at Stage IV] to 90[at Stage I] over a span of five times[4]. The established standard for diagnosing and grading ovarian cancer is histopathological assessment, which discerns various histological variations. Accurate interpretation of cellular morphology is vital for determining the various ovarian cancer types and guiding treatment planning[5]. good pathologists with moxie in ovarian excrescences are the most good for bearing this responsibility. nonetheless, cases of inconsistencies among different observers in their grading assessments have been proved. These variations in interpreting histopathology can affect in squishy prognostic projections, lower than optimal remedial approaches, and a deterioration in the quality of life for cases[16,17].

Background Work

This section discusses various styles for grading ovarian cancer, predicated on cell type. Accurate identification of the ovarian cancer type is vital for creating personalized treatment plans for cases. Numerous studies have aimed to meliorate the cancer netting process and have reacted in the preclinical stage during the last decade. still, manual image analysis by expert pathologists is not harmonious among different individualities, and it's also truly time-consuming. Recently, ML algorithms have been roundly used for the original netting and opinion of ovarian cancer. various styles are recommended for point birth from ultrasonic images and posterior type. This section also explores several state- of- the- art ML- predicated approaches for detecting ovarian cancer. Kastureet al.[14] introduced an enhanced deep CNN called KK- Net, which efficiently and directly classified four different classes. The authors also conducted comparisons with multiple deep- knowledge and transfer- knowledge models for benchmarking. The study results indicate that the proposed KK- Net achieved an delicacy of 91 on the TCGA dataset. In a similar tone, Akazawa et al.[15] suggested a machine- knowledge- predicated system for ovarian cancer discovery. The study revealed that the ML model XG Boost[XGB] achieved an delicacy of 80. Mingyang Lu et al. [8] selected features for 349 Chinese patients with 49 variables using MRMR and simple decision trees to predict ovarian cancer. In comparison to the risk of ovarian cancer and the risk of ovarian malignancy algorithms [ROMA and ROCA], the study found that logistic regression was the most successful approach. The approach was found to be more accurate than conventional methods by Emma L. Barber et al. [9] when they used natural language processing and machine learning to analyze CT scan reports of patients who had undergone OC surgery in order to identify women with OC based on medical case histories.

Chen et al. EOC [12] analysed patient cancer genome atlas data [13] to find genetic variants linked to 35OCa-CR and 162OCa-CS tumours. Laios et al. created logistic regression and KNN-based predictive models for patients with advanced OC using information from the ovarian database on peritoneal cancer and OC. utilizing methods like Lasso





Nithya

regression, SVMs, and random forests, a risk model for the Immune Microenvironment in EOC was established utilizing the clinical pathologic data of EOC from Shi-yi Liu et al. [14] and the data from the Cancer Genome Atlas [FPKM sequences]. It was discovered that higher immune cell counts in EOCs predicted better results and antitumor characteristics.

Diagnosis classification of Data Prediction:

The data from the Cancer Genome Atlas [TCGA][17,12] are used in this study. They correspond of 585 ovarian cancer cases. The unnormalized gene expression counts from the mRNA sequencing data from National Cancer Institute Genomic Data Common[GDC] are used for discriminative gene expression analysis with DESeq2[23]. The clinical data of the cases are used for good or bad issues and platinum resistance or sensitive groups. The outgrowth and platinum response status were not available for some cases in this study. To address this, two approaches were taken. In the first approach, cases were filtered predicated on the vacuity of mRNA sequencing data and their type as either having a good or bad outgrowth. In the alternate approach, cases were demanded to have both mRNA sequencing data and platinum response status available. After filtering, the remaining case data were erratically divided into training, testing, and independent evidence datasets. The training dataset was employed to train the machine knowledge models, whereas the testing dataset was used to test the performance of these models in multiple trials. ultimately, the evidence dataset was employed to estimate the performance of the models on data that were not previously used for training or testing.

Technologies and MethodsInvolved

Model Selection And Training

A number of machine learning approaches were considered, in particular support vector machines, Decision Tree models, and K nearest neighbour algorithms as base models in this study, and also Max voting, Stacking, Bagging, Boosting, and Stacking of various ensemble learning techniques were used. The models were trained using appropriate training algorithms and produced optimal performance.

Model Evaluation:

As a means of evaluating whether the models are capable of predicting events in the future, multiple performance metrics were applied. A number of metrics were calculated to assess different aspects of how well the model performed, such as AUC-ROC, F1 score, recall, accuracy, precision, and specificity are used to determine the model performance [15].

Interpretation And Analysis

The implications of the model analyses and evaluations were carefully analysed and interpreted. Key findings, including performance metrics and statistical analyses, were presented. The implications of the findings for ovarian cancer prediction were discussed, highlighting the potential clinical or biological significance of the identified features and the models predictive capabilities.

Implementation of Methods

The machine learning styles have been all trained with 50 of the data named as a training set and also constantly tested on 25 of the data named as a test set. When the performance reaches the asked value, it's tested formerly on the remaining 25 to estimate how well the system performs on unseen data. All of the styles have been trained as double classifiers to identify the correct class by their gene expression profile. The models have been tested with the formalized data and data from the top element analysis. The training of the models has been done in different Jupyter Tablets on the " Cancer Genomics Cloud " handed by Seven islets. For each machine knowledge model, the f1- score, delicacy, perceptivity, and particularity have been calculated to determine their predictive performance. The confusion matrix of the classifiers is used to assess the performance, and scatterplots are used to compare the different criteria across the models. The machine knowledge styles used in this study are K- means clustering[15,16], Naïve Bayes[17], logistic regression[18,19], supported vector machines[10,11], Random Forest[12,13], and





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XB Goost[14]. All the styles used were integrated via the sk learn library in Python. For the K- means Clustering system and the Naïve Bayes Classifier, the standard hyper parameters have been used as a reference. For the four other styles, optimization has been achieved using grid quest, inputting different hyper parameter sets to find the best- performing model.

The Working Procedure for Predicting Ovarian Cancer

Input: Ovarian Cancer Dataset from Kaggle Output: Predicted Ovarian Cancer [Positive or Negative] with Model Interpretability

- Begin
- data ← Load the input dataset from Kaggle containing Ovarian Cancer data.
- if data.value is NaN or empty:
- Replace NaN or missing values in the dataset.
- Preprocessing:
- For each column in the dataset:
- if data.dtypes is equal to 'object':
- Encode categorical data in the column.
- Split data into features and target
- $x \leftarrow \text{data.drop 'Ovarian Cancer' column from the dataset.}$
- $y \leftarrow \text{data.'Ovarian Cancer' Target variable, specifically.}$
- Split data for training and testing
- $x_{\text{train}}, x_{\text{test}}, y_{\text{train}}, y_{\text{test}} \leftarrow \text{Split data [features and target] into training and testing sets.}$
- Train model
- model ← Train a model using x_{train} [training features] and y_{train} [training target].
- Test model
- predict ← Test the trained model using x_{test} [testing features].
- Explainable AI [XAI] - SHAP values Apply XAI techniques [e.g., SHAP values] to interpret the model predictions
- explainer ← Create a SHAP explainer for the trained model.
- shap_values ← Compute SHAP values for x_{test} .
- Visualize SHAP values or generate explanations to understand feature importance and model predictions.
- Apply various classifiers
- model ← Apply different classifiers using the trained model.
- Compute performance evaluation metrics
- Calculate and analyze performance metrics
- End

Machine learning techniques

Support Vector Machine [SVM]

For many years, the healthcare industry has made extensive use of statistical learning algorithms like SVM to solve problems including regression and classification in addition to generating predictions regarding outcomes [16, 17]. This classification approach assigns a classification to the dataset based on which of the two available hyperplanes is the most suitable [38]. A linear combination of a kernel and SVM is represented by Eq. [1], where p_j stands for patterns in the training set, S is the SVM, and $q_j \in \{+1, -1\}$ is the associated class label.

$$f[p] = \sum p_j \varepsilon S a_j q_j K[p_j, p] + b \quad [1]$$

K-Nearest Neighbour

For locating comparable features in the training dataset based on the test data, the K-Nearest Neighbor approach is among the simplest and fastest techniques [39]. The distance between any given set of data and all of the prior data





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can be calculated using a variety of distance techniques. The Manhattan, Euclidian, and Minkowski distance algorithms are what they are [40]. The formulae for calculating the Euclidian, Manhattan, and Minkowski distances are given in Eqs. [2]–[4], as appropriate[17].

$$Euclidean = \sqrt{\sum_{i=1}^k [x_i - y_i]^2} \quad [2]$$

$$Manhattan = \sum_{i=1}^k |x_i - y_i| \quad [3]$$

$$Minkowski = [\sum_{i=1}^k [|x_i - y_i|^q]^{\frac{1}{q}} \quad [4]$$

Decision tree, or DT

DT is not a supervised learning classifier that uses parametric learning. Decision trees are made up of leaf nodes that indicate the decision's final result and an assortment of interior nodes that are required for forming the decisions. We employ Eq. [5] [41] to build a node of the DT.

$$E''[d_i] = [T_0[d_i] - T[d_i]] + K[\epsilon_0[d_i] - \epsilon[d_i]] + \sum_{j=1}^{c_i} p_{i+j} E_0[d_{i+j}] \quad [5]$$

A heuristic search function is applied to a node in order to get the correct decision for this node based on the values provided by E'' . It is the evaluation function for the node[16].

Findings and Conversation

The suggested system was trained and tested on data ranging from 20 percent to 80 percent, respectively, as part of the testing and training procedure. To determine which model is the best, a range of machine learning classifiers has been employed, including DT, SVM, K-NN, MVC, GB, XGB, and stacking. Combining the performance of various classifiers yields the optimal machine learning model; metrics like accuracy, recall, precision, and the F1-score are all used to evaluate models. Each classifier's performance was assessed using a k-fold stratified cross-validation method. By splitting the dataset into five subgroups and preserving the original class distribution at each fold, five-fold stratified cross-validation is performed. This approach eliminates imbalanced class scenarios by guaranteeing that each fold contains a representative proportion of examples from each class. A fresh fold acts as the test set and the remaining folds act as the training set for each iteration. Performance metrics are produced for each run and averaged over the five folds to give a thorough and trustworthy assessment of the model's performance, especially when there is an imbalance in the distribution of classes. Stratified cross-validation avoids biases that can occur from standard cross-validation when handling uneven class frequencies[16,17,18,19].

CONCLUSION

Ovarian cancer poses a serious threat to the global community, underscoring the urgency of prompt treatment. Machine learning [ML] models have emerged as essential tools for forecasting the disease's outcome, and early detection of ovarian cancer is key to reducing the disease's severity. In this study, early detection and prediction are advanced by the use of an ensemble machine learning classification algorithm. There are five steps in the suggested methodology: loading the dataset on ovarian cancer, preparing the data, choosing features, putting the classifier into practice, and analyzing the SHAPley score. The ensemble learning classifiers scored an astounding 89% accuracy rate. It not only tackles accountability issues but also offers explicit recommendations for the use of machine learning techniques in medical research. Exploring novel disease biomarkers through explainable models requires collaboration between computer scientists and medical specialists. Future studies will employ deep learning and image processing to attain improved accuracy. The integration of these tools, the optimization of explain ability methodologies like SHAPley scores, and interdisciplinary collaboration are critical for the improvement of treatment for ovarian cancer. Significant progress in the treatment of ovarian cancer may result from research initiatives and larger assessments utilizing a variety of datasets.





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Fig-1: Diagnosing Process of Predicting and Identify the Tissues

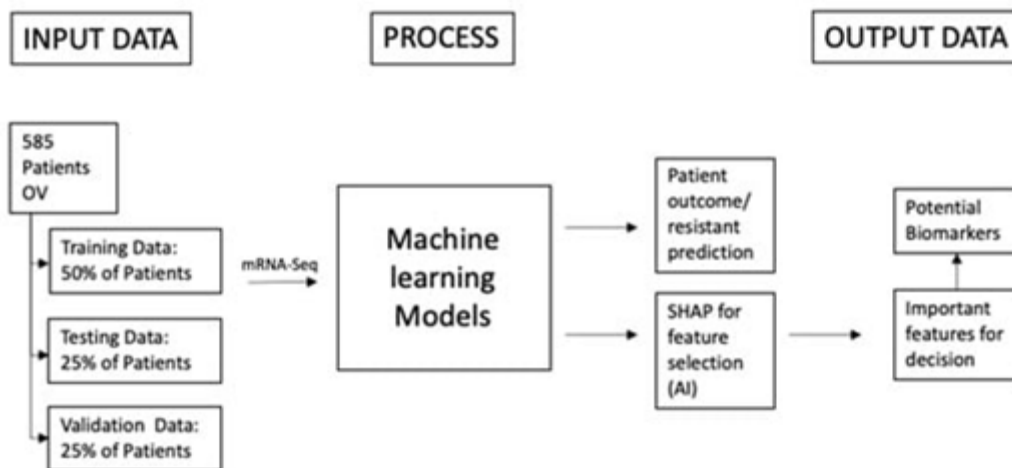


Fig-2:Evaluation Analysis of Ovarian Cancer Data Using Machine Learning





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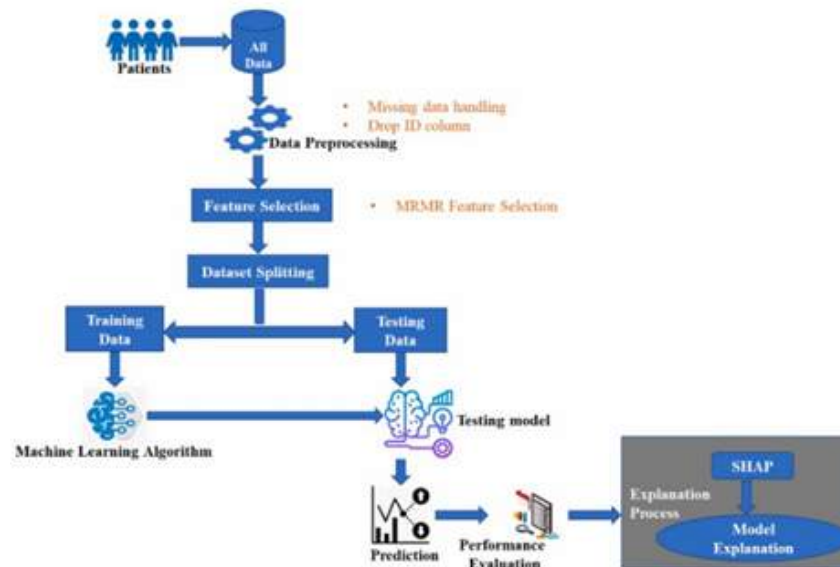


Fig-3: Diagnosing Ovarian Cancer Cells

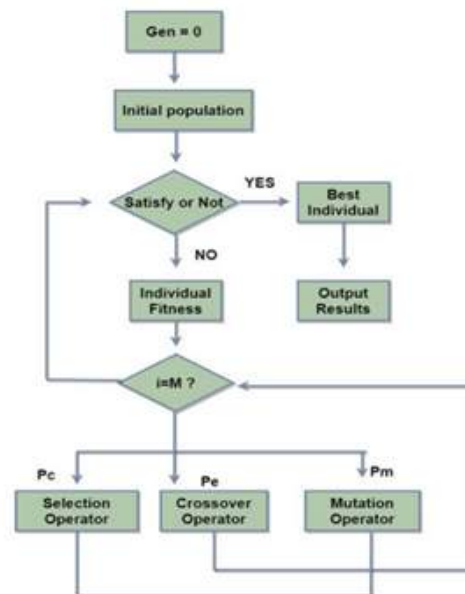


Fig-4 :A systemic Flow Chart of the Input behind the Technologies

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RESEARCH ARTICLE

Biofortification of Millets with Oyster Mushroom for Enhanced Zinc Bioavailability

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ABSTRACT

This study focused on the biofortification of pearl and finger millets with oyster mushrooms to enhance zinc availability and improve overall nutritional value. Different mixing ratios were tested under untreated and heat moisture treated (HMT) conditions. Results showed a significant increase in zinc content and bioavailability, particularly in HMT samples. Sulfate levels, indicating the presence of sulfur-containing amino acids, also improved. Carbohydrate content varied with treatment, while protein and amino acid concentrations increased with mushroom enrichment. HMT improved solubility, suggesting enhanced digestibility and absorption. The fortified blends offer a sustainable, low-cost strategy for addressing micronutrient deficiencies. This method effectively utilizes the nutritional richness of oyster mushrooms. It holds promise for vulnerable populations in developing regions

Keywords: Biofortification, Millets, Oyster Mushroom, Zinc Bioavailability, Heat Moisture Treatment (HMT), Micronutrient Deficiency

INTRODUCTION

Zinc deficiency is a widespread public health issue, affecting over two billion people globally, particularly in developing countries where plant-based diets are predominant (WHO, 2020). Zinc plays a crucial role in immune function, cognitive development and growth especially in children, making it essential to address this nutrient deficiency in vulnerable populations. Traditional interventions such as zinc supplementation and fortification have proven effective but are often expensive and unsustainable in resource-poor settings (Wessells and Brown, 2012). Millets are often referred to as "miracle grains", which are widely grown in many parts of African and Asian



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continents and are hardy, drought-resistant crops that serve as a major food source for millions of people (Patil *et al.*, 2022). They are rich in fiber, protein and essential minerals. However, despite their benefits, millets contain high levels of phytates, which inhibit zinc absorption, thereby limiting their nutritional potential (Kumar *et al.*, 2019). Addressing this challenge could substantially improve the nutritional outcomes for populations that rely heavily on millet as a staple. Fortifying millet flours with zinc-dense food sources, such as oyster mushrooms offers a novel, cost-effective approach to improve zinc bioavailability. Oyster mushrooms are rich in bioavailable zinc, vitamins and other essential nutrients, and they grow well on agricultural waste, making them an accessible and sustainable solution (Kalac, 2016). Recent research suggests that incorporating oyster mushrooms into cereal-based foods can enhance mineral bioaccessibility, offering a promising strategy to address micronutrient deficiencies (Adebayo *et al.*, 2020). However, the potential of using zinc-rich oyster mushrooms to fortify millet flours has not been fully explored. One promising solution was the incorporation of zinc-dense oyster mushrooms into millet-based foods to enhance zinc bioavailability. Recent studies suggest that such functional food fortification can significantly improve mineral absorption (Adebayo *et al.*, 2020). Although there have been a few attempts to blend mushrooms into foods like bread, cookies, and cakes, issues with altered taste and aroma have reduced consumer acceptance (Karenia *et al.*, 2023). However, products particularly those made from heat-moisture-treated (HMT) using pearl and finger millet offer a culturally acceptable and modifiable base for fortification.

MATERIALS AND METHODS

Selection, Collection and Preparation of mushroom spawn and millets

The oyster mushroom (*Pleurotus spp.*) spawn was procured from Adhithya mushroom farm, Pakkothipalayam, Pollachi. Care was taken to ensure the spawn was fresh, viable and contamination-free prior to inoculation. The spawn was stored under refrigerated conditions (4–8°C) until use. For the present study, finger millet (*Eleusine coracana*) and pearl millet (*Pennisetum glaucum*) were selected based on their high nutritional value, especially their iron and zinc content, low glycemic index and suitability for complementary food development.

Preparation of Substrate

A total of 6 kg of paddy straw was used as the cultivation substrate. The straw was chopped into small pieces to facilitate even soaking and sterilization. The chopped paddy straw was soaked in clean water for 2 hours. Zinc sulfate was added to the soaking water to enhance the mineral content of the substrate, potentially contributing to increased zinc bioavailability in the final mushroom-millet formulation. Pasteurization of the substrate was carried out using the hot water treatment method. In a wide-mouth container, the chopped paddy straw was added and allowed to boil in water for 1 hour. This method was widely used by small-scale growers to reduce microbial load without complete sterilization.

Spawning Procedure

Spawn was added at a rate of approximately 3% of the wet weight of the substrate. After filling, the substrate was gently compressed by hand, and the mouth of the bag was secured using a rubber band. Small pinholes were made at the bottom and sides of the bags using a sterile needle to allow for drainage and air exchange. Humidity inside the cultivation room was maintained by spraying water on the outer walls of the bags twice daily. The bags were incubated at ambient temperature for 23 days, during which a full spawn run was achieved, as indicated by complete mycelial colonization of the substrate.

Production of mushrooms on rice straw enriched with zinc sulfate

Mushrooms were grown on substrates enriched with zinc sulfate (ZnSO_4) which was performed by following the procedure described by Zięba *et al.*, 2020 with some modifications. Rice straw substrates were soaked in a solution of ZnSO_4 in concentrations of 50mg/kg, 100 mg/kg, 150 mg/kg, 200 mg/kg, 250 mg/kg and 500 mg/kg. Substrates without Zinc was used as control. Substrates were first sterilized and then inoculated with actively growing oyster



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mushroom spawn. The substrate was watered thrice a day to maintain ZnSO_4 in soluble form and relative humidity of the room was maintained to promote mushroom fruiting.

Preparation of mushroom flour and millet flour

Fruiting body of mushroom from substrates with varying ZnSO_4 concentrations was harvested separately at maturity, chopped into small flakes and that was dried at 50°C in order to remove moisture content before milled into fine flour. The flours were stored separately in clean food grade plastic buckets for further experiments. The selected millets were washed separately with clean tap water, dried to remove moisture content using an electric oven before milled into fine flour (Onyango and Wanjala, 2018). One portion of both the millet samples were subjected to Heat Moisture Treatment (HMT), while the other portion remained untreated. Both treated and untreated flour samples were properly stored and preserved for further analysis in higher studies.

Millet-mushroom flour blends

Mushrooms with the highest Zn contents was selected for milling. The millet powder was mixed with mushroom powder in different ratios. The 20% (w/w) mushroom powder was chosen as an upper limit following findings by Sheikh *et al.*, 2010.

Determination of zinc contents in biofortified millet- mushroom flours

The zinc (Zn) content in different concentrations of mushroom fruiting bodies was determined using the Zn analysis method (Aoac, 1995).

Solubility test for mushroom blends (Rohini *et al.*, 2023)

200 mg of millet-mushroom flour mixed with 500 μl of distilled water and centrifuge for about 20 minutes. Then the powder was placed in the filter paper and allow the powder to dry off. Initial weight of the filter paper was taken. After the water was completely absorbed, the weight of the powder was taken along with the filter paper. The solubility of the fruit powder is measured by Solubility = final weight after drying-weight of filter paper

Proximate analysis:**Estimation of carbohydrates (Yemm *et al.*, 1954)**

The total amount of carbohydrates in millet-mushroom flour was estimated by anthrone method. The millet-mushroom flour was taken for estimation. 100 mg of glucose was diluted with 100 ml distilled water as stock solution. 10 ml stock solution was diluted in 100 ml distilled water as working standard. 0.2% of anthrone reagent was mixed with ice cold concentrated sulphuric acid. In test tubes, different concentrations from 0.1 to 1 was taken and one test tube was kept as blank with distilled water and one test tube was filled with sample in needed concentration. To each test tube, 4ml of anthrone reagent was added and heated for 8 mins. in water bath. The test tube solution turned into green colour according to its concentration. The reading was taken in UV spectrophotometer at 620nm.

Estimation of protein (Ranjini *et al.*, 2017)

The total amount of protein in millet-mushroom flour was estimated by Lowry method. 50 mg Bovine Serum Albumin was dissolved in distilled water and make it to 50 ml. Dilute 10 ml stock solution to 50 ml distilled water and kept as working standard solution. Three types of reagents have been prepared. 2% of sodium carbonate in 0.1N sodium hydroxide was kept as reagent A. 0.5% copper sulphate in 1% potassium sodium tartarate was kept as reagent B. By mixing 50 ml of reagent A and 1 ml of reagent B prior to use and kept as reagent C. Folin Ciocalteu reagent was prepared by mixing 1 ml of reagent in 1 ml of water. Different concentrations were prepared from 0.1-1 ml was taken in different test tubes and add 5 ml of reagent C in each test tubes and kept for 10 min. To each test tubes, add 0.5 ml of Folin Ciocalteu reagent and mix well. The solution was kept in dark for about 30 min. The solution turns to blue colour. The reading was taken in UV spectrophotometer at 660 nm.



**Sowmiya****Estimation of amino acids (Sadasivam and Manickam, 1995)**

To estimate the total amount of millet-mushroom flour by dissolving 50 mg leucine in 50 ml of distilled water and kept as stock solution. From that stock solution, take 10 ml and add 90 ml of distilled water to it and kept as working standard solution. Series of concentrations from 0.1-1 ml was prepared in test tubes and each test tubes were made upto 1 ml by adding distilled water. To each test tubes, add 1 ml of ninhydrin solution and kept in water bath for about 20 minutes, the colour of the solution turns purple. Then add 5 ml of diluent solution to each test tubes. The diluent solution was prepared by adding equal amount of distilled water and n-propanol. Then the test tubes were kept for 15 min. and undisturbed. Then the absorbance read at 570 nm in UV spectrophotometer. The process was triplicate to read the concordant value.

RESULTS AND DISCUSSION**Zinc Content in Mushroom**

The zinc content in oyster mushrooms increased with rising sample concentrations of zinc up to a certain level. At 50 mg/kg, the zinc content was 2.36 mg/kg, which gradually rose to 3.57 mg/kg at 250 mg/kg concentration. However, at the highest concentration of 500 mg/kg, the zinc content slightly decreased to 3.33 mg/kg. This indicates that while zinc accumulation in oyster mushrooms generally increases with higher supplementation, excessive concentrations beyond 250 mg/kg may not result in proportional zinc uptake and could even lead to a decline in accumulation efficiency and result is depicted in table 1. In the present study, zinc supplementation in the substrate led to an increase in zinc content within oyster mushroom fruiting bodies, rising from 2.36 mg/kg at 50 mg/kg supplementation to a peak of 3.57 mg/kg at 250 mg/kg. However, at 500 mg/kg supplementation, a slight decline to 3.33 mg/kg was observed, suggesting a potential saturation point or physiological limitation in zinc uptake. These findings align with those of Zoysa *et al.* (2023), who reported that increasing zinc levels in the substrate enhanced mushroom yield up to a certain concentration, beyond which the yield declined. Specifically, substrates containing 100 mg ZnSO₄ provided the highest yield increase, while higher concentrations led to reduced yields, indicating that excessive zinc may negatively affect mushroom growth and zinc accumulation.

Similarly, Gąsecka *et al.* (2015) observed that zinc enrichment in *Pleurotus ostreatus* and *Pleurotus eryngii* resulted in increased zinc content in the fruiting bodies. However, the extent of accumulation varied between species, and excessive supplementation did not proportionally increase zinc content, highlighting species-specific responses and potential limitations in zinc uptake mechanisms. Furthermore, Gąsecka *et al.* (2021) demonstrated that supplementing culture media with inorganic zinc salts increased both biomass production and zinc bioaccumulation in *Pleurotus* spp. mycelia. This suggests that controlled zinc supplementation can enhance the nutritional value of mushrooms, although the form and concentration of zinc, as well as cultivation conditions, play crucial roles in determining the efficiency of bioaccumulation. The observed decline in zinc content at the highest supplementation level in the current study may be attributed to the saturation of zinc transport systems or potential toxicity effects at elevated zinc concentrations. This phenomenon underscores the importance of optimizing zinc supplementation levels to maximize nutritional benefits without compromising mushroom growth or health.

Sulfate content in mushroom

The sulfate content in oyster mushrooms showed a steady increase with rising concentrations of zinc sulfate supplementation. Starting at 23.6 mg/kg for the 50 mg/kg treatment, the sulfate content rose to 35.7 mg/kg at 250 mg/kg. However, at the highest supplementation level of 500 mg/kg, the sulfate content slightly declined to 33.3 mg/kg. These results suggest that sulfate accumulation increases with supplementation up to a certain point, after which the uptake may begin to decrease and the result is depicted in table 2. The present study indicated that sulfate uptake by oyster mushrooms improve with increasing zinc sulfate concentrations in the substrate, reaching a peak at 250 mg/kg. This suggests an efficient absorption of sulfate from the supplemented media. However, the decline at 500 mg/kg could be due to several factors including nutrient competition, inhibition of sulfate transporters or physiological stress caused by excess zinc.



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Similar findings have been reported by Zoysa *et al.* (2023), who observed that moderate levels of zinc sulfate enhanced mineral content in mushrooms, but higher concentrations led to diminished accumulation and potential toxicity. This is supported by Gasecka *et al.* (2015), who highlighted that nutrient uptake in *Pleurotus* species follows a non-linear pattern, often peaking before a decline due to metabolic regulation or ion interference. The reduction in sulfate at the highest concentration might also be attributed to substrate imbalance or reduced bioavailability of sulfate due to chemical interactions at higher zinc levels. These findings highlight the importance of identifying an optimal supplementation level to achieve effective biofortification without negatively affecting nutrient absorption.

Solubility

The water solubility test revealed notable differences between treated and untreated samples of both *Eleusine coracana* and *Pennisetum glaucum*. In untreated conditions, finger millet showed a higher solubility (17.1%) compared to its treated counterpart (8.8%). Similarly, pearl millet exhibited higher solubility in the untreated form (14%) than in the treated sample (11%). This reduction in water solubility due to treatment suggests that the applied process may have altered the structural or chemical properties of the millet flour. The decrease in solubility is likely due to the denaturation or rearrangement of soluble components such as proteins, sugars, or starches during treatment. For example, heat or chemical treatments can induce cross-linking of proteins or gelatinization of starches, thereby reducing their water solubility. This is consistent with findings from previous studies that show processing—particularly heat-based treatments—can reduce solubility by causing structural modifications in grain components (Sharma *et al.*, 2018; Rani *et al.*, 2020). While reduced solubility might suggest a loss of certain functional properties (e.g., dispersion in water), it can also indicate increased stability or reduced digestibility, which might be desirable in certain food applications like controlled release or slow energy release products. For instance, lower solubility might be preferred in dietary formulations targeting glycemic control. Overall, these results show that treatment significantly impacts the functional properties of millet flours. Depending on the intended use (e.g., weaning food, beverage mix, or dietary fibre supplement), the solubility behaviour could inform processing decisions and the result is depicted in table 3.

Similarly, Hithamani and Srinivasan (2014), reported that domestic processing methods such as sprouting and pressure-cooking led to a reduction in polyphenol content in both finger millet and pearl millet. Although their focus was on polyphenols, the processing methods could similarly affect water solubility by altering the grain's structural components. Conversely, Usha *et al.* (2013) found that hydrothermal processing increased the solubility and swelling power of finger millet at ambient temperature. This suggests that the type of processing technique plays a crucial role in determining the solubility outcomes. The observed decrease in solubility in the current study could be attributed to the specific treatment applied, which may have led to protein denaturation or starch gelatinization, thereby reducing the availability of water-soluble components. Such structural modifications can hinder the interaction of flour particles with water, leading to decreased solubility.

Estimation of carbohydrate in prepared millets and millet-mushroom flour

The estimated carbohydrate content in both finger millet and pearl millet varied significantly between heat moisture treated and untreated samples at two different concentrations (0.1 µg/ml and 0.2 µg/ml). Finger Millet at 0.1 µg/ml: Treated sample showed 10 µg/ml carbohydrates whereas untreated sample showed 56 µg/ml. At 0.2 µg/ml: Treated sample showed 30 µg/ml and untreated sample showed 58 µg/ml. Pearl Millet at 0.1 µg/ml: Treated sample showed 10 µg/ml and untreated sample showed 61 µg/ml at 0.2 µg/ml: Treated sample showed 63 µg/ml whereas untreated sample showed 65.9 µg/ml and the result is depicted in table 4. The results clearly indicated that untreated millet samples had consistently higher carbohydrate content compared to their heat moisture treated counterparts, particularly at the lower concentration (0.1 µg/ml). In finger millet, the untreated sample at 0.1 µg/ml had over five times more carbohydrates than the treated sample. A similar pattern was observed in pearl millet, although at 0.2 µg/ml, the treated and untreated values were more comparable (63 vs. 65.9 µg/ml), suggesting the treatment had less impact at higher concentrations. Similarly, Chandrasekara & Shahidi (2011) and Nirmala *et al.* (2018) reported that thermal treatments alter starch structure, often reducing its solubility and extractability in aqueous solutions. Adegunwa *et al.* (2012) noted that heat processing leads to reduced simple sugar availability, due to starch



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retrogradation and the formation of resistant starch. The carbohydrate estimation of blended samples containing finger millet (FM) and oyster mushroom (OM) at different treatment types and ratios revealed notable differences in carbohydrate content. Among the heat moisture treated (HMT) samples, the blend with equal parts of finger millet and mushroom (0.5:0.5) exhibited the highest carbohydrate content, with values of 102 $\mu\text{g/ml}$ at 0.1 $\mu\text{g/ml}$ concentration and 123 $\mu\text{g/ml}$ at 0.2 $\mu\text{g/ml}$. In contrast, the blend with a higher proportion of mushroom (0.25:0.5) showed the lowest carbohydrate values in this group, measuring 69.3 $\mu\text{g/ml}$ and 75 $\mu\text{g/ml}$ respectively. This suggests that increasing the mushroom content in HMT blends may reduce carbohydrate availability.

For the untreated samples, the blend with a higher proportion of finger millet (0.5:0.25) demonstrated the highest overall carbohydrate levels, yielding 134.2 $\mu\text{g/ml}$ at 0.1 $\mu\text{g/ml}$ and 153 $\mu\text{g/ml}$ at 0.2 $\mu\text{g/ml}$. Even the untreated blend with a lower millet ratio (0.25:0.5) showed comparatively higher values (78 $\mu\text{g/ml}$ and 93 $\mu\text{g/ml}$) than most HMT samples. Notably, the untreated 0.5:0.5 blend recorded 61 $\mu\text{g/ml}$ and 65.9 $\mu\text{g/ml}$, which were lower than the corresponding HMT sample at the same ratio, indicating that heat treatment may have improved solubility or extractability in this specific case and the result is given in table 4. Overall, the data indicates that untreated finger millet contributes to higher carbohydrate content, particularly when present in greater proportions, while heat moisture treatment tends to reduce the measurable carbohydrate levels, possibly due to starch gelatinization or formation of resistant starches. The current study observed that untreated finger millet (FM) blended with oyster mushroom (OM) showed significantly higher carbohydrate content than the heat moisture treated (HMT) samples. These findings are in agreement with studies such as Pathak *et al.* (2017), which reported that native starches in finger millet exhibit higher solubility and accessibility to reagents compared to heat-treated samples. Heat treatment, especially moist heat, causes starch gelatinization and retrogradation, which may lead to reduced extractable carbohydrate content due to the formation of resistant starch (RS), as also discussed by Sandhu & Lim (2008).

In addition, Soni *et al.* (2020) highlighted that thermal processing decreases the glycemic response of millets by modifying their carbohydrate structure, making them beneficial for diabetic diets but also less reactive in chemical estimations like phenol-sulfuric acid assays. This supports the observation in the present study, where HMT blends, particularly those with higher mushroom content, recorded lower carbohydrate values (e.g., HMT FM + OM (0.25:0.5) had only 69.3 $\mu\text{g/ml}$ at 0.1 $\mu\text{g/ml}$ and 75 $\mu\text{g/ml}$ at 0.2 $\mu\text{g/ml}$). Furthermore, the carbohydrate contribution from oyster mushrooms is generally lower than that of cereals. According to Mau *et al.* (2001), oyster mushrooms typically contain 4–6% carbohydrates on a dry weight basis, which is relatively modest. Hence, blends with a higher proportion of mushroom showed lower carbohydrate values across both HMT and untreated groups in the present work. The estimated carbohydrate content in blends of pearl millet and oyster mushroom showed significant variation depending on the treatment method and blend ratio. Among heat moisture treated (HMT) samples, the 0.5:0.5 ratio recorded the highest values at 114 $\mu\text{g/ml}$ (0.1 $\mu\text{g/ml}$ concentration) and 135 $\mu\text{g/ml}$ (0.2 $\mu\text{g/ml}$ concentration). Other HMT combinations like 0.5:0.25 and 0.25:0.5 exhibited lower values, particularly the latter which yielded the lowest carbohydrate levels (76 and 80.1 $\mu\text{g/ml}$, respectively).

Untreated samples demonstrated even higher carbohydrate content across all blend ratios. The untreated 0.5:0.5 blend had the highest values overall, with 142.5 $\mu\text{g/ml}$ and 155 $\mu\text{g/ml}$ at the respective concentrations. The 0.5:0.25 and 0.25:0.5 ratios also presented moderate levels, with both showing a trend of increased carbohydrate content at higher concentrations and the result is depicted in table 5. These results are in agreement with previous findings that heat moisture treatment (HMT) of millets often leads to reduced extractable carbohydrates due to starch gelatinization and the formation of resistant starches (Sandhu & Lim, 2008). This is evident from the lower carbohydrate values in HMT samples compared to their untreated counterparts. Furthermore, the inclusion of oyster mushroom, which has relatively lower carbohydrate content (~4–6%, Mau *et al.*, 2001), contributes to dilution of total carbohydrates, especially in blends with higher mushroom ratios. Comparatively, untreated blends retain more native starch which is readily extractable and reactive during carbohydrate estimation, consistent with reports by Pathak *et al.* (2017) and Soni *et al.* (2020). The high carbohydrate levels observed in untreated 0.5:0.5 blends highlight the influence of treatment on carbohydrate availability.





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Estimation of Protein In Millets and Millet Mushroom Flour

The estimated protein content of heat moisture treated (HMT) and untreated finger millet and pearl millet at two concentrations (0.1 µg/ml and 0.2 µg/ml) revealed substantial variation. For finger millet, the HMT samples showed relatively low protein levels with 10 µg/ml at 0.1 µg/ml and 32.5 µg/ml at 0.2 µg/ml concentrations. In contrast, the untreated finger millet exhibited higher protein levels of 46 µg/ml and 59.6 µg/ml at the same concentrations. Similarly, in pearl millet, HMT samples recorded 10 µg/ml and 64 µg/ml for 0.1 µg/ml and 0.2 µg/ml concentrations, respectively. The untreated pearl millet had the highest protein content among all groups with 71 µg/ml and 76.2 µg/ml at 0.1 µg/ml and 0.2 µg/ml concentrations, respectively.

The results clearly demonstrate that untreated millets possess higher measurable protein content compared to their heat moisture treated counterparts. This observation aligns with previous findings by Shobana *et al.* (2013) and Devi *et al.* (2014), who noted that heat-based pre-treatments may cause denaturation or complex formation between proteins and carbohydrates, making some proteins less extractable or measurable by standard biochemical methods. The sharp increase in protein content from 0.1 µg/ml to 0.2 µg/ml concentrations in all samples suggests that concentration significantly influences the detection efficiency. However, HMT appears to reduce protein solubility or extractability, possibly due to protein aggregation or cross-linking during thermal exposure, which is consistent with reports by Hadimani *et al.* (2001). The protein content of various blends of finger millet (FM) and oyster mushroom (OM) was estimated at two concentrations (0.1 µg/ml and 0.2 µg/ml). At 0.1 µg/ml, the highest protein content was observed in Untreated FM + OM (0.5:0.5) with 126 µg/ml, followed by Untreated FM + OM (0.5:0.25) with 90.8 µg/ml, and Untreated FM + OM (0.25:0.5) at 80 µg/ml. Among the heat moisture treated (HMT) blends, the highest protein value was 92 µg/ml in the 0.5:0.5 ratio, followed by 75 µg/ml and 63 µg/ml for the 0.5:0.25 and 0.25:0.5 blends, respectively. At 0.2 µg/ml concentration, protein levels increased in all blends. Untreated FM + OM (0.5:0.5) remained the highest at 145 µg/ml, while the lowest was HMT FM + OM (0.25:0.5) with 78 µg/ml. Overall, untreated blends exhibited higher protein levels than their treated counterparts. The 0.5:0.5 blend ratio was most effective in both treated and untreated conditions, possibly due to a more balanced protein contribution from both ingredients. The increase in protein content at higher concentrations (0.2 µg/ml) also validates the method's sensitivity and the presence of extractable proteins.

The results of this study show a clear distinction in protein content between heat moisture treated (HMT) and untreated blends of finger millet (FM) and oyster mushroom (OM), across various mixing ratios and concentrations. Specifically, untreated FM + OM blends consistently demonstrated higher protein content than their HMT counterparts at both 0.1 µg/ml and 0.2 µg/ml concentrations. This observation aligns with findings from Shobana *et al.* (2013), who reported that heat treatments like steaming or pressure cooking can lead to protein denaturation and formation of insoluble complexes with starches and polyphenols, reducing the extractable and measurable protein levels in millets. The same trend is supported by Devi *et al.* (2014), where untreated finger millet had significantly higher crude protein content than thermally processed samples.

Furthermore, Hadimani *et al.* (2001) indicated that dry heat treatments alter the functional properties of millet proteins, making them less soluble, especially under laboratory extraction conditions. This provides a plausible explanation for the reduced protein content observed in HMT samples in the current study. Interestingly, the 0.5:0.5 ratio of FM and OM in both treated and untreated forms yielded the highest protein values, which supports findings by Patil *et al.* (2016) who demonstrated that blending cereals with protein-rich mushrooms enhances the overall nutritional profile, particularly in unprocessed blends. Also, the increase in protein quantification from 0.1 to 0.2 µg/ml concentration across all samples is consistent with trends observed by Nandini *et al.* (2019), who highlighted that higher sample concentrations lead to increased extractability and colorimetric detection of proteins. Overall, this comparative discussion underscores that thermal treatment, while beneficial for digestibility and shelf-life, may reduce bioavailable proteins, especially when the goal is maximizing protein intake. Therefore, untreated millet-mushroom blends may be more suitable for protein-enriched dietary formulations, particularly in functional foods and weaning products.





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The protein content of different blends of pearl millet (PM) and oyster mushroom (OM) at two concentrations (0.1 µg/ml and 0.2 µg/ml) showed a distinct trend. At 0.1 µg/ml, the untreated PM + OM (0.5:0.5) blend showed the highest protein content at 130 µg/ml, followed by untreated PM + OM (0.5:0.25) at 92.4 µg/ml, and untreated PM + OM (0.25:0.5) at 79 µg/ml. Among the heat moisture treated (HMT) samples, protein content was lower across all blend ratios, with values ranging from 70.5 µg/ml to 87 µg/ml. At 0.2 µg/ml concentration, there was a general increase in protein levels. The untreated 0.5:0.5 blend again ranked highest with 153 µg/ml, while the lowest was recorded in the HMT 0.25:0.5 blend at 85 µg/ml. The data highlights that untreated blends exhibit higher protein concentrations compared to their heat-treated counterparts. This observation aligns with studies by Shobana *et al.* (2013) and Devi *et al.* (2014), who reported that heat treatments such as roasting or steaming can result in protein denaturation or aggregation, thereby reducing solubility and detectability during colorimetric assays. The consistently higher protein levels in the untreated PM + OM (0.5:0.5) samples affirm findings by Patil *et al.* (2016), who demonstrated that incorporating mushrooms into cereal blends boosts protein quality and quantity, particularly when processing is minimal.

Furthermore, Hadimani *et al.* (2001) and Nandini *et al.* (2019) emphasized that thermal treatments, while useful for reducing antinutrients and improving digestibility, may compromise the protein extractability due to interactions between proteins and carbohydrates or polyphenols. The increase in measured protein at 0.2 µg/ml concentration is in line with expected trends based on the standard colorimetric assay sensitivity and suggests that sample concentration directly influences protein quantification accuracy. Protein estimation was conducted on both heat moisture treated (HMT) and untreated samples of finger millet and pearl millet at two concentrations: 0.1 µg/ml and 0.2 µg/ml. At 0.1 µg/ml, HMT finger millet and HMT pearl millet each recorded a protein content of 10 µg/ml, while untreated pearl millet showed a higher value of 32 µg/ml. The highest protein content at this concentration was observed in untreated finger millet, with a value of 49.8 µg/ml. At the higher concentration of 0.2 µg/ml, protein content increased across all samples. HMT finger millet rose to 29.5 µg/ml, HMT pearl millet reached 44 µg/ml, and untreated pearl millet increased to 41 µg/ml. Untreated finger millet again displayed the highest protein value at this concentration, recording 52 µg/ml. Overall, untreated samples, particularly finger millet, consistently showed higher protein levels compared to their treated counterparts, and protein concentration increased with higher sample concentration in all cases.

The present study assessed the protein content of heat moisture treated (HMT) and untreated finger millet and pearl millet at two concentrations (0.1 µg/ml and 0.2 µg/ml). The findings revealed notable variations in amino acid content based on both treatment and millet type. At the lower concentration (0.1 µg/ml), untreated finger millet exhibited the highest amino acid content (49.8 µg/ml), followed by untreated pearl millet (32 µg/ml), while both HMT samples recorded only 10 µg/ml. At the higher concentration (0.2 µg/ml), amino acid content increased across all samples, with untreated finger millet again yielding the highest value (52 µg/ml), followed by HMT pearl millet (44 µg/ml), untreated pearl millet (41 µg/ml), and HMT finger millet (29.5 µg/ml). These results suggest that heat moisture treatment may not uniformly enhance protein extractability, particularly in finger millet at lower concentrations. The relatively lower protein content observed in HMT finger millet aligns with findings by Devi *et al.* (2014), who reported that while HMT can improve protein digestibility and functional properties, it may lead to partial denaturation or reduced extractability of amino acid under certain conditions.

Similarly, Shobana *et al.* (2013) highlighted that finger millet's amino acid content tends to be more sensitive to thermal processing compared to other millets, potentially explaining the lower values observed in HMT finger millet at 0.1 µg/ml. Conversely, the significant increase in protein content for HMT pearl millet at 0.2 µg/ml (44 µg/ml) suggests a more favorable response to thermal processing, which is supported by the work of Saleh *et al.* (2013), who found that controlled heat treatment can enhance amino acid solubility and release in pearl millet by altering protein matrix interactions. This is consistent with the noticeable protein increase from 10 µg/ml to 44 µg/ml in HMT pearl millet across the two concentrations tested in the current study. Moreover, the consistently higher protein content in untreated finger millet across both concentrations underscores its rich natural protein composition, which was similarly emphasized in the studies of Ravindran (1991) and Malleshi (2007). Their research noted that finger millet



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contains essential amino acids and tends to retain nutritional integrity in its raw form, making it a valuable dietary protein source, especially in undernourished populations. Amino acid estimation was conducted on both heat moisture treated (HMT) and untreated combinations of finger millet (FM) and oyster mushroom (OM) at varying ratios and two concentrations (0.1 µg/ml and 0.2 µg/ml). At 0.1 µg/ml, the highest amino acid content was observed in untreated FM + OM (0.25:0.5) at 119 µg/ml, followed by HMT FM + OM (0.25:0.5) at 96 µg/ml, and untreated FM + OM (0.5:0.25) at 87 µg/ml. The lowest amino acid value was recorded in HMT FM + OM (0.5:0.5) at 59.2 µg/ml. At 0.2 µg/ml, the protein values increased across all samples, with untreated FM + OM (0.25:0.5) again showing the highest value (138 µg/ml), while HMT FM + OM (0.5:0.5) remained the lowest at 63.7 µg/ml. Generally, mixtures with higher proportions of oyster mushroom (0.25:0.5) exhibited higher protein content in both treated and untreated forms.

Manzi *et al.* (2004), who reported that oyster mushrooms possess high-quality Amino acid, including essential amino acids, which are easily extractable in untreated form. The combination with finger millet, a cereal known for its modest Amino acid content but high nutritional density, creates a synergistic blend that improves overall protein yield, particularly when oyster mushroom proportion is higher. The lower Amino acid content observed in heat moisture treated samples may be attributed to protein denaturation or Maillard reactions during the thermal process. According to Sharma *et al.* (2013), heat treatments such as autoclaving, steaming, or HMT can lead to structural alterations in Amino acid, including aggregation and reduced solubility, which affects extraction efficiency and detectable Amino acid levels. This may explain why HMT FM + OM (0.5:0.5) recorded the lowest protein content at both concentrations in this study.

Singh and Raghuvanshi (2012) noted that while heat treatment can improve the digestibility of some millets, it can simultaneously reduce the measurable Amino acid content due to complex formation with other macronutrients or reduced availability of nitrogenous compounds. In our study, the Amino acid content in HMT FM + OM (0.25:0.5) was lower (129 µg/ml) compared to its untreated equivalent (138 µg/ml), highlighting this exact phenomenon. Moreover, the increase in Amino acid content with higher concentrations (from 0.1 µg/ml to 0.2 µg/ml) across all samples is consistent with general biochemical trends and supports the proportionality of extractable protein with sample concentration, as also observed in the work by Malleshi and Hadimani (1993). The Amino acid estimation of HMT and untreated mixtures of pearl millet (PM) and oyster mushroom (OM) at various ratios and concentrations showed a clear trend. At 0.1 µg/ml, the highest Amino acid content was observed in untreated PM + OM (0.5:0.5) at 89 µg/ml, followed by HMT PM + OM (0.5:0.5) with 83.3 µg/ml. The lowest value was seen in HMT PM + OM (0.5:0.25) at 63.3 µg/ml. At 0.2 µg/ml, values generally increased, with untreated PM + OM (0.5:0.5) again showing the highest Amino acid content at 90.9 µg/ml, while HMT PM + OM (0.5:0.25) had the lowest at 77.2 µg/ml.

The study revealed that untreated PM + OM mixtures tended to have slightly higher amino acid content compared to HMT-treated samples, particularly at the 0.1 µg/ml concentration. This suggests that heat moisture treatment may result in minor amino acid denaturation or reduced extractability, consistent with findings by Sharma *et al.* (2013), who reported similar effects in heat-treated cereal blends due to structural amino acid changes. Interestingly, HMT PM + OM (0.25:0.5) showed a noticeable increase in amino acid from 69.7 µg/ml at 0.1 µg/ml to 86.2 µg/ml at 0.2 µg/ml, suggesting that oyster mushroom's higher ratio may help buffer the loss of amino acid extractability during heat treatment. This supports the idea proposed by Manzi *et al.* (2004) that oyster mushrooms contribute significantly to amino acid enhancement in composite food products. In comparison to earlier studies, such as Singh and Raghuvanshi (2012), which emphasized the amino acid -rich nature of untreated millets, our findings reaffirm that minimal processing retains more measurable amino acid, particularly in combinations involving amino acid -rich ingredients like mushrooms.

SUMMARY AND CONCLUSION

This study focused on the biofortification of millets with oyster mushrooms as a sustainable approach to enhance zinc availability and improve the overall nutritional profile of millet-based foods. Pearl millet and finger millet were





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combined with oyster mushrooms in varying ratios and subjected to both untreated and heat moisture treated (HMT) conditions. The project evaluated key nutritional parameters including zinc content, sulfate content, solubility, carbohydrate, protein, and amino acid content. Zinc estimation revealed that biofortified mixtures, especially under HMT conditions, exhibited increased zinc concentration and bioavailability, which is crucial for combating micronutrient deficiencies. Sulfate content, an indicator of sulfur-containing amino acids, also showed enhancement in treated samples. Carbohydrate analysis indicated that treatment and mixing ratios influenced sugar concentration, while protein and amino acid estimations reflected improved nutritional density in mixtures with higher mushroom content. The solubility of zinc and other nutrients improved in HMT samples, suggesting enhanced digestibility and absorption potential.

Overall, the integration of oyster mushroom with millets significantly enriched the nutritional profile, particularly in zinc and essential amino acids, aligning with the goals of sustainable food fortification and addressing malnutrition. The biofortification of millets with oyster mushrooms proved to be an effective strategy for enhancing zinc availability and improving the overall nutrient composition of millet-based foods. The results demonstrated that heat moisture treatment further amplified the bioavailability of nutrients, particularly zinc and proteins. This approach not only leverages the rich micronutrient content of oyster mushrooms but also aligns with eco-friendly and low-cost food enhancement techniques suitable for vulnerable populations. Given the rising concerns of micronutrient deficiencies, particularly in developing regions, this study supports the potential of functional millet-mushroom blends as a practical dietary intervention. Future work could explore sensory acceptability, long-term storage stability, and scalability of such fortified products for public health implementation.

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Table 1: Effect of Zinc Levels on Mushroom Content

Sample Concentration	50mg/kg	100 mg/kg	150mg/kg	200 mg/kg	250 mg/kg	500 mg/kg
Zinc content in oyster mushroom	2.36	3.15	3.07	3.29	3.57	3.33

Table 2: Sulfate Content in Oyster Mushrooms at Different Zinc Sulfate Levels

Sample Concentration	50mg/kg	100 mg/kg	150mg/kg	200 mg/kg	250 mg/kg	500 mg/kg
Sulfate content in Oyster mushroom	2.36	3.15	3.07	3.29	3.57	3.33





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Table 3: Solubility Variation in Finger and Pearl Millet

S.No.	sample	Sample type	Water Solubility in %
1	<i>Eluesine coracana</i>	HM treated	8.8
		Un treated	17.1
2	<i>Pennisetum glaucum</i>	HM treated	11
		Un treated	14

Table 4: Carbohydrate Content in Treated and Untreated Millet Samples

Sample Type	Treatment	Concentration (µg/ml)	Estimated carbohydrate µg/ml
Finger Millet	Heat Moisture Treated	0.1	10
	Heat Moisture Treated	0.2	30
	Untreated	0.1	56
	Untreated	0.2	58
Pearl Millet	Heat Moisture Treated	0.1	10
	Heat Moisture Treated	0.2	63
	Untreated	0.1	61
	Untreated	0.2	65.9

Table 5: Carbohydrate Content in FM–OM Blends at Varying Ratios and Treatments

Sample Type	0.1 µg/ml	0.2 µg/ml
HMT FM + OM (0.5:0.5)	102.0	123.0
HMT FM + OM (0.5:0.25)	72.0	86.0
HMT FM + OM (0.25:0.5)	69.3	75.0
Untreated FM + OM (0.5:0.5)	61.0	65.9
Untreated FM + OM (0.5:0.25)	134.2	153.0
Untreated FM + OM (0.25:0.5)	78.0	93.0

Table 6: Carbohydrate Content in PM–OM Blends at Varying Ratios and Treatments

Sample Type	0.1 µg/ml	0.2 µg/ml
HMT PM + OM (0.5:0.5)	114	135
HMT PM + OM (0.5:0.25)	79	92
HMT PM + OM (0.25:0.5)	76	80
Untreated PM + OM (0.5:0.5)	142.5	155
Untreated PM + OM (0.5:0.25)	82	95
Untreated PM + OM (0.25:0.5)	83	96

Table 7: Protein Content in Treated and Untreated Millet Samples

Sample type	Treatment	Concentration (µg/ml)	Estimated protein µg/ml
Finger Millet	Heat Moisture Treated	0.1	10
	Heat Moisture Treated	0.2	32.5
	Untreated	0.1	46
	Untreated	0.2	59.6
Pearl millet	Heat Moisture Treated	0.1	10
	Heat Moisture Treated	0.2	64
	Untreated	0.1	71
	Untreated	0.2	76.2





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Table 8: Protein Content in FM–OM Blends at Varying Ratios and Treatments

Sample Type	0.1 µg/ml	0.2 µg/ml
HMT FM + OM (0.5:0.5)	92	112
HMT FM + OM (0.5:0.25)	75	82
HMT FM + OM (0.25:0.5)	63	78
Untreated FM + OM (0.5:0.5)	126	145
Untreated FM + OM (0.5:0.25)	90.8	124
Untreated FM + OM (0.25:0.5)	80	86.3

Table 9: Protein Content in PM–OM Blends at Varying Ratios and Treatments

Sample Type	0.1 µg/ml	0.2 µg/ml
HMT PM + OM (0.5:0.5)	87	98.7
HMT PM + OM (0.5:0.25)	81.9	87
HMT PM + OM (0.25:0.5)	70.5	85
Untreated PM + OM (0.5:0.5)	130	153
Untreated PM + OM (0.5:0.25)	92.4	97
Untreated PM + OM (0.25:0.5)	79	96

Table 10: Estimation of amino acid in millets and millet mushroom flour

Sample type	Treatment	Concentration (µg/ml)	Estimated protein µg/ml
Finger Millet	Heat Moisture Treated	0.1	10
	Heat Moisture Treated	0.2	29.5
	Untreated	0.1	32
	Untreated	0.2	41
Pearl millet	Heat Moisture Treated	0.1	10
	Heat Moisture Treated	0.2	44
	Untreated	0.1	49.8
	Untreated	0.2	52

Table 11: Amino acid Content in FM–OM Blends at Varying Ratios and Treatments

Sample Type	0.1 µg/ml	0.2 µg/ml
HMT FM + OM (0.5:0.5)	59.2	63.7
HMT FM + OM (0.5:0.25)	79	82
HMT FM + OM (0.25:0.5)	96	129
Untreated FM + OM (0.5:0.5)	69.7	75
Untreated FM + OM (0.5:0.25)	87	93.6
Untreated FM + OM (0.25:0.5)	119	138

Table 12: Amino acid Content in PM–OM Blends at Varying Ratios and Treatments

Sample Type	0.1 µg/ml	0.2 µg/ml
HMT PM + OM (0.5:0.5)	83.3	87.3
HMT PM + OM (0.5:0.25)	63.3	77.2
HMT PM + OM (0.25:0.5)	69.7	86.2
Untreated PM + OM (0.5:0.5)	89	90.9
Untreated PM + OM (0.5:0.25)	75	86.5
Untreated PM + OM (0.25:0.5)	72	79.7





Sowmiya

		
Fig.1: Raw paddy straw	Fig 2: Mushroom spawn	Fig.3: Hot water sterilization
		
Fig.4: Paddy Straw with Spawn	Fig.5: Hanging bags	Fig.6: Mature mushrooms with fruiting
		
Fig.7: HMT Finger millet	Fig .8: HMT Pearl millet	Fig.9: HMTmillets blends
		
Fig.10: untreated blends	Fig.11: HMT Finger millet	Fig.12: Untreated Finger

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RESEARCH ARTICLE

The Study of Masculinities Portrayed In the Punjabi Film *Chann Pardesi*: A Psychological Persepective

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ABSTRACT

This paper aims to study the masculinities of three male characters in the cult classic Punjabi film *Chann Pardesi* (1981) namely Harnek Singh, Jagirdar Joginder Singh and Tulsi. This movie revolves around a female protagonist named Kammo who wants to get married to her love interest, a poor man named Harnek Singh who works as a laborer in the fields of a wealthy landlord Joginder Singh. Kammo becomes a victim of the landlord's lustful eyes who sexually abuses her and, in that process impregnates her. This paper will prove how Joginder Singh and Harnek Singh, despite coming from different social and financial backgrounds, are dictated by id which makes them practice the masculinity of ostentation. This paper will also show how the character of Tulsi, an intrigue practicing the masculinity of complicity, is dictated by id in some scenarios and ego in other scenarios, thus proving that masculinity and the Freudian concepts of id, ego and superego, both are slippery in nature and are subjected to change with respect to the temporal and spatial elements.

Keywords: characters, masculinity, laborer, wealthy

INTRODUCTION

The Punjabi movie *Chann Pardesi* (1981) is a movie that displays men embodying different types of masculine performances based on social, economic and psychological variables. The abuse of power by Joginder Singh is evident when he sexually abuses Kammo, a woman who is without any familial or financial substructure just to satisfy his phallogocentric pride, which, in fact, is the main theme that runs in the movie. Kammo's husband, Harnek, leaves Kammo in a fit of fury after coming to know that the child that Kammo gave birth to was not his blood and he felt betrayed. He went to Joginder Singh at his home in order to confront him. Both of these characters show the





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collision of like masculinities. This movie is an exemplification of how the hegemonic masculinity violates women, inferior men, as well as the men themselves who practice such masculinity, as goes according to the concept of “triad of men’s violence” given by sociologist Michael Kauffman who says that “violence has long been institutionalized as an acceptable means of solving conflicts” (Kauffman 3). If the characters of Joginder and Harnek are studied, it can be observed how fragile their masculinities are because they are directly linked to their self-worth.

Since masculinity is a fluxional concept, it can be observed that Joginder Singh is overcome by superego and leaves his domineering ways when he is financially weak and tries to fix things between himself and his son birthed by Kammo whom he refused to accept after he was born. Harnek’s dominating masculinity becomes a soft one when he backs off from attacking Joginder’s son in law that would have quenched his almost two decades long thirst for revenge and all because he recognized Joginder’s daughter as the one who saved his life once. So, the male characters depicted in the movie showcase different kinds of masculinities along with its slipperiness and unpredictability which makes it worthy of a study.

METHODOLOGY

In this paper, the theory of gender, in particularly the study of various types of masculinities will be studied along with giving it a psychological Freudian element. According to Butler, gender is “doing” and the body is reduced to “a mere instrument” while performing gender, the inculcation of which behavior eventually becomes the identity of an individual (34,12). She also mentions the Freudian concept of melancholic masculinity in which a man feels angry and sometimes blames himself for a lost object of love “(83) and is constantly striving to regain it. In this book “A History of Masculinity”, Ivan Jablonka says “there are a thousand ways of being a man: hence the idea of masculinities” (ix), while emphasizing that this set of behavior is learned, an acquired one, and not natural to the males (66). He also gives the concept of the masculinity of ostentation in which a man is driven to commit a crime at the smallest offense. Male pride is linked to the masculinity of ostentation by Jablonka, which he termed to be catastrophic “for public health and the environment”. According to Connell, this behavior can be termed as “masculinity of protest” which is a response to social impotency”. If a man embodies virility, it “is expressed in an even more aggressive form by the occupation of public space, offensive public behavior, petty delinquency, brawls and riots”(Jablonka 232).

Raewyn Connell in her book “masculinities” have categorized masculinity into a hierarchy with hegemony at the apex followed by complicity, then subordination and lastly marginalization. Having borrowed the term “hegemonic” from Gramsci, Connell associates this type of masculinity with power and dominance acquiring the top most position in the hierarchy of masculinity. Criminal masculinity is one of its subtypes which include men practicing offensive and hyper-masculine behavior. Men executing subordinate masculinity provide the shoulder on which hegemonic men stand and exert their power because the hegemonic men exploit the subordinate ones, fleecing them for their own capital advantage. Working class men come under this category, as well as the feminist men and melancholic men who are seen as effeminate versions of the males. The proletariat men, having no financial asset, pride themselves on their ability to work and their robustness. Complicit men, on the other hand, are termed as “slacker version of hegemonic masculinity” by Connell because they gain from the hegemonic privilege and ensures that the order keeps prevailing (Masculinities 79). And ultimately, marginalized masculinity includes men who are deemed as racially inferior, according to Connell. So, the methodology undertaken for the study proposed in this paper is going to be the model of masculinity provided by R.W. Connell.

RESULTS AND DISCUSSIONS

Joginder Singh: The Landlord

In the essay “Hegemonic Masculinity: Rethinking the Concept”, authors Connell and Messerschmidt argued that only a small minority, a splinter group of men come under the category of hegemony. They define it as the





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embodiment of “the currently most honored way of being a man”, which required “all other men to position themselves in relation to it”, and it philosophically “legitimated the global subordination of women to men” (832). The character of Joginder Singh is a hegemonic male because he owns the means of production since he is a landlord and exploits the bodies of poor men who work for him, he also owns the weapons of destruction since he roams around the village with a gun and dogs. He also encapsulates what Jablonka refers to as the masculinity of ostentation in which men seek revenge for the slightest offense. This is concretized in his actions when he rapes Kammo just because Tulsi told him that she had rejected his proposal to keep her as his mistress. According to Kauffman, a man committing an act of rape is actually his “expression of inferiority” (9) due to the fear of getting rejected (6). Being a hegemonic man, he views women as objects and when Kammo dances at a function at his home, Joginder Singh watches her through his lascivious stare. Ever since he set his eyes upon her, he wanted to possess her. When introduced to Kammo for the first time, he shoots the birds in the sky, making the imagery of a hunter hunting his prey quite evident, and in real life scenario, a women, that is Kammo, becomes his prey. Being a hegemonic male, he owns the weapons of destruction and orders his men to kill Harnek when he is confronted by him, who then throw Harnek into a river thinking him dead. It is because “the masculinities of domination assert their legitimacy by reducing, even destroying the other masculinities (Jablonka 183)

An image depicting Amrish Puri as Joginder Singh

According to Connell and Messerschmidt, “men can adopt hegemonic masculinity when it is desirable; but the same men can distance themselves strategically from hegemonic masculinity at other moments (841). In the same manner, when Joginder Singh is dethroned from his status, and is a hegemonic male no more, he expresses his wish to reconcile with his illegitimate son Lali whom he had initially refused to accept. It can also be argued that when he possessed monetary wealth, Joginder Singh had the police under his thumb and when he loses legal tender, police arrested him when he shot Tulsi. Thus, hegemony comes to the men with money.

Harnek Singh: The Rebel

Harnek Singh is introduced to the viewer in the beginning of the movie as a worker who labours in the fields of Joginder Singh, having no land of his own to till. He is the only labourer who works hard. Harnek is financially and socially a subordinate man in stark contrast to the position of Joginder Singh, and is constantly proving his masculinity by tilling the land at a faster pace.

An image depicting Kulbushan Kharbanda as Harnek Singh

According to Kauffman, “[f]or a working-class boy, the avenue of mastering the world of business, politics, the professions, and wealth is all but denied. For him male power is after defined in the form of working-class machismo. The power to dominate is expressed in a direct physical form” (7). He could have happily continued to work under Joginder Singh if only his beloved turned wife hadn’t given birth to a child who was Joginder Singh’s. From a subordinate masculine man, he became a representative of a turbulent masculinity when he rebelled against the landlord and tried to usurp his place and become hegemonic himself. But since he did not have material wealth, he could not do that and was stuck being a turbulently masculine male in the shape of a rebel bandit. By becoming a bandit, he had access to weapons to kill Joginder Singh. Joginder Singh was introduced as a man with a horse and a gun, but Harnek transformed himself into becoming that kind of a man.

He is also a man whom Meg Luntun referred to as “petty tyrant” because he committed violence against his wife in the household when he comes to know that the child she had given birth to is not his own (Kauffman 9). Blinded by fury, he also tried to kill the child himself, and when he failed to kill Joginder Singh the first time he tried to seek vengeance, his masculinity became turbulent and posed a threat to the hegemonic order. Turbulent masculinity, in fact, is a sub culture of the hegemonic masculinity.

Tulsi: The Intrigue

Tulsi, in the movie “Chann Pardesi” is the accountant of the landlord Joginder Singh as well as an evil intrigue whose schemes move the plot of the movie forward. He is a mercenary, extremely greedy for money, who wants to have his





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job secure under Joginder Singh and arrange things for him at his whim. When Joginder Singh tells him that he has taken fancy of Kammo, he goes to Kammo and proposed her to be the landlord's mistress in exchange of gold and when she refused him, he instills anger in the landlord's heart by exaggerating her refusal and then sends Harnek away for work. This paves a clear path to the landlord who chased Kammo on his horse before sexually abusing her in the absence of Harnek.

An image depicting Om Puri as Tulsi

Being a man practicing the masculinity of complicity, he helped to maintain the power of a hegemonic male the landlord, by suppressing the subordinate man and women. Since it is a lesser version of the hegemonic masculinity, it enjoys the advantages that came along with supporting the hegemonic order.

The psychological take on these characters

Under psychoanalysis, the Austrian psychiatrist Sigmund Freud provided with the concept of 'id' in which an individual is governed by the pleasure principle and libidinal instincts, 'superego' in which an individual is directed by morality principle, and 'ego' which balances the needs of id without compromising on the proprieties under superego (M.H. Abrams 321). If the characters of the movie *Chann Pardesi* are studied according to this psychological frame, it can be observed that Joginder Singh as well as Harnek, both are directed by the 'id' because they are easily vanquished by emotions such as anger, pride, and grief, which makes them take rash steps. If Joginder Singh on one hand sexually abuses Kammo in order to take revenge because she had refused his sexual advances, Harnek Singh, unable to kill the landlord, becomes a bandit as he could not tolerate the downward movement and becoming the epitome of failed masculinity. It is after Joginder Singh loses his wealth that id leaves him and he transforms into a prototype of a superego and wished to fix things between himself and his illegitimate son.

Tulsi, on the other hand, was governed by ego in the major part of the movie for he is a scheming intrigue who thinks carefully and plans things without acting out rashly. However, it is after Joginder Singh lost his wealth that Tulsi began questioning his own financial security as a result of which, the excessive greed makes his personality lopsided being overtaken by id and he blackmails the landlord for money which ended up Joginder Singh shooting him.

CONCLUSION

The movie *Chann Pardesi* provides the viewer with a plethora of different types of masculinities, out of which only three have been discussed in this paper, the ones which seemed prominent as far as the plot of the movie is concerned. It has been observed in the study above that the hegemonic masculinity is in stark contrast with the masculinity of subordination, moreover, the concept of masculinity is not a fixed one since it keeps on changing according to the circumstantial element. The Freudian elements of id, ego and superego can also be associated with the kinds of masculinities practiced by the male characters, as is evident from this study.

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RESEARCH ARTICLE

Correlation of Core Endurance and Lower Limb Strength with Performance in Adolescent Badminton Players

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ABSTRACT

High-intensity racquet sports like badminton require rapid directional shifts, frequent jumps, and powerful overhead smashes. This cross-sectional study observed the relationship between adolescent players' smash accuracy and velocity and their lower limb strength and core endurance. The research was conducted from September 2017 to March 2019 at Manav Rachna International Institute of Research and Studies in Faridabad, Haryana, India. Convenience sampling was used to recruit 100 badminton players, with 85 completing the study. Participants aged 11 to 15 years had at least one year of badminton experience at district or state academies. The plank test measured core endurance, the vertical jump test assessed lower limb strength, the forehand smash stroke performance test evaluated smash accuracy, and a radar gun recorded smash velocity. Statistical analysis was performed using Pearson's correlation coefficient, with a significance level of $p \leq 0.005$. The participants' average age was 13.45 ± 1.09 years. Smash velocity and core endurance showed a weak, non-significant correlation ($r = -0.028$). Smash accuracy was positively correlated with smash velocity ($r=0.468$), and lower limb strength was also positively correlated with smash velocity ($r=0.364$). In teenage badminton players, smash velocity was favourably associated with lower limb strength and smash accuracy; however, no significant relationship was found between smash velocity and core endurance.

Keywords: Radar Gun, Racket Sports, Smash Stroke, Smash, adolescent athletes, lower limb strength



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INTRODUCTION

Badminton is one of the most popular racquet sports worldwide, involving a mix of speed, agility, balance, coordination, and explosive strength [1-4]. The game is characterised by frequent short bursts of high-intensity activities such as jumping, lunging, quick directional changes, and overhead strokes [3, 4]. Among various badminton strokes, the forehand smash is considered one of the most vital offensive skills because it combines speed with directional control and directly contributes to scoring points [8]. Smash performance is dependent on the coordinated contact of various body segments along the kinetic Chain. During an overhead smash, force is generated in the lower limbs and transferred to the upper extremity and racket via the trunk [13,14]. Thus, physical abilities like trunk function and lower limb explosive force may affect the quality of smash performance. While trunk function aids in postural control, proximal stability, and the transfer of force between the lower and upper body, lower limb explosive power is crucial for push-off and jumping motions [5,6,15]. Previous research has highlighted the significance of core-related training, lower-limb conditioning, balance, and neuromuscular control for badminton performance [3, 8, 16-21]. However, fewer studies have investigated how field-tested measures of trunk endurance and lower-limb explosive power affect smash velocity in adolescent badminton players. Furthermore, trunk function is sometimes referred to as core strength, even when evaluated using static endurance-based field tests. Because the plank test more truly measures trunk muscular endurance than maximum trunk strength, it is critical to analyse such results carefully. Thus, the current study aimed to find out how the trunk endurance and lower limb explosive power of adolescent badminton players relate to their smash velocity and accuracy.

MATERIALS AND METHODS

Study Design: Between September 2017 and March 2019, Manav Rachan International University in Faridabad, Haryana, India, hosted this cross-sectional study. The study's goal was to investigate how adolescent badminton players' core endurance and lower limb strength related to their smash velocity and accuracy.

participants: Convenience sampling was used to enrol 100 badminton players, of whom 85 finished the study and were included in the final analysis. There were 25 female and 60 male players in the final sample. Players were recruited from Manav Rachna Sports Academy, L.K. Mehta Academy, and the senior Shree Ram Model High School in Faridabad.

Eligibility Criteria: Players had to be between the ages of 11 and 15 and have played badminton at the district or state level for at least a year. Informed consent was taken from parents/coaches. Individuals who had recently had a fracture, had a neurological condition, or had surgery within the preceding six months were excluded.

Ethical Considerations: The Institutional Ethical Committee of the Faculty of Allied Health Science provided ethical clearance (MRIIRS/FAHS/2017/165). Before their involvement in the study, individuals gave their informed consent, as did any applicable parents or coaches.

Study Procedure: Before testing, demographic information such as age, height, weight, and BMI was obtained. For 10 to 15 minutes, all participants went through a normal warm-up that included running and active stretching. After the warm-up, individuals were evaluated for core endurance, lower-limb strength, smash accuracy, and smash velocity.

Core Endurance Test: Participants were engaged in a 10 to 15-minute active warm-up session, which included activities such as jogging, walking, stretching, and jumping. Adequate stretching of both upper and lower limb muscles was conducted.



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Prone: The forearms and toes supported the participants' body weight as they remained in a prone position. Participants were instructed to maintain a neutral position of head, shoulder, spine, pelvis, and legs. Ask the players to breathe normally during the procedure. Holding time was measured by using a stopwatch. When the participants were unable to hold their position and were pelvically moved up and down, recordings were noted. 3 trials were taken with 2-minute rest intervals between them.

Side: - The test was done with the specified players who were lying on the other side and were supported by the "foot and elbow." It was performed on both sides. Players were instructed to maintain a neutral position of supine and pelvic and to breathe in a normal way during testing [10].

Vertical Jump Test: Athletes stand beside walls and attempt to reach up as far as possible with their hands closest to the wall while maintaining both feet on the ground. This is done to measure their lower limb explosive power. First, the athlete colours the tip of his middle finger. Next, they place a mark on the wall with their fingertip. The standing reach point was at this location (M1). Next, the participant leapt as far as they could from their still posture and used their middle fingers to mark the wall (M2). The distance in centimetres between M1 and M2 was recorded. The participant completed the test three times, with a 20-second break between trials, and the athlete's explosive power was assessed by averaging the measured distances (11,12).

Forehand Smash Stroke Performance Test: smash accuracy was assessed using the Forehand Smash Stroke Performance Test. Players performed 10 maximum forehand smash strokes after a typical warm-up, resting for five to ten seconds in between. A 60 x 60 cm target was divided into three equal-sized colored zones in the upper right corner of the singles court: red = 3 = 3 points, blue = 2 points, and yellow = 1 point. With a maximum score of 30 points, accuracy was calculated as (total score ÷ 30) × 100 (8,9).

Smash Velocity Test: smash velocity was measured using a radar gun placed behind the badminton court and aligned with the approximate path of the shuttlecock. After familiarisation, participants performed 3 maximal smashes with 5 to 10 seconds rest intervals between attempts, and the recorded values were used for analysis (8).

Statistical Analysis: IBM SPSS Statistics version 26.0 was used for data analysis. Mean ± standard deviation was used to express descriptive statistics. The relationship between core endurance, lower limb strength, and smash accuracy with smash velocity was examined using the Pearson correlation coefficient. At $p \leq 0.005$, statistical significance was established.

RESULTS: The study involved 85 badminton players, including 60 males and 25 girls. The average age of participants was 13.45 ± 1.09 years. The tables (1-14) provide the descriptive data obtained for the plank test, lower limb strength test, smash velocity, and smash accuracy. Correlation research revealed that core endurance, as measured by the plank test, had a negligible and insignificant connection with smash velocity ($r=0.028$). Lower limb strength had a positive link with smash velocity ($r=0.364$), as did smash accuracy ($r=0.468$). These data suggest that players with better jump performance and smash accuracy had higher smash velocity, although core endurance did not have a significant relationship with smash velocity in this study.

DISCUSSION

The present study examined the relationship of core endurance and lower-limb strength with smash velocity and smash accuracy in adolescent badminton players. The findings showed that lower-limb strength and smash accuracy were positively associated with smash velocity, whereas core endurance demonstrated a negligible and non-significant relationship with smash velocity. These results suggest that, in this study, greater lower-limb strength and better accuracy were linked with higher smash velocity, while static core endurance, as assessed by the plank test, was not independently associated with smash speed.



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The positive association between lower-limb strength and smash velocity is consistent with the biomechanical demands of badminton. The forehand smash is a high-velocity, whole-body action in which force is generated from the lower limbs and transferred through the trunk to the upper extremity in a proximal-to-distal sequence. Ariff and Rambely (2008) and Rasmussen et al. (2010) described the badminton smash as a coordinated kinetic-chain movement that depends on efficient segmental energy transfer across the body. From this perspective, players with greater lower-limb strength capacity may be better able to generate push-off force, achieve favourable body positioning, and transfer energy more effectively during overhead stroke execution, thereby contributing to greater shuttle velocity. This interpretation is further supported by Preeti et al. (2019), who reported improvements in lower-limb strength, dynamic balance, agility, and coordination following Pilates-based training in badminton players, indicating that physical capacities linked with lower-body performance may influence badminton-specific skills. More recent evidence also strengthens this interpretation. Wang et al. (2025) reported that resistance training improves performance-related variables in competitive badminton players, with particularly favourable effects on jump-related and power-based outcomes, while Lu et al. (2025) found that velocity-based resistance training improved lower-limb strength and footwork speed in elite university badminton players. Collectively, these findings support the present result that lower-limb strength is an important contributor to smash velocity.

Another important finding of the present study was the positive relationship between smash accuracy and smash velocity. This suggests that higher smash speed was not achieved at the expense of directional control. Instead, players who produced faster smashes also tended to demonstrate better target performance. This pattern may reflect the contribution of overall stroke proficiency, coordination, timing, and movement control to successful smash execution. Jamil (2001) emphasized that badminton accuracy depends on a combination of fitness, speed, and skill, which is consistent with the present observation that velocity and accuracy may improve together in more proficient players. Recent evidence supports this integrated view. Wang et al. (2026) demonstrated that fatigue reduced both forehand jump smash speed and accuracy, indicating that these two performance variables are closely linked through neuromuscular control and stroke quality. Thus, the present finding likely reflects the fact that players with better technical and physical proficiency can produce both faster and more accurate smashes.

In contrast, core endurance measured using the plank test was not significantly associated with smash velocity. This finding should be interpreted cautiously and should not be taken to mean that trunk function is unimportant in badminton performance. A more likely explanation is that the plank test reflects static isometric trunk endurance, whereas the badminton smash requires dynamic trunk stabilisation, rotational control, intersegmental coordination, and rapid force transmission. Kibler et al. (2006) described the trunk as a central link for force transfer and proximal stability in athletic movement, and Willardson (2007) similarly emphasized that core stability contributes to sports performance through control and efficient force transmission rather than through isolated static endurance alone. Therefore, a field-based plank test may not adequately capture the sport-specific contribution of the trunk during a powerful overhead stroke. This interpretation is consistent with badminton-specific evidence. Hassan (2017) and Solanki and Gill (2021) reported that core stability training improved dynamic balance and smash stroke performance in badminton players, while Ma et al. (2024), in a systematic review and meta-analysis, concluded that core strength training can improve badminton performance, particularly in explosive and skill-related outcomes. Taken together, these findings suggest that trunk function remains important, but a static plank measure may not be sufficiently specific to demonstrate a direct association with smash velocity in the present study.

The age and developmental characteristics of the participants may also help explain the present findings. The study included adolescent badminton players with a mean age of 13.45 ± 1.09 years. At this stage of development, performance is influenced not only by isolated physical capacities but also by growth, maturation, technical learning, motor coordination, and exposure to structured training. In younger players, variables such as jump performance and stroke accuracy may show a clearer relationship with smash velocity than a simple field-based measure of core endurance. This may explain why lower-limb strength and accuracy emerged as more sensitive correlates of smash performance than core endurance in the present study. From a practical perspective, the present findings suggest that training programmes aimed at improving smash performance in adolescent badminton players should give



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considerable emphasis to lower-limb strength conditioning and stroke-specific technical practice. Exercises targeting jump ability, rapid push-off, force production, and landing control may support improvements in smash velocity, while technical drills focusing on controlled shuttle placement may help enhance both accuracy and stroke effectiveness. At the same time, core training should not be excluded, as the core remains essential for postural control, movement efficiency, and force transfer; however, its contribution may be better assessed through dynamic and sport-specific measures rather than static endurance tests alone. Overall, the findings of the present study indicate that smash velocity in adolescent badminton players is more closely associated with lower-limb strength and stroke accuracy than with core endurance. Future studies should therefore use longitudinal or interventional designs, include more sport-specific measures of trunk performance such as rotational power and dynamic control, and account for potentially important factors such as sex, maturation, training load, and playing level.

CONCLUSION

The present study concludes that lower limb strength and smash accuracy are positively associated with smash velocity in adolescent badminton players, whereas core endurance does not show a significant association with smash velocity. These findings suggest that players with better jump-related explosive performance and better accuracy tend to produce faster smashes. Although core functions remain important in badminton performance, a static core endurance test may not adequately reflect the dynamic trunk contribution required during a high-velocity smash. Therefore, training programmes aimed at improving smash performance should place greater emphasis on lower limb strength and stroke-specific technical practice, while future studies should use more sport-specific measures of core function to clarify its role in smash execution.

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Table 1: Demographic Details:

Variables	Mean±SD	P Value
Age (Years)	13.45±1.09	≤ 0.005
Experience (years)	2.71±0.92	≤ 0.005
Height (Cm)	2.44±0.36	≤ 0.005
Weight (Kg)	43.20±9.14	≤ 0.005
Body Mass Index (Kg/m ²)	17.68±2.81	≤ 0.005

Interpretation: The table summarises the mean and standard deviation for core plank, smash velocity, and smash accuracy





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Table 2: The mean values of Core Plank, Smash Velocity, and Accuracy (Smash Stroke Performance) were 74.26 ± 19.41 , 64.25 ± 23.77 and 18.90 ± 12.48 .

Variables	Mean $\pm$ SD	P Value
Core Plank	74.26 ± 19.41	≤ 0.005
Smash Velocity	64.25 ± 23.77	≤ 0.005
Accuracy (Smash Stroke Performance)	18.90 ± 12.48	≤ 0.005

Interpretation: The table summarises the mean and standard deviation for core plank, smash velocity, and smash accuracy.

Table 3: The mean and standard deviation of LLEP and Smash Velocity were 29.14 ± 8.21 and 64.25 ± 23.77 .

Variables	Mean $\pm$ SD	P Value	R value
LLEP	29.14 ± 8.21	≤ 0.005	-0.028).
SMASH VELOCITY	64.25 ± 23.77	≤ 0.005	0.364

Interpretation: This table presents the means and standard deviations for lower-limb strength and smash velocity.

Table 4: Mean and Standard Deviation of Accuracy & Smash Velocity were 18.90 ± 12.48 and 64.25 ± 23.77 .

Variables	Mean $\pm$ SD	P Value	R value
Accuracy	18.90 ± 12.48	≤ 0.005	0.468
Smash Velocity	64.25 ± 23.77	≤ 0.005	0.364

Interpretation: Table present the descriptive statistics for smash accuracy and smash velocity among the players



Figure 1: Prone Plank Test

Interpretation: This Figure illustrates the prone test used to assess static core muscle endurance in the participants.



Figure 2: Right Lateral Plank Test

Interpretation: This figure shows the right lateral plank test performed to evaluate lateral core endurance on the right side





Figure 3:Left Lateral Plank

Interpretation: This figure depicts the left lateral plank test used to assess lateral core endurance on the left side



Figure 4: Vertical Jump

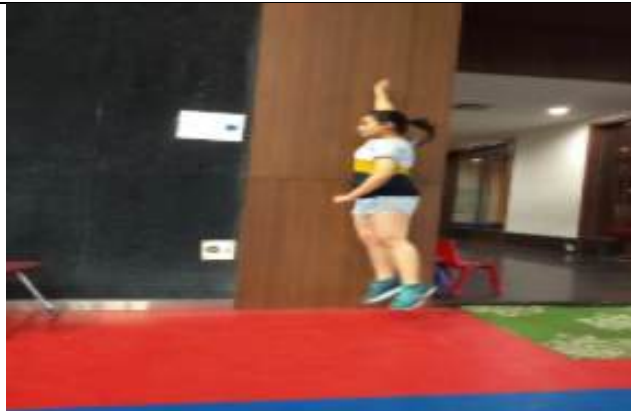
Interpretation: The figure presents the vertical jump assessment used to evaluate lower limb strength



Figure 5: Vertical jump-starting position

Interpretation: This figure shows the starting position adopted before performing the vertical jump test.



Nitin Kumar Indora *et al.*,**Figure 6: Vertical jump**

Interpretation: This figure illustrates the execution phase of the vertical jump test during maximal upward propulsion.

**Figure 7: Forward-Stroke Smash Performance Test**

Interpretation: This figure demonstrates the forward stroke smash performance test used to assess smash accuracy

**Figure 8: Smash Velocity Test**

Interpretation: This figure presents the smash velocity test used to measure shuttle speed smash execution.



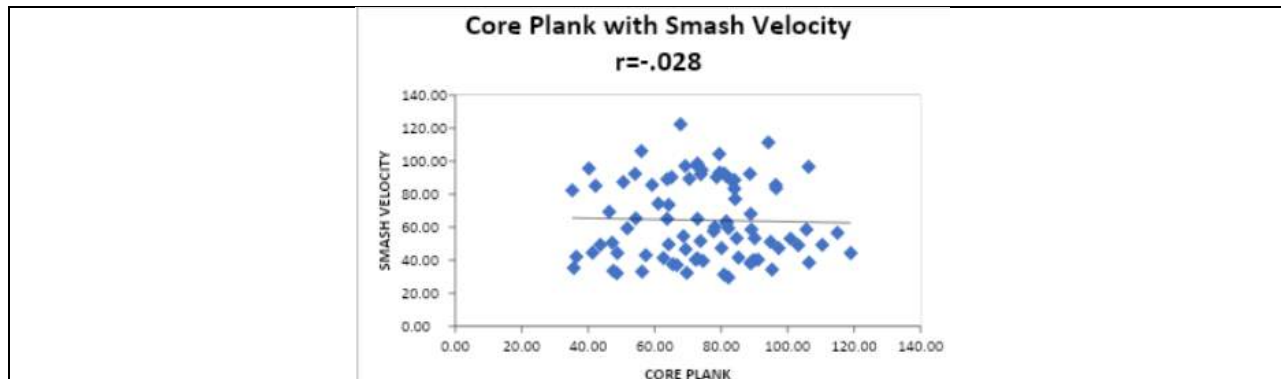


Figure 9: Scatter graph Correlation between Core Plank with Smash Velocity, Interpretation: This figure shows the scatter plot representing the correlation between core plank and smash velocity.

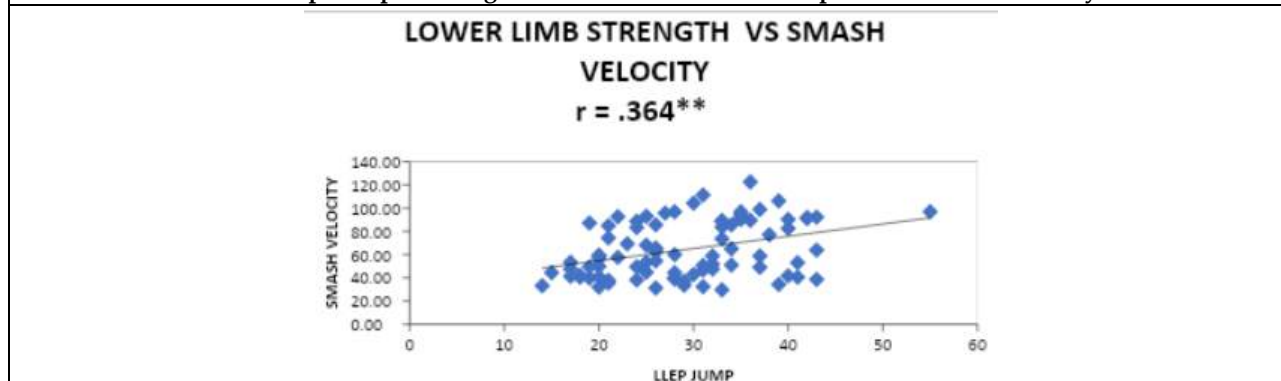


Figure 10: Scatter graph correlation between LLEP and Smash Velocity Interpretation: This figure presents the scatter plot illustrating the relationship between lower limb strength and smash velocity.

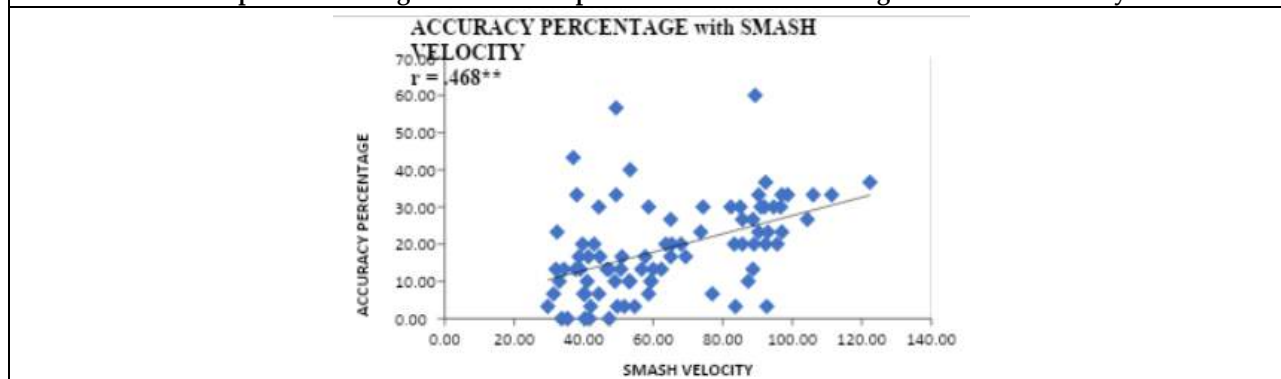


Figure 11: Scatter graph correlation between the Accuracy test and Smash Velocity Interpretation: This Figure shows the scatter plot demonstrating the correlation between smash accuracy and smash velocity

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