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May this noble endeavor continue to flourish and remain evergreen—deeply rooted in wisdom and excellence—spreading renewed awareness, multidimensional insight and enlightenment for generations to come.

\- Editors

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The Chromatic Restrained Domination on Direct Product with Wheel Graphs

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ABSTRACT

Let $G = (V, E)$ be a graph. A subset D of V is said to be a chromatic restrained dominating set (or $crd-$set) of G if D is a restrained dominating set of G and $\chi(< D >) = \chi(G)$. The minimum cardinality taken over all minimal chromatic restrained dominating sets is called the chromatic restrained domination number of G, denoted by $\gamma_r^c(G)$. In this article, we determine the chromatic restrained domination number for the direct product of certain standard graphs with wheel graphs.

Keywords: *Domination, Restrained Domination, Chromatic Number, Direct Product*

AMS Subject Classification: 05C15, 05C69

1. Introduction

All the graphs $G = (V, E) = (n, m)$ considered here are simple, finite and undirected, with neither loops nor multiple edges. For $D \subseteq V$, the subgraph induced by D is denoted by $\langle D \rangle$. A $k-$vertex coloring of a graph is an assignment of $k-$colors to its vertices. The coloring is proper if no two adjacent vertices are assigned the same color. A coloring in which $k-$ colors are used is a $k-$coloring. A graph is $k-$colorable if it has a proper $k-$coloring. The minimum k for which a graph G is $k-$colorable is called its chromatic number and denoted by $\chi(G)$. Graph Theory terminologies which are not defined here can be seen in [1] and [2].

A set $D \subseteq V$ of vertices in a graph G is called a dominating set if every vertex $u \in V$ is either an element of D or is adjacent to an element of D. The minimum cardinality taken over all minimal dominating sets is called the domination number of G and is denoted by $\gamma(G)$. A set $D \subseteq V$ is a restrained dominating set if every vertex in $V - D$ is adjacent to a vertex in D and another vertex in $V - D$ [3]. The minimal cardinality taken over all minimal restrained dominating sets is called the restrained domination number of G and is denoted by $\gamma_r(G)$. A set D is a γ_r-set if D is a restrained dominating set of cardinality $\gamma_r(G)$.

For graphs G and H, the $direct\ product\ G \times H$ (also known as the tensor product, cross product, cardinal product, kronecker product) is the graph with vertex set $V(G) \times V(H)$ where two vertices (x, y) and (v, w) are adjacent if and only if $xv \in E(G)$ and $yw \in E(H)$ [4].

A set $D \subseteq V$ is a $chromatic\ preserving\ set$ or a cp-set if $\chi(< D >) = \chi(G)$ and the minimum cardinality taken over all cp-set in G is called the $chromatic\ preserving\ number$ or cp-number of G, denoted by $cpn(G)$ [5]. T. N. Janakiraman and M. Poobalaranjani introduced this concept. They also defined the concept of dom-chromatic set of a graph. A subset D of V is said to be a $dom - chromatic\ set$ (or dc-set) if D is a dominating set and $\chi(< D >) = \chi(G)$ [6]. The minimum cardinality taken over all minimal dom-chromatic sets in G is called the $dom - chromatic\ number$ and is denoted by $\gamma_{ch}(G)$. Several authors including S. Balamurugan extended this idea and studied various dom-chromatic parameters such as chromatic connected domination, chromatic total domination, chromatic strong domination, chromatic weak domination, and so on [7], [8], [9], [10]. In this paper, the chromatic restrained domination number on the direct product of some standard graphs with wheel graphs is obtained.

2. Main Results

Definition 2.1 Let $G = (V, E)$ be a graph. A subset D of $V(G)$ is said to be a $chromatic\ restrained\ dominating\ set$ (or crd −set) if D is a restrained dominating set and $\chi(< D >) = \chi(G)$. The minimum cardinality taken over all minimal chromatic restrained dominating sets is called the $chromatic\ restrained\ domination\ number$ of G, denoted by $\gamma_r^c(G)$. Throughout this paper, the chromatic restrained domination number on the direct product of two graphs G and H is denoted by $\gamma_r^c(G \times H)$.

Theorem 2.2 For $r \geq 4$, $\gamma_r^c(K_r \times W_s) = \begin{cases} 4 & if\ s = 4 \\ 3 & if\ s = 5 \\ 2s + 1 & if\ s\ is\ even,\ s \geq 6 \\ 4 & if\ s\ is\ odd,\ s \geq 7 \end{cases}$.

Proof: Let $V(K_r \times W_s) = \{(u_i, v_j)/1 \leq i \leq r, 0 \leq j \leq s - 1\}$ where $u_i \in K_r$ and $v_j \in W_s$. Denote the rows of $K_r \times W_s$ by $V_1, V_2, \ldots, V_r$ and the columns by $X_0, X_1, \ldots, X_{s-1}$. Clearly, (u_1, v_0) is adjacent to all the vertices except the vertices of V_1 and X_0 in $K_r \times W_s$ and $\chi(K_r \times W_s) = \begin{cases} 3\ if\ s\ is\ odd \\ 4\ \ if\ s\ is\ even. \end{cases}$

Case (i): $s = 4$

Since K_r and W_4 are complete, every vertex of $K_r \times W_4$ is adjacent to all the vertices except the vertices in particular row or column in which it belongs. Consider $D_1 =$

$\{(u_1, v_0), (u_2, v_1), (u_3, v_2), (u_4, v_3)\}$ where every vertex belongs to different row and column. Clearly, D_1 is a restrained dominating set. Also, $\langle D_1 \rangle$ is complete and $\chi(\langle D_1 \rangle) = 4 = \chi(K_r \times W_s)$. Thus, D_1 is a chromatic restrained dominating set and so, $\gamma_r^c(K_r \times W_s) \leq |D_1| = 4$. Since $\chi(K_r \times W_s) = 4, \gamma_r^c(K_r \times W_s) < 4$ is impossible. Therefore, $\gamma_r^c(K_r \times W_s) = 4$.

Case (ii): $s = 5$

Consider $D_2 = \{(u_1, v_0), (u_2, v_1), (u_3, v_2)\}$. Since every vertex in V_1 and W_0 are adjacent to (u_2, v_1) or (u_3, v_2) and the remaining vertices are adjacent to (u_1, v_0) with $\langle V(K_r \times W_s) \backslash D_2 \rangle$ is connected, D_2 is a restrained dominating set. Also, $\chi(\langle D_2 \rangle) = 3 = \chi(K_r \times W_s)$, which implies D_2 is a chromatic restrained dominating set of $K_r \times W_s$. Thus, $\gamma_r^c(K_r \times W_s) \leq 3$. As $\chi(K_r \times W_s) = 3, \gamma_r^c(K_r \times W_s) \geq 3$. Therefore, $\gamma_r^c(K_r \times W_s) = 3$.

Case (iii): s is even, $s \geq 6$

Clearly, $\chi(K_r \times W_s) = 4$. Take $D_3 = \{(u_1, v_0), (u_1, v_1), (u_2, v_0)\}$. Then, D_3 is a minimal γ_r −set of $K_r \times W_s$ and $\gamma_r(K_r \times W_s) = 3$. But $\chi(\langle D_3 \rangle) = 2 \neq 4$. Thus, D_3 does not forms a γ_r^c −set for $K_r \times W_s$. In order to construct a minimal chromatic restrained dominating set with $\chi = 4$, consider $D_4 = \{(u_1, v_0), (u_1, v_1), \ldots, (u_1, v_{s-1}), (u_2, v_0), (u_2, v_1), \ldots, (u_2, v_{s-2})\} \cup \{(u_3, v_0), (u_4, v_0)\}$. Then, D_4 is a γ_r^c −set with cardinality $s + s - 1 + 2 = 2s + 1$. Hence, $\gamma_r^c(K_r \times W_s) \leq 2s + 1$. Removing a vertex (u_i, v_j) for any i, j from D_4 affects the chromatic preserving number of $K_r \times W_s$ and so, $\gamma_r^c(K_r \times W_s) < 2s + 1$ is not possible. Therefore, $\gamma_r^c(K_r \times W_s) = 2s + 1$.

Case (iv): s is odd, $s \geq 7$

Considering D_2, every vertex except some of the vertices in row V_1 of $K_r \times W_s$ is not adjacent to any one of the vertices of D_2. Thus, D_2 is not a restrained dominating set. Take $D_5 = D_2 \cup \{(u_2, v_0)\}$. Clearly, D_5 is a restrained dominating set and as $D_2 \subset D_5, \chi(\langle D_5 \rangle) = 3$. Thus, D_5 forms a γ_r^c −set of $K_r \times W_s$ and $\gamma_r^c(K_r \times W_s) \leq 4$. Suppose there exists a chromatic restrained dominating set S such that $|S| < 4$. Then, $|D_2| < |S| < |D_5|$, that is $3 < |S| < 4$, which is not possible. Therefore, $\gamma_r^c(K_r \times W_s) = 4$.

Theorem 2.3 For any $r \geq 3, s \geq 5, \gamma_r^c(P_r \times W_s) = r$.

Proof: Let $V(P_r \times W_s) = \{(u_i, v_j) / 1 \leq i \leq r, 0 \leq j \leq s - 1\}$ and denote the columns of $P_r \times W_s$ by $X_0, X_1, X_2, \ldots, X_{s-1}$. Also, $\chi(P_r \times W_s) = 2$. Consider $D = V(X_0) = \{(u_i, v_0) / 1 \leq i \leq r\}$ with cardinality r. Clearly, D is a restrained dominating set of $P_r \times W_s$ and $\gamma_r(P_r \times W_s) \leq r$. Suppose there exists a restrained dominating set S such that $|S| < r$. Then, there exists at least one of the vertex in $V \backslash S$ which is not adjacent to any of the vertex in S. Thus, $\gamma_r(P_r \times W_s) < r$ is not possible and so, $\gamma_r(P_r \times W_s) = r$. Moreover, D is an independent

set. Thus, $\chi(\langle D\rangle) = 1 \neq \chi(P_r \times W_s)$. Let $D_1 = (D\backslash\{(u_1, v_0)\} \cup \{(u_2, v_1)\}$. Then, D_1 is a restrained dominating set and as $(u_3, v_0)(u_2, v_1) \in E(P_r \times W_s), \chi(\langle D_1\rangle) = 2 = \chi(P_r \times W_s)$. This implies that, D_1 is a chromatic restrained dominating set of $P_r \times W_s$ and therefore, $\gamma_r^c(P_r \times W_s) = |D_1| = r$.

Observation 2.4 For $r > 4$,

(i) if r is odd, then $\gamma_r^c(C_r \times W_4) = 2r$.

(ii) if r is even, then $\gamma_r^c(C_r \times W_4) = \begin{cases} \frac{2r}{3} + 1 & if\ r \equiv 0(mod\ 3) \\ \left\lceil \frac{2r}{3} \right\rceil + 1 & if\ r \equiv 1(mod\ 3) \\ \left\lceil \frac{2r}{3} \right\rceil & if\ r \equiv 2(mod\ 3). \end{cases}$

Theorem 2.5 For any $r \geq 4, s \geq 5, \gamma_r^c(C_r \times W_s) = \begin{cases} r & if\ r\ is\ even \\ 2r & if\ r\ is\ odd. \end{cases}$

Proof: Let $V(C_r \times W_s) = \{(u_i, v_j)/1 \leq i \leq r, 0 \leq j \leq s-1\}$ and denote the columns of $C_r \times W_s$ by V_j, where $|V_j| = r$. Clearly, $\chi(C_r \times W_s) = \begin{cases} 2 & if\ r\ is\ even \\ 3 & if\ r\ is\ odd \end{cases}$. Consider $D = V_1 = \{(u_i, v_0)/1 \leq i \leq r\}$. Then, D is a minimal restrained dominating set and $\gamma_r(C_r \times W_s) = |D| = r$. Since D is an independent set, $\chi(\langle D\rangle) = 1 \neq \chi(C_r \times W_s)$. Thus, D is not a chromatic restrained dominating set of $C_r \times W_s$.

Case $(\boldsymbol{i})$: r is even

Consider $D_1 = (D\backslash\{(u_r, v_0)\} \cup \{(u_{r-1}, v_1)\}$. Then, D_1 is also a restrained dominating set of $C_r \times W_s$. Since $(u_{r-2}, v_0)(u_{r-1}, v_1) \in E(C_r \times W_s), \chi(\langle D_1\rangle) = 2 = \chi(C_r \times W_s)$. This implies that, D_1 is a γ_r^c −set of $C_r \times W_s$ and $\gamma_r^c(C_r \times W_s) \leq |D_1| = r$. Since $\gamma_r(C_r \times W_s) = r, \gamma_r^c(C_r \times W_s) < r$ is impossible. Therefore, $\gamma_r^c(C_r \times W_s) = r$.

Case $(\boldsymbol{ii})$: r is odd

As $\chi(C_r \times W_s) = 3$, let $D_2 = D \cup \{(u_x, v_1)/1 \leq x \leq r-1\} \cup \{(u_1, v_2)\}$. As $D \subset D_2$ and $\langle V\backslash D_2\rangle$ remains connected, D_2 is a restrained dominating set. Also, $\chi(< D_2 >) = 3$. Thus, D_2 is a γ_r^c −set of $C_r \times W_s$ and so, $\gamma_r^c(C_r \times W_s) \leq |D_2| = 2r$. As any γ_r^c −set with cardinality less than $2r$ does not forms a cp −set, $\gamma_r^c(C_r \times W_s) \geq 2$. Hence, $\gamma_r^c(C_r \times W_s) = 2r$.

Theorem 2.6 For any $r \geq 2, s \geq 4$, $\gamma_r^c(K_{1,r} \times W_s) = 3$.

Proof: Let $V(K_{1,r} \times W_s) = \{(u_i, v_j)/0 \leq i \leq r, 0 \leq j \leq s-1\}$ with cardinality $(r+1)s$. Clearly, $\chi(K_{1,r} \times W_s) = min\{\chi(K_{1,r}), \chi(W_s)\} = 2$. Denote the rows of $K_{1,r} \times W_s$ by $V_0, V_1, \ldots, V_r$ and columns by $X_0, X_1, X_2, \ldots, X_{s-1}$, where no two elements of $V_1, V_2, \ldots, V_r$ are adjacent. Consider $D = \{(u_0, v_0), (u_1, v_0), (u_0, v_1)\}$. Then, (u_0, v_0) is adjacent to all the vertices except the vertices of V_0, X_0 and the vertices of V_0 and X_0 are adjacent to (u_1, v_0) and

(u_0, v_1) respectively. Also, $< V(K_{1,r} \times W_s) \backslash D >$ contains no isolated vertices. Thus, D is a restrained dominating set and $\gamma_r(K_{1,r} \times W_s) \leq |D| = 3$. As every minimal restrained dominating set must contain the maximum degree vertex (u_0, v_0) of $K_{1,r} \times W_s$ together with another vertex from V_0 and X_0, $\gamma_r(K_{1,r} \times W_s) \geq 3$. Hence, $\gamma_r(K_{1,r} \times W_s) = 3$. Moreover, $(u_1, v_0)(u_0, v_1) \in E(K_{1,r} \times W_s)$ and so, $\chi(< D >) = 2 = \chi(K_{1,r} \times W_s)$. This implies that, D is a γ_r^c −set of $K_{1,r} \times W_s$ and $\gamma_r^c(K_{1,r} \times W_s) = 3$.

Theorem 2.7 For any $r, s \geq 2$ and $m \geq 4, \gamma_r^c(K_{r,s} \times W_m) = 4$.

Proof: Let $V(K_{r,s}) = \{u_1, u_2, \ldots, u_r, u_{r+1}, \ldots, u_{r+s}\}$ and $V(W_m) = \{v_0, v_1, v_2, \ldots, v_{m-1}\}$ with a full degree vertex v_0. Then, $V(K_{r,s} \times W_m) = \{(u_i, v_j)/1 \leq i \leq r + s, 0 \leq j \leq m - 1\}$. Also, $\chi(K_{r,s} \times W_m) = 2$. Consider $D = \{(u_r, v_0), (u_{r+1}, v_0), (u_r, v_1), (u_{r+1}, v_1)\}$. Clearly, D is a restrained dominating set and $\chi(< D >) = 2 = \chi(K_{r,s} \times W_m)$. Thus, D is a chromatic restrained dominating set of $K_{r,s} \times W_m$and $\gamma_r^c(K_{r,s} \times W_m) \leq 4$. Any minimum γ_r^c −set must contain at most one vertex from $(u_x, v_0), 1 \leq x \leq r$ and $(u_y, v_0), r + 1 \leq y \leq r + s$, so that it is adjacent to every vertex other than the vertices in the first column. Thus, choosing at most one vertex from $(u_x, v_z), 1 \leq x \leq r, 1 \leq z \leq m - 1$ and from $(u_y, v_z), r + 1 \leq y \leq r + s, 1 \leq z \leq m - 1$ makes the vertices of first column adjacent. This implies that, any minimum γ_r^c −set must contain at least four vertices, so that $\gamma_r^c(K_{r,s} \times W_m) \geq 4$. Therefore, $\gamma_r^c(K_{r,s} \times W_m) = 4$.

Theorem 2.8 Let W_r and W_s denotes the wheel graph where $r, s \geq 4$.

(i) If r and s are even, then $\gamma_r^c(W_r \times W_s) = max\{r, s\}$.

(ii) If at least one of r, s is odd,

$$\gamma_r^c(W_r \times W_s) = \begin{cases} 3 & if\ r, s \leq 5 \\ 4 & if\ r > 5\ or\ s > 5. \\ 5 & if\ r, s > 5 \end{cases}$$

Proof: Let $V(W_r) = \{u_0, u_1, u_2, u_3, \ldots, u_{r-1}\}$ and $V(W_s) = \{v_0, v_1, v_2, v_3, \ldots, v_{s-1}\}$ where u_0, v_0 are the full degree vertices in W_r, W_s. Also, $|V(W_r)| = r$ and $|V(W_s)| = s$. Clearly, $V(W_r \times W_s) = \{(u_i, v_j)/0 \leq i \leq r - 1, 0 \leq j \leq s - 1\}$ and $|V(W_r \times W_s)| = rs$. Moreover, $W_r \times W_s$ contains r rows and s columns.

Case (i): r and s are even

Then the vertex set of $W_r \times W_s$ can be partitioned in column wise into four disjoint subsets V_1, V_2, V_3, V_4 where $V_1 = \{(u_i, v_0)/0 \leq i \leq r - 1\}$, $V_2 = \{(u_i, v_j)/0 \leq i \leq r - 1, 1 \leq j \leq s - 3, j\ is\ odd\}$, $V_3 = \{(u_i, v_j)/0 \leq i \leq r - 1, 2 \leq j \leq s - 2, j\ is\ even\}$ and $V_4 =$

$\{(u_i, v_{s-1})/0 \leq i \leq r-1\}$. Clearly, $V_1 \cup V_2 \cup V_3 \cup V_4 = V(W_r \times W_s)$ and V_1, V_2, V_3, V_4 are independent. Thus, $\chi(\langle V_1 \rangle) = \chi(\langle V_2 \rangle) = \chi(\langle V_3 \rangle) = \chi(\langle V_4 \rangle) = 1$. Furthermore, $\chi(W_r \times W_s) = 4$ where each of the four subsets in $V(W_r \times W_s)$ receives different colors. Let $D = \{(u_0, v_0), (u_1, v_0), (u_0, v_1)\}$. Clearly, D is a dominating set of $W_r \times W_s$, since (u_1, v_0) is adjacent to the elements of $V(W_r \times W_s) \backslash D$ which belongs to the first row, (u_0, v_1) is adjacent to the elements of $V(W_r \times W_s) \backslash D$ that belongs to the first column and (u_0, v_0) is adjacent to all the remaining elements of $V(W_r \times W_s) \backslash D$. In addition, D is a restrained dominating set of $W_r \times W_s$ since there exists no vertex of degree zero in $V(W_r \times W_s) \backslash D$. Therefore, $\gamma_r(W_r \times W_s) \leq |D| = 3$. Since $\gamma(W_r \times W_s) = 3$, $\gamma_r(W_r \times W_s) \geq 3$. Hence, $\gamma_r(W_r \times W_s) = 3$. But $\chi(\langle D \rangle) = 2 \neq 4$. Thus, D is not a chromatic restrained dominating set. Let $D_2 = \{(u_0, v_0), (u_1, v_1), (u_2, v_2), (u_3, v_3), \ldots, (u_{r-1}, v_{r-1})\} \cup \{(u_{r-2}, v_{(r-1)+1}), (u_{r-1}, v_{(r-1)+2}), (u_{r-2}, v_{(r-1)+3})\}$ if $r < s$, $D_3 = \{(u_0, v_0), (u_1, v_1), (u_2, v_2), (u_3, v_3), \ldots, (u_{s-1}, v_{s-1})\} \cup \{(u_{(s-1)+1}, v_{s-2}), (u_{(s-1)+2}, v_{s-1}), \ldots, (u_{r-1}, v_{s-1})\}$ if $r > s$ and $D_4 = \{(u_0, v_0), (u_1, v_1), (u_2, v_2), \ldots, (u_r, v_r)\}$ if $r = s$ with $|D_2| = |D_3| = |D_4| = max\{r, s\}$. Since, $D_2 - \{(u_0, v_0)\}, D_3 - \{(u_0, v_0)\}$ and $D_4 - \{(u_0, v_0)\}$ forms an odd cycle on $max\{r, s\} - 1$ vertices and (u_0, v_0) is adjacent to all those $max\{r, s\} - 1$ vertices of the odd cycle and so, $\chi(\langle D_2 \rangle) = \chi(\langle D_3 \rangle) = \chi(\langle D_4 \rangle) = 4 = \chi(W_r \times W_s)$. Also, D_2, D_3 and D_4 are restrained dominating sets of $W_r \times W_s$. Therefore, D_2, D_3 and D_4 are the minimum chromatic restrained dominating sets of $W_r \times W_s$ and $\gamma_r^c(W_r \times W_s) \leq max\{r, s\}$. Since $\chi(W_r \times W_s) = 4$, any chromatic restrained dominating set must contain all the vertices of any smallest odd cycle together with (u_0, v_0) where the vertices of the odd cycle must be other than the vertices in the first row and first column. But the smallest odd cycle in $W_r \times W_s$contains $max\{r, s\} - 1$ vertices. Thus, all the $max\{r, s\} - 1$ vertices of the odd cycle together with (u_0, v_0) forms a chromatic restrained dominating set and so, $\gamma_r^c(W_r \times W_s) \geq max\{r, s\}$. Therefore, $\gamma_r^c(W_r \times W_s) = max\{r, s\}$.

Case ($\boldsymbol{ii}$): Either r or s is odd (or) both r and s are odd

If r is odd, then the vertex set can be partitioned in row wise into three disjoint subsets $V_1 = \{(u_0, v_j)/0 \leq j \leq s-1\}$, $V_2 = \{(u_i, v_j)/0 \leq j \leq s-1, 1 \leq i \leq r-2, i \text{ is odd}\}$ and $V_3 = \{(u_i, v_j)/0 \leq j \leq s-1, 2 \leq i \leq r-1, i \text{ is even}\}$. If s is odd, then the vertex set can be divided into three disjoint subsets in column wise where $V_1 = \{(u_i, v_0)/0 \leq i \leq r-1\}$, $V_2 = \{(u_i, v_j)/0 \leq i \leq r-1, 1 \leq j \leq s-2, j \text{ is odd}\}$ and $V_3 = \{(u_i, v_j)/0 \leq$

$i \leq r-1, 2 \leq j \leq s-1, j \text{ is even}\}$. Since no two vertices of V_1, V_2 and V_3 is adjacent, $\chi(\langle V_1 \rangle) = \chi(\langle V_2 \rangle) = \chi(\langle V_3 \rangle) = 1$ in both the cases. Also, $\chi(W_r \times W_s) = 3$, where each subset of $V(W_r \times W_s)$ receives different colors. Clearly, $\gamma_r(W_r \times W_s) = 3$ (From Case (i)). But $\chi(\langle D \rangle) = 2 \neq 3$ and so D is not a chromatic restraained dominating set of $W_r \times W_s$.

Subcase (i): $r, s < 5$

Let $D_5 = \{(u_0, v_0), (u_1, v_1), (u_2, v_2)\}$. Then D_5 is a restrained dominating set of $W_r \times W_s$. Since $\langle D_5 \rangle$ forms a $3-$ cycle, $\chi(\langle D_5 \rangle) = 3 = \chi(W_r \times W_s)$. Therefore, D_5 is a chromatic restrained dominating set of $W_r \times W_s$ and $\gamma_r^c(W_r \times W_s) \leq 3$. Since $\gamma_r(W_r \times W_s) = 3$, $\gamma_r^c(W_r \times W_s) < 3$ does not hold. Therefore, $\gamma_r^c(W_r \times W_s) = 3$.

Subcase (ii): $r > 5$ or $s > 5$

Consider $D_5 = \{(u_0, v_0), (u_1, v_1), (u_2, v_2)\}$. If $r > 5$, then some vertices of $W_r \times W_s$ in the first column is not adjacent to any vertex of D_5. Let $D_6 = D_5 \cup \{(u_0, v_1)\}$. Then, D_6 is a restrained dominating set of $W_r \times W_s$ and $\chi(\langle D_6 \rangle) = 3 = \chi(W_r \times W_s)$. Thus, D_6 is a chromatic restrained dominating set and $\gamma_r^c(W_r \times W_s) \leq |D_6| = |D_5| + 1$. If $s > 5$, then some vertices in the first row of $W_r \times W_s$ is not adjacent to any one of the elements in D_5. So, consider $D_7 = D_5 \cup \{(u_1, v_0)\}$. Then, D_7 is a chromatic restrained dominating set of $W_r \times W_s$ since it is restrained dominating and $\chi(\langle D_7 \rangle) = 3$. Therefore, $\gamma_r^c(W_r \times W_s) \leq |D_7| = 4$. Thus, if $r > 5$ or $s > 5$, $\gamma_r^c(W_r \times W_s) \leq 4$. Suppose, there exists a chromatic restrained dominating set S such that $|S| < 4$. Then $|D| < |S| < |D_7| = |D| + 1$, which is impossible. Therefore, $\gamma_r^c(W_r \times W_s) = 4$.

Subcase (iii): $r, s > 5$

If D_5 is considered, then $\chi(\langle D_5 \rangle) = 3$ but D_5 is not a restrained dominating set since some of the vertices in the first row and first column of $W_r \times W_s$ receives no adjacency in D_5. Let $D_8 = D_5 \cup \{(u_0, v_1), (u_1, v_1)\}$. Then, $\chi(\langle D_8 \rangle) = 3$ and D_8 is a restrained dominating set. Therefore, D_8 is a chromatic restrained dominating set of $W_r \times W_s$ and $\gamma_r^c(W_r \times W_s) \leq |D_8| = |D_5| + 2 = 5$. Suppose there exists a chromatic restrained dominating set S_1 such that $|S_1| < 5$. Then $|D| < |S_1| < |D_8| = |D| + 2$. The only possible cardinality for S_1 is $|S_1| = |D| + 1 = 4$. But, there does not exist a chromatic restrained dominating set with cardinality four, if both $r, s > 5$. Therefore, $\gamma_r^c(W_r \times W_s) = 5$.

3. Conclusion

In this study, we determined the chromatic restrained domination number for the direct product of certain standard graphs with wheel graphs. The obtained results reveal how the structural interaction between these graphs influences their domination behaviour. As a future

direction, similar techniques may be applied to other graph products or extended to broader classes of derived graphs and complex networks.

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Ancient and Modern Mathematics: How the Past Meets the Present in Today's Classrooms

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ABSTRACT

Mathematics is often seen as a tough subject, but its roots go back to some of the most practical problems people faced thousands of years ago like counting, building, and trading. This paper explores how ancient civilizations such as the Egyptians, Greeks, Indians, Chinese, and Islamic scholars developed early math ideas, many of which still influence the way we learn today. It also looks at how modern math powered by technology, theory, and applications has grown from those ancient foundations. By comparing the two, we see how blending old wisdom with modern tools can make math more meaningful for students. Finally, the paper looks at how today's education system teaches math, what's working, what's not, and how we can make learning better by connecting the past and present in classrooms.

Keywords*: Ancient Mathematicians, Modern Mathematics, History of Mathematics, Evolution of Mathematics, Learning Methods, Tech-powered Math.*

Introduction

Let us be honest, when most people hear the word "math," they either love it or want to run from it. But here is something interesting, math did not start with textbooks and calculators. It began with people trying to solve real problems how to count sheep, divide land, or predict when to plant crops.

In this paper, I want to take you on a journey from the ancient world of pyramids and counting rods, to the modern world of calculus, coding, and AI. We will also look at how students like us are learning math today, and how combining ancient and modern ideas might actually make math easier and more fun.

Ancient Mathematics: More Than Just Old Numbers

Imagine life thousands of years ago. No phones, no Google, no calculators just people, nature, and big questions.

Why Did Ancient People Need Math?

- To count crops, animals, or trade items.
- To measure land and build things like pyramids or temples.
- To track time, seasons, calendars, stars.

What Different Civilizations Figured Out

- Babylonians used a base-60 number system that's why we have 60 minutes in an hour.
- Egyptians used geometry to figure out land areas after floods.
- Greeks (like Euclid) made math logical with proofs.
- Indians gave the world the number zero and developed early algebra and trigonometry.
- Chinese used counting rods and created early versions of matrices.
- Islamic mathematicians translated and built on Greek and Indian ideas and created algebra.

Modern Mathematics: More Than Just Formulas

Math now is everywhere from smartphones to space travel. We use it in science, business, weather forecasting, and even social media.

Types of Modern Math:

- Pure math: More about logic and theory like algebra, number theory, or calculus.
- Applied math: Solving real-world problems in medicine, engineering, or finance.
- Tech-powered math: With tools like Python, GeoGebra, or AI, we can now model complex things like pandemics or climate change.
- Modern math is built on the shoulders of ancient math.

Bringing Ancient and Modern Math Together

About how the old and the new come together.

Some Ancient Ideas We Still Use:

- Geometry comes from the Greeks.
- Zero and the decimal system came from India.
- Algebra got its name from Arabic scholars.
- Trigonometry came from a mix of Greek and Indian astronomy.

How They Mix in Today's Learning:

- Vedic math tricks (from ancient India) help with fast mental math.
- Magic squares from China teach patterns and logic.
- Ancient logic puzzles are still used in competitions and classrooms.

So even when we think we are learning "modern" math we are often working with ancient ideas, just using new tools to explore them.

How Students Learn Math Today

What's Happening in Classrooms:

- Most schools still focus on formulas, exams, and memorization.
- Sometimes we learn how to solve a problem, but not why it works.
- Many students end up saying, “It is not useful in real life.”

Good Changes Are Happening:

- Apps and websites (like You Tube, GeoGebra, Khan Academy) make learning more interactive.
- Some teachers use games, puzzles, and real-life problems to teach math.
- Schools are starting to use project-based learning where math is part of solving something real, like building a model or creating a budget.

How Mathematics is Taught Around the World

To better understand how math education can improve, it helps to look at what is happening in other countries:

Japan

- Focus is on deep understanding, not just getting the right answer.
- Teachers use a method called “Lesson Study” where they plan, observe, and refine lessons together.
- Emphasis is placed on problem-solving and reasoning.

Finland

- No heavy focus on standardized tests.
- Math is taught in a relaxed but effective way often through real-world context and discovery.
- Students are encouraged to ask questions and explore, not just memorize.

Singapore

- Uses the Concrete-Pictorial-Abstract (CPA) approach: Start with hands-on objects, then pictures, then symbols.
- Heavy emphasis on visual learning and model drawing.
- Their textbooks are used globally because of their step-by-step clarity.

United States

- The U. S curriculum is less centralized and historically focussed on a spiral curriculum where topics are revisited over many years.
- Recently, more schools are using Common Core standards, which focus on critical thinking and understanding concepts, not just procedures.

India

- Strong in theoretical and exam-based teaching.

- Vedic math is being reintroduced in some schools for speed and mental agility.
- Some schools are now combining traditional rigor with tech tools like Byju's and Cuemath.

China

- Emphasis on practice, repetition, and discipline.
- Utilizes interactive, whole-class instruction that often includes students presenting solutions and connecting mathematical concepts to other disciplines.
- Recently, more efforts are being made to encourage creativity and application.

What If We Mixed Ancient Wisdom with Modern Tools?

What if we did not treat ancient math as "history" and modern math as "hard," but instead saw them as partners?

Here's What We Could Do:

- Teach the stories behind math like Who invented it? Why? How did it help them?
- Use ancient techniques like abacus or Vedic math to build number sense.
- Combine those with modern tools like interactive apps and even coding.
- Focus less on just getting the right answer and more on understanding and creativity.

Conclusion: Why This Matters

Mathematics is not just numbers and symbols on a page. It is a human journey from cave drawings to calculators, from counting sheep to coding satellites. Ancient math shows us where it all began. Modern math shows us where it can go. And students today? We are the bridge between the two.

So let us not separate the old and the new let us learn from both, and maybe, just maybe, math will stop feeling like a mystery and start feeling like a superpower.

Student Survey

The survey was conducted among 65 college students from various disciplines to know their opinions about mathematics.

1. How would you describe your interest in mathematics?

a) High
b) Moderate
c) Low
d) No interest

Category	Frequency	Percent	Valid Percent	Cumulative Percent
High	8	12.3%	12.3%	12.3%
Moderate	38	58.5%	58.5%	70.8%

Low	13	20.0%	20.0%	90.8%
No interest	6	9.2%	9.2%	100.0%
Total	65	100.0%	100.0%	

2. How often do you look forward to mathematics classes?

a) Always
b) Often
c) Sometimes
d) Rarely
e) Never

Category	Frequency	Percent	Valid Percent	Cumulative Percent
Always	10	15.4%	15.4%	15.4%
Often	19	29.2%	29.2%	44.6%
Sometimes	24	36.9%	36.9%	81.5%
Rarely	8	12.3%	12.3%	93.8%
Never	4	6.2%	6.2%	100.0%
Total	65	100.0%	100.0%	

3. Do you enjoy solving mathematical problems?

a) Yes
b) No
c) Sometimes

Category	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	35	53.8%	53.8%	53.8%
No	10	15.4%	15.4%	69.2%
Sometimes	20	30.8%	30.8%	100.0%
Total	65	100.0%	100.0%	

4. What emotion do you feel the most during math classes?

a) Excited
b) Confident
c) Nervous
d) Anxious
e) Scared

Category	Frequency	Percent	Valid Percent	Cumulative Percent
Excited	17	26.2%	26.2%	26.2%
Confident	24	36.9%	36.9%	63.1%
Nervous	11	16.9%	16.9%	80.0%
Anxious	9	13.8%	13.8%	93.8%
Scared	4	6.2%	6.2%	100.0%
Total	65	100.0%	100.0%	

5. Do you experience math anxiety?

a) Yes

b) No

c) Sometimes

Category	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	22	33.8%	33.8%	33.8%
No	17	26.2%	26.2%	60.0%
Sometimes	26	40.0%	40.0%	100.0%
Total	65	100.0%	100.0%	

6. Has mathematics ever affected your self-confidence?

a) Positively

b) Negatively

c) No impact

Category	Frequency	Percent	Valid Percent	Cumulative Percent
Positively	25	38.5%	38.5%	38.5%
Negatively	13	20.0%	20.0%	58.5%
No impact	27	41.5%	41.5%	100.0%
Total	65	100.0%	100.0%	

7. How do you feel before a math exam?

a) Calm

b) Slightly stressed

c) Very stressed

d) Fearful

Category	Frequency	Percent	Valid Percent	Cumulative Percent
Calm	12	18.5%	18.5%	18.5%
Slightly stressed	35	53.8%	53.8%	72.3%
Very stressed	13	20.0%	20.0%	92.3%
Fearful	5	7.7%	7.7%	100.0%
Total	65	100.0%	100.0%	

8. What is your overall difficulty level in mathematics?

a) Very easy
b) Easy
c) Moderate
d) Difficult
e) Very Difficult

Category	Frequency	Percent	Valid Percent	Cumulative Percent
Very easy	5	7.7%	7.7%	7.7%
Easy	12	18.5%	18.5%	26.2%
Moderate	30	46.2%	46.2%	72.3%
Difficult	13	20.0%	20.0%	92.3%
Very difficult	5	7.7%	7.7%	100.0%
Total	65	100.0%	100.0%	

9. What are your biggest difficulties in mathematics?

a) Understanding concepts
b) Applying formulas
c) Solving problems
d) Time management
e) Lack of practice
f) Anxiety
g) Teaching methods

Category	Frequency	Percent
Understanding concepts	13	20.0%
Applying formulas	19	29.2%
Solving problems	20	30.8%

Time management	27	41.5%
Lack of practice	15	23.1%
Anxiety	10	15.4%
Teaching methods	7	10.8%

10. How often do you need additional help to understand mathematics?

a) Always
b) Often
c) Sometimes
d) Rarely
e) Never

Category	Frequency	Percent	Valid Percent	Cumulative Percent
Always	17	26.2%	26.2%	26.2%
Often	9	13.8%	13.8%	40.0%
Sometimes	33	50.8%	50.8%	90.8%
Rarely	5	7.7%	7.7%	98.5%
Never	1	1.5%	1.5%	100.0%
Total	65	100.0%	100.0%	

11. Has mathematics improved your skills in these areas?

a) Logical thinking
b) Problem-solving
c) Decision-making
d) Analytical thinking

Category	Frequency	Percent
Logical thinking	17	26.2%
Problem-solving	37	56.9%
Decision-making	14	21.5%
Analytical thinking	12	18.5%

12. Do you think math is important for your future career?

a) Yes
b) No
c) Maybe

Category	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	39	60.0%	60.0%	60.0%
No	7	10.8%	10.8%	70.8%
Maybe	19	29.2%	29.2%	100.0%
Total	65	100.0%	100.0%	

13. Does your teacher/instructor make mathematics easier to understand?
    a) Yes
    b) No
    c) Sometimes

Category	Frequency	Percent	Valid Percent	Cumulative Percent
Yes	37	56.9%	56.9%	56.9%
No	5	7.7%	7.7%	64.6%
Sometimes	23	35.4%	35.4%	100.0%
Total	65	100.0%	100.0%	

14. Which teaching method helps you learn best?
    a) Step-by-step explanation
    b) Visual/graphical teaching
    c) Real-life examples
    d) Group learning
    e) Practice worksheets
    f) Digital/interactive tools

Category	Frequency	Percent
Step-by-step explanation	42	64.6%
Visual/graphical teaching	15	23.1%
Real-life examples	20	30.8%
Group learning	23	35.4%
Practice worksheets	16	24.6%
Digital/interactive tools	6	9.2%

15. What changes would help improve your understanding of mathematics?
    a) More practice sessions
    b) Better explanations

c) Interactive learning
d) Reduced pressure
e) Real-life applications
f) Extra classes

Category	Frequency	Percent
More practice sessions	35	53.8%
Better explanations	25	38.5%
Interactive learning	20	30.8%
Reduced pressure	12	18.5%
Real-life applications	12	18.5%
Extra classes	8	12.3%

16. Which method helps you understand math better?
a) Traditional teaching (chalk & board)
b) Modern teaching (smart boards, videos, apps)
c) Combination of both

Category	Frequency	Percent	Valid Percent	Cumulative Percent
Traditional	22	33.8%	33.8%	33.8%
Modern	12	18.5%	18.5%	52.3%
Combination	31	47.7%	47.7%	100.0%
Total	65	100.0%	100.0%	

17. How often do you use digital tools (YouTube, apps, online quizzes) to learn math?
a) Always
b) Often
c) Sometimes
d) Rarely

Category	Frequency	Percent	Valid Percent	Cumulative Percent
Always	12	18.5%	18.5%	18.5%
Often	26	40.0%	40.0%	58.5%
Sometimes	24	36.9%	36.9%	95.4%
Rarely	3	4.6%	4.6%	100.0%
Total	65	100.0%	100.0%	

18. Does math impact your overall academic performance?

a) Positively
b) Negatively
c) No impact

Category	Frequency	Percent	Valid Percent	Cumulative Percent
Positively	42	64.6%	64.6%	64.6%
Negatively	12	18.5%	18.5%	83.1%
No impact	11	16.9%	16.9%	100.0%
Total	65	100.0%	100.0%	

19. What type of math questions do you find most difficult?

a) Word problems
b) Logical reasoning
c) Multi-step problems
d) Application problems

Category	Frequency	Percent
Word problems	19	29.2%
Logical reasoning	17	26.2%
Multi-step problems	19	29.2%
Application problems	10	15.4%

20. What is your overall opinion about learning mathematics?

Most students feel that mathematics is useful, interesting, and important for future learning and logical thinking, though many also find it difficult and challenging. Some believe it depends on interest and practice, while a few view it as unnecessary or a waste of time. Overall, opinions are mixed, with both positive and negative experiences.

Formulas used to find the Solution

- Frequency = Number of occurrences of a value
- Percent = $\left(\frac{\text{Frequency}}{\text{Total number of cases}}\right) \times 100$
- Valid Percent = $\left(\frac{\text{Frequency}}{\text{Total valid responses}}\right) \times 100$
- Cumulative Percent = $\sum_{i=1}^{n} \text{Valid Percent}_i$

Survey Conclusion

The survey shows that students have mixed feelings about mathematics. While some view math for the skills it develops, others struggle due to difficulties in understanding concepts, applying formulas, and managing time. The responses shows that many students still find math challenging and often need extra support. Overall, the survey highlights the students opinions about mathematics their learning experiences, confidence levels, and the teaching methods

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Stability Analysis to the Graphical Modelling of Zika Virus by Mosquito Transmission

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ABSTRACT

Zika virus, a rapidly spreading mosquito-borne flavivirus, poses major public-health concerns. By representing the host-vector interactions and environmental factors as a directed graph, we examine the stability of the disease-free state through key graph parameters such as the basic reproduction number (R_0). Using a directed graph framework, human–vector interactions are modeled through F and V matrices. The Jacobian at the disease-free equilibrium (DFE) is derived and a Routh Hurwitz Criterion is applied in the theorem which provides explicit positivity conditions for stability. These conditions align with the threshold $R_0 < 1$, ensuring DFE stability and Zika elimination. For $R_0 \geq 1$, stability breaks down, indicating possible persistence of transmission.

Keywords: *Zika Virus, Mosquito Transmission, Basic Reproduction Number, Jacobian Matrix, Disease-Free Equilibrium.*

AMS Subject Classification: 05C20, 05C22, 47A10, 00A71

1 Introduction

The Zika virus (ZIKV) continues to pose a significant threat to global public health due to its rapid transmission dynamics, its association with congenital abnormalities, and the absence of approved antiviral treatments. Although classical compartmental models have offered important insights into ZIKV epidemiology, recent approaches emphasize the need for structural modelling frameworks capable of capturing heterogeneous transmission pathways, including mosquito-borne infection, sexual transmission [1], and gender-specific progression rates. Graph-theoretic methods provide a powerful mathematical structure for representing such complex interactions. By encoding epidemiological compartments as nodes and transmission or transition processes as weighted directed edges, graph-based models offer a transparent and algebraically tractable way to investigate disease spread.

The basic reproduction number, R_0 is a fundamental threshold quantity that determines whether an infectious disease can invade and persist in a fully susceptible population [4]. Biologically, R_0 represents the expected number of secondary infections produced by a single infected individual introduced into an otherwise disease-free environment. If $R_0 < 1$, the

disease-free equilibrium is locally asymptotically stable, implying that the infection will eventually die out. Conversely, when If $R_0 > 1$, the DFE becomes unstable and the disease can successfully invade the population. Thus, If R_0 provides both a biological and mathematical criterion for assessing the potential for Zika virus transmission within the network-structured system.

In this study, we develop a deterministic Zika virus transmission model formulated on a directed weighted graph. The derived digraph captures all epidemiologically relevant flows among susceptible, exposed, infectious, and recovered human and vector compartments. Using this representation, we construct the system's Jacobian matrix directly from the graph at the disease-free equilibrium (DFE)[2], allowing the local behavior of the system to be assessed without explicitly formulating the full set of nonlinear differential equations.

The model's structure naturally leads to a decomposition of the Jacobian into matrices describing **new infection pathways (F)** and **transition or out-flow processes (V)**, consistent with the next-generation matrix framework. Unlike traditional approaches that rely on analytical inversion of V, the graph-based method enables stability assessment through the spectral properties of the combined matrix $J = F - V$. In particular, we employ Routh-Hurwitz Criteria to examine the local stability of the DFE. The proposed framework demonstrates how graph theory can simplify the construction of epidemiological models and provide alternative pathways for deriving threshold conditions traditionally associated with the basic reproduction number R_0. Overall, this article highlights the utility of graph-based modelling for vector-borne diseases, offering a flexible and robust methodology for analyzing equilibrium states and disease invasion criteria.

2 Directed Weighted Graph of ZIKV

To formulate the transmission dynamics of the Zika virus model, we adopt a graph-theoretic representation in which epidemiological compartments Susceptible, Exposed, Infected and Recovery compartments of human and vector are encoded as vertices and all transmission or transition processes are represented as directed, weighted edges[3],[5]. Let D = (V, E) be a directed weighted graph with Vertex set V = {1,2,…,7} and edge set $E \subseteq V \times V$, where each edge $i \rightarrow j$ is assigned a weight w_{ij} corresponding to the biological rate of movement from compartment i to compartment j. The adjacency matrix A = (a_{ij}) is thus defined by

$$a_{ij} = \begin{cases} w_{ij} & if\ i \rightarrow j \in E, \\ 0 & otherwise. \end{cases}$$

The graph {D= (V, E)} where

V(D)={S_H,E_H,I_H,R_H,S_V,E_V,I_V}

E(D)={S_HE_H, E_HI_H, I_HR_H, I_VS_H, I_HS_V, S_VE_V, E_VI_V} = {$\lambda_H, V_H, \gamma_H, \beta_{VH}, \beta_{HV}, \lambda_V, V_V$}

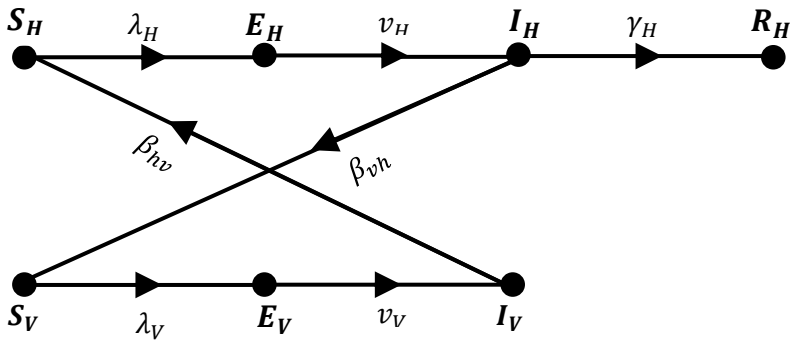


Figure 1*:* Schematic of the Zika transmission graphical model. The arrow represents transitions between the compartments and also the interactions between humans and mosquitoes.

Parameter	Description
λ_H	The force from infection for humans
λ_V	The force from infection for mosquitoes
v_H	Human progression rate from exposed rate state to infectious state
v_V	Mosquito progression rate from exposed rate state to infectious state
β_{VH}	Probability of pathogen transmission from an infectious human to a susceptible mosquito
β_{HV}	Probability of pathogen transmission from an infectious mosquito to a susceptible human
γ_H	Human recovery rate

Table 1: Description of all parameters used in this model [6]

3 Disease Free Equilibrium Point and Basic Reproduction Number

In the digraph representation of the Zika transmission model, the infectious subsystem is identified purely through the structure of nodes and edges. **At the disease-free equilibrium**, the digraph system satisfies $\boldsymbol{E_H = I_H = E_V = I_V = 0}$ which implies that all infection-related

nodes carry zero population. The DFE corresponds to a network state with no active infection pathways, serving as the reference point for linearization and stability analysis.

We define the set, $X_I = \{E_H, I_H, E_V, I_V\} = \{0,0,0,0\}$ which contains all compartments that participate directly in the creation or propagation of infection in either humans or vectors. These nodes form an induced subgraph of the full epidemiological network. Following the graph-theoretic formulation, the linearized system near E_0 can be written as $X_I^* = (F - V)X_I$, where F represents the rate of appearance of new infections and V denotes the transfer of individuals between infected compartments and their removal due to recovery or death. Though there is no death rate included in the digraph, but since the infected mosquitoes has finite lifespan, considering the mosquito death rate as μ_V. The Jacobian of the infected subsystem is then $\mathbf{J} = \mathbf{F} - \mathbf{V}$. This decomposition is completely equivalent to the classical next-generation method but derived **directly from graph topology** rather than symbolic ODEs. Then the Jacobian of the derived digraph is

$$J = \begin{pmatrix} 0 & 0 & 0 & \beta_{HV} \\ 0 & 0 & 0 & 0 \\ 0 & \beta_{VH} & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} - \begin{pmatrix} V_H & 0 & 0 & 0 \\ -V_H & \gamma_H & 0 & 0 \\ 0 & 0 & V_V & 0 \\ 0 & 0 & -V_V & \mu_V \end{pmatrix}$$

$$J = \begin{pmatrix} -V_H & 0 & 0 & \beta_{HV} \\ V_H & -\gamma_H & 0 & 0 \\ 0 & \beta_{VH} & -V_V & 0 \\ 0 & 0 & V_V & -\mu_V \end{pmatrix}$$

Theorem: (Local Stability of the Disease-Free Equilibrium)

The disease-free equilibrium E_0 is locally asymptotically stable if $R_0 < 1$ satisfying the condition $\beta_{HV}\beta_{VH} < \mu_V\gamma_H$ and the following Routh–Hurwitz inequalities hold:

(i) $C_3 C_2 > C_1$,

(ii) $C_3C_2C_1 + C_1^2 > C_3^2C_0$. The equilibrium E_0 is unstable if $R_0 > 1$.

Proof: The characteristic equation of the above Jacobian matrix is $\lambda^4 C_4 + \lambda^3 C_3 + \lambda^2 C_2 + \lambda C_1 + C_4 = 0$ where $C_4 = 1$,

$$C_3 = V_H + \gamma_H + V_V + \mu_V,$$

$$C_2 = V_H\gamma_H + V_VV_H + V_V\gamma_H + \mu_VV_V + V_H\mu_V + \mu_V\gamma_H,$$

$$C_1 = V_H\gamma_HV_V + V_H\gamma_H\mu_V + V_VV_H\mu_V + \mu_V\gamma_HV_V,$$

$$C_0 = V_H\gamma_HV_V\mu_V - V_HV_H\beta_{HV}\beta_{VH}.$$

Now we are going to analyze the stability of R_0 using Routh–Hurwitz Stability Criterion. For the quadratic equation $\lambda^4 + C_3\lambda^3 + C_2\lambda^2 + C_1\lambda + C_0 = 0$, to determine the stability of $R_0 < 1$,

all the coefficients C_i should be positive and all the roots of the polynomial has a negative real part iff all the Hurwitz determinants $\Delta_K > 0$,for all $k = 1,2, \dots, n$.

Note that $C_0 = V_H\gamma_H V_V\mu_V - V_H V_V\beta_{HV}\beta_{VH}$

$$= V_H\gamma_H V_V\mu_V\left(1 - \frac{\beta_{HV}\beta_{VH}}{\mu_V\gamma_H}\right)$$

$$= V_H\gamma_H V_V\mu_V(1 - {R_0}^2)$$

From this define ${R_0}^2 = \frac{\beta_{HV}\beta_{VH}}{\mu_V\gamma_H}$. Thus for $R_0 < 1$, $\beta_{HV}\beta_{VH} < \mu_V\gamma_H$ which implies $C_0 > 0$. All other coefficients C_1, C_2, C_3 are sums and products of positive parameters and are therefore strictly positive. Therefore, all the coefficients C_i should be positive. The Hurwitz determinants are $\Delta_1 = C_3$, $\Delta_2 = C_3C_2 - C_1$, $\Delta_3 = C_3C_2C_1 - C_1^2 - C_3^2C_0$ and $\Delta_4 = C_0\Delta_3$. Obviously $\Delta_1 > 0$. Since C_1, C_2 and C_3 has only positive terms, expanding Δ_2 also gives positive terms satisfying the condition $C_3C_2 > C_1$.Therefore, $\Delta_2 > 0$. Now $\Delta_3 = C_3C_2C_1 - C_1^2 - C_3^2C_0 = C_1(C_3C_2 - C_1) - C_3^2C_0 = \Delta_2C_1 - C_3^2C_0$. We already have $\Delta_2 > 0$ and if $C_0 \le 0$ which implies $-C_3^2C_0 \ge 0$. Then $\Delta_3 = \Delta_2C_1 - C_3^2C_0 \ge \Delta_2C_1 > 0$. But this is not possible, since $R_0 < 1 \Leftrightarrow C_0 > 0$. So $\Delta_3 > 0$ if the inequality $\Delta_2C_1 > C_3^2C_0 \Rightarrow C_3C_2C_1 + C_1^2 > C_3^2C_0$ is satisfied. Again $\Delta_4 = C_0\Delta_3 > 0$ if and only if $C_0 > 0$ and $\Delta_3 > 0$. Since all $C_i's$ under the condition $\beta_{HV}\beta_{VH} < \mu_V\gamma_H$ and all the Hurwitz determinants are positive satisfying the inequalities $C_3C_2 > C_1$ and $C_3C_2C_1 + C_1^2 > C_3^2C_0$, $R_0 < 1$. Thus all the eigen values have negative real parts and the disease free equilibrium E_0 is locally asymptotically stable.

If $R_0 > 1$, then $C_0 < 0$. The coefficient sign sequence:$1, C_3, C_2, C_1, C_0$ contains exactly one sign change. By Descartes' Rule of Signs, there is exactly one positive real root, so E_0 is unstable.

4 Conclusion

The graph-theoretic framework combined with the Routh–Hurwitz stability theorem provides a rigorous analytical foundation for understanding Zika virus transmission dynamics. By formulating the Jacobian through the F and V matrices extracted from the directed graph, the stability of the disease-free equilibrium can be assessed without relying on classical ODE-driven methods. The derived positivity conditions on the Hurwitz determinants confirm that the DFE is asymptotically stable whenever the system parameters ensure $R_0 < 1$, fully consistent with epidemiological theory. Conversely, violation of these conditions typically when $R_0 > 1$, implies the onset of instability and the potential persistence of infection. Overall, the results highlight the effectiveness of graph-driven analysis in revealing stability boundaries and guiding control strategies for Zika virus spread.

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On the edge domination of certain molecular graphs

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ABSTRACT

Chemical graph theory connects molecular characteristics to a molecular graph. It is used for the investigation of the properties through QSAR and QSPR models through graph invariants such as topological indices. The tool for encryption methods like, basic method and insertion method encrypting any chemical formula uses graph domination. Silicates are parallel sheets of silicate tetrahedra, they are widely present in nature and typically found in clay-related minerals on the earth surface. In this paper, we investigate the edge domination problem for certain molecular graphs, more precisely the molecular graphs of silicate and oxide.

Keywords: *Molecular graph, domination, edge domination, silicate, oxide*

1 Introduction

Chemical graph theory is a field of mathematical chemistry in which graph theory methods are used to mathematically model chemical occurrences. Chem-informatics is a new field that brings together chemistry, mathematics, and information science. In the underlying chemical structure, a molecular (chemical) graph is a simple finite graph in which the atoms are represented by vertices and the chemical bonds are represented by edges. However, this representation does not only provide a visual insight into molecular structures, but inherits many useful information about chemical properties of molecules. Many physical and chemical properties of molecules have been shown to be well correlated with graph theoretical invariants termed topological indices or molecular descriptors in QSAR and QSPR studies. The chemical information derived through topological index has been found useful in chemical documentation, isomer discrimination, structure property correlations, etc.

The investigation of the dominating sets in a graph is one of the key and well-known concepts in graph theory. The variety of applications to both theoretical and real-world problems, such as facility location problems, QSAR and QSPR studies, computational biology and biomedical analysis [1], may be one of the reasons for this area's consistent and rapid growth. Among the domination-type parameters that have been studied, the two most fundamental ones are the domination number and the edge domination number. Researchers

have been interested in the relationship between various topological indices and domination number of a graph for a long time, and this topic is still relevant today [2 – 5]. Thus, domination problem has applications in all those areas where topological indices have some applications.

All molecular graphs considered in this paper are simple, connected and undirected. Let $G = (V, E)$ be a graph with vertex set $V(G)$ and edge set $E(G)$. For an edge uv, we call u and v the end vertices of uv. An edge dominates itself and the edge adjacent to it. Two edges are independent if they have no end vertex in common. Let G_1 and G_2 be subgraphs of G. Then G_1 and G_2 are said to be disjoint if they have no vertex in common and edge disjoint if they have no edge in common.

Mitchell and Hedetniemi [16] introduced the concept of edge domination. A set $D \subset E$ is an edge domination set if each edge of $E \setminus D$ is adjacent to an edge in D. The minimum cardinality of an edge dominating set of G is called the edge domination number and is denoted by $\gamma'(G)$. An edge dominating set D is called an independent edge dominating set if no two edges in D are adjacent. The (independent) edge domination problem in a graph is to find a minimum (independent) edge dominating set of the graph. Edge domination is a natural analog of vertex domination and has been studied in a variety of papers, see for instance [6, 8 – 14, 17 – 20].

2 A molecular graph of silicate

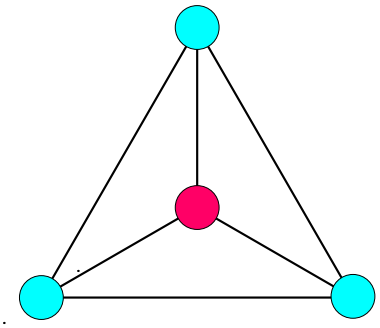


Figure 1 A tetrahedron SiO_4 with oxygen vertices and silicon vertex depicted by fluorescent blue and pink bullets respectively

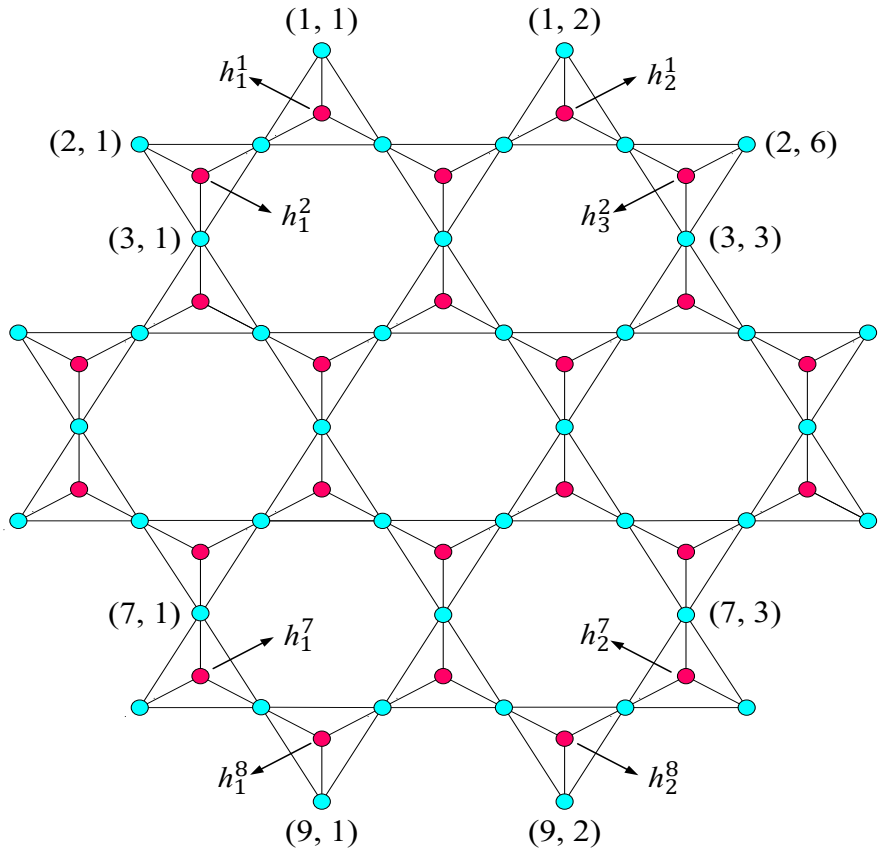


Figure 2 A molecular graph of silicate *SL* (2)

Silicates are obtained by fusing metal oxides or metal carbonates with sand. The tetrahedron (SiO_4) is basic unit of silicates. Almost all silicates contain (SiO_4) tetrahedra. A silicate sheet is a ring of tetrahedrons which are linked by shared oxygen vertices to other rings in a two-dimensional plane that produces a sheet-like structure. Cyclic silicates are structures which give cycles of different length after being linked by shared oxygen vertices. From chemical point of view, the corner vertices of tetrahedron (SiO_4) are actually the oxygen atoms and central vertex represents silicon atom. These corner atoms called as oxygen vertices, central atom as silicon vertex and bonds between them as edges from graphical point of view. $SL(n)$ denotes a silicate network of dimension n, where n is the number of hexagons between the center and boundary of $SL(n)$. A silicate network of dimension two is shown in Figure 2. The number of vertices in $SL(n)$ are $15n^2 + 3n$ and number of edges are $36n^2$ [21].

2.1 Python program to draw *SL*(*n*)

The following python program generates the molecular graph of $SL(n)$.

```
#Import numpy as np
import matplotlib.pyplot as plt
import math
def silicate(n):
```

```
#close all;axissquare;hold on
  for T in range(0,1,0.01):
    rad1=0.07;
    for I in range(-2*n, 2*n):
      for j in range(-2*n,2*n):
        for k in range(-2*n, 2*n):
          if((j-k) == i and (i%2 !=0 or j%2 !=0 or k%2 !=0)):
            xs= -(j+k)/math.sqrt(3)+rad1*math.cos(2*math.pi*T)
            ys= i+rad1*math.sin(2*math.pi*T)
            plt.figure()
            plt.plot(xs,ys)


          if(i%2==0 and i!=2*n):
            for t in range( -1, 1):
                 if (t!=0):
                    xs1=-(j+1/3+k-
1/3)/math.sqrt(3)+rad1*math.cos(2*math.pi*T)
                    ys1= t*(i+2/3)+rad1*math.sin(2*math.pi*T)
                    plt.figure()
                    plt.plot(xs1,ys1)

                    plt.plot([-(j+1 / 3+k-1 / 3)/math.sqrt(3) -
(j+k)/math.sqrt(3)], [(i+2/3) * i])
                    plt.plot([-(j+1/3+k-1/3)/math.sqrt(3) -
(j+1+k)/math.sqrt(3)], [(i+2/3) * i+1])
                    plt.plot([-(j+1/3+k-1/3)/math.sqrt(3) -(j+k-
1)/math.sqrt(3)], [(i+2/3) * i+1])
                    plt.plot([-(j+1/3+k-1/3)/math.sqrt(3) -
(j+k)/math.sqrt(3)], [-(i+2/3) * -i])
                    plt.plot([-(j+1/3+k-1/3)/math.sqrt(3) -
(j+1+k)/math.sqrt(3)], [-(i+2/3) * -(i+1)])
                    plt.plot([-(j+1/3+k-1/3)/math.sqrt(3) -(j+k-
1)/math.sqrt(3)], [-(i+2/3) * -(i+1)])
n=10
for i in range(n):
  for j in [-1, 1]:
    if j!=0:
      plt.plot([(4*(n-1)+3-2*(i-1))/math.sqrt(3) * -(4*(n-1)+3-2*(i-
1))/math.sqrt(3)], [j*(2*i-1) * (j*(2*i-1))])
      plt.plot([j*(4*(n-1)+3-2*(i-1))/math.sqrt(3) * j*(2*(n-1)-4*(i-
1))/math.sqrt(3)], [-(2*i-1) * (2*n)])
      plt.plot([j*(4*(n-1)+3-2*(i-1))/math.sqrt(3) * j*(2*(n-1)-4*(i-
1))/math.sqrt(3)], [(2*i-1) * (-2*n)])
silicate(n)
```

2.2 Edge domination number of $SL(n)$

We propose a level numbering scheme for $SL(n)$ where each vertex is identified by a pair x, y where x denotes the level number in which the vertex exists and y denotes the location of the vertex in that level. See Figure 2.

We now proceed to obtain the edge domination number for the graph of $SL(1)$. The following results are obvious.

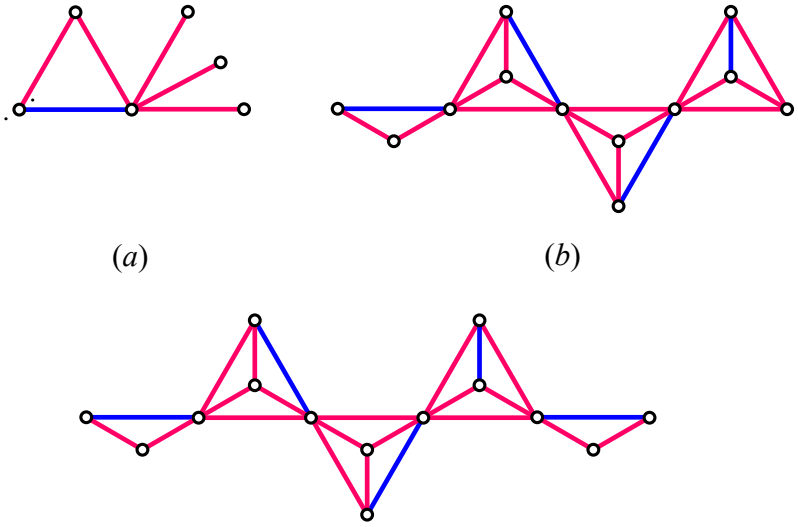


Figure 3 The subgraphs (*a*) H_1^i (*b*) H_2^i (*c*) H_3^i

Lemma 1 $\gamma'(H_1^i) = 1$.

Lemma 2 $\gamma'(H_2^i) = 4$.

Lemma 3 $\gamma'(H_3^i) = 5$.

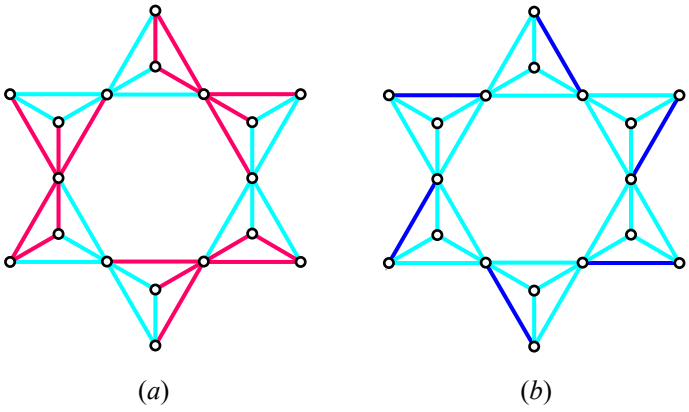


Figure 4 (*a*) Edge disjoint union in *SL*(1) (*b*) Dominating edges in *SL*(1)

Lemma 4 $\gamma'(SL(1)) = 6$.

Proof. It is easy to see that the graph $SL(1)$ contains six edge disjoint union of subgraphs H_1^i. Since $\gamma'(H_1^i) = 1$, it follows that $\gamma'(SL(1)) = 6$. □

Lemma 5 $\gamma'(SL(2)) = 22$.

Proof. Clearly D = {((1, 1), (2, 3)), ((2, 1), (2, 2)), ((2, 4), (3, 2)), ((1, 2), h_2^1), ((2, 5), (2, 6)), ((3, 1), (4, 3)), ((4, 1), (4, 2)), ((4, 4), (5, 2)), ((5, 1), (6, 1)), ((6, 2), (7, 1)), ((6, 3), (6, 4)), ((3, 3), (4, 7)), ((4, 5), (4, 6)), ((4, 8), (5, 4)), ((5, 3), (6, 5)), ((6, 6), (7, 3)), ((6, 7), (6, 8)), ((8, 1), (8, 2)), ((7, 2), (8, 3)), ((8, 4), (9, 2)), ((8, 5), (8, 6)), (h_1^8, (9, 1))} is an edge dominating set of *SL*(2). This means that $\gamma'(SL(2)) \leq 22$.

On the other hand the graph *SL* (2) contains two edge disjoint copies of *SL*(1) together with two subgraphs H_3^i. Hence by Lemmas 3 and 4, $\gamma'(SL(2)) \geq 22$. □

We now proceed to investigate the edge domination problem for the graph *SL*(*n*), *n* ≥ 3. We begin with a lower bound.

Lemma 6 Let *G* be *SL*(*n*), *n* ≥ 3. Then $\gamma'(G) \geq \begin{cases} \frac{1}{2}(9n^2+6n-3), & n\ odd; \\ \frac{1}{2}(9n^2+6n-4), & n\ even. \end{cases}$

Proof. We have two cases.

Case 1: *n* odd.

It is clear that the graph *G* = *SL*(*n*) contains $\frac{3n^2+1}{4}$ number of edge disjoin copies of *SL* (1) together with 3(*n* – 1) number of edges on the boundary of *SL*(*n*). Hence by Lemma 4,

$$\gamma'(G) \geq 6\left(\frac{3n^2+1}{4}\right) + 3(n-1) = \frac{1}{2}(9n^2+6n-3).$$

Case 2: *n* even.

Clearly *G* = *SL*(*n*) contains $\frac{3n^2-2n}{4}$ number of edge disjoin copies of *SL* (1), *n* – 2 number of edge disjoint union of subgraph H_2^i, two subgraphs of H_3^i and 2*n* – 4 number of edges on the boundary of *SL*(*n*). Hence by Lemmas 2, 3 and 4,

$$\gamma'(G) \geq 6\left(\frac{3n^2-2n}{4}\right) + 4(n-2) + (2n-4) = \frac{1}{2}(9n^2+6n-4).$$

We now determine an upper bound for the edge domination number of *SL*(*n*).

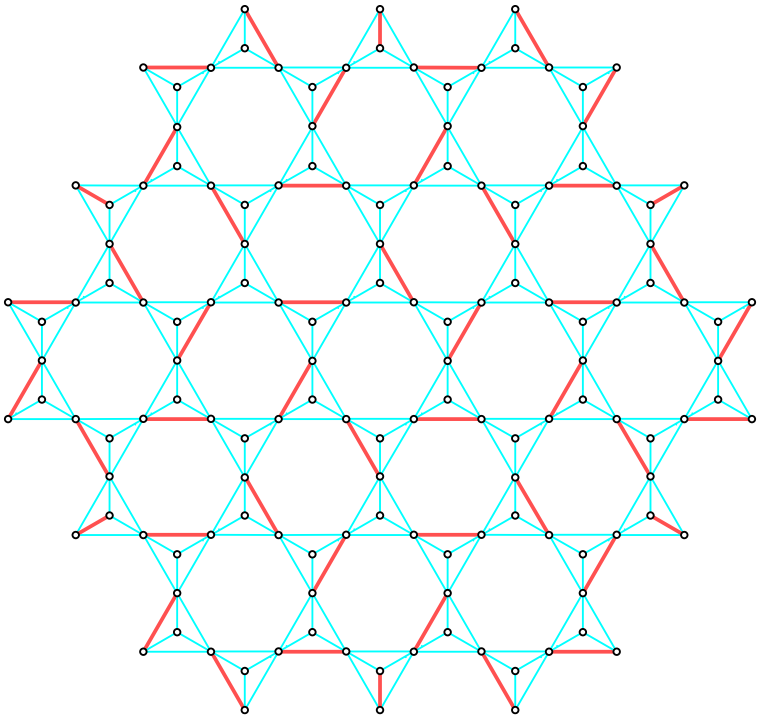


Figure 5 A silicate network *SL* (3) with dominating edges marked

Theorem 1 Let G be $SL(n)$, $n \geq 3$. Then $\gamma'(G) \geq \begin{cases} \frac{1}{2}(9n^2 + 6n - 3), & n\ odd; \\ \frac{1}{2}(9n^2 + 6n - 4), & n\ even. \end{cases}$

Proof. We consider the following cases.

Case 1: n odd.

It suffices to exhibit an edge dominating set of cardinality $\frac{1}{2}(9n^2 + 6n - 3)$.

For $1 \leq i \leq \frac{n-1}{2}$, $1 \leq j \leq \frac{n+2i-1}{2}$, let $D_1 = \{((4i - 3, 2j - 1), (4i - 2, 4j - 1)), ((4i - 2, 4j - 3), (4i - 2, 4j - 2)), ((4i - 1, 2j - 1), (4i, 4j - 2)), ((4i, 4j - 1), (4i + 1, 2j)), ((4i, 4j), (4i, 4j + 1)), ((4i - 2, 4j), (4i - 1, 2j))\}$. Clearly

$$|D_1| = 6\sum_{i=1}^{\frac{n-1}{2}} \left\lceil \frac{n + 2i - 1}{2} \right\rceil = 6\left(\frac{n-1}{2}\right)\left(\frac{3n-1}{4}\right).$$

For $i = \frac{n+1}{2}$, $1 \leq j \leq n$, let $D_2 = \{((4i - 3, 2j - 1), (4i - 2, 4j - 1)), ((4i - 2, 4j - 3), (4i - 2, 4j - 2)), ((4i - 1, 2j - 1), (4i, 4j - 3)), ((4i, 4j - 2), (4i + 1, 2j - 1)), ((4i, 4j - 1), (4i, 4j)), ((4i - 2, 4j), (4i - 1, 2j))\}$. It is clear that $|D_2| = 6n$.

For $\frac{n+3}{2} \leq i \leq n$, $1 \leq j \leq \frac{3n-2i+1}{2}$, let $D_3 = \{((4i - 3, 2j), (4i - 2, 4j)), ((4i - 2, 4j - 2), (4i - 2, 4j - 1)), ((4i - 1, 2j - 1), (4i, 4j - 3)), ((4i, 4j - 2), (4i + 1, 2j - 1)), ((4i, 4j - 1), (4i, 4j)), ((4i - 2, 4j + 1), (4i - 1, 2j))\}$. Clearly

$$|D_3| = 6\sum_{i=\frac{n+3}{2}}^{n}\left[\frac{3n-2i+1}{2}\right] = 6\left(\frac{n-1}{2}\right)\left(\frac{3n-1}{4}\right).$$

For $1 \le i \le \frac{n-1}{2}$, let D_4 = {((1, 2i), h_{2i}^{1}), ((4i, 1), h_{1}^{4i}), ((4i, 2n + 4i), h_{n+2i}^{4i}), ((2n+4i, 1), $h_{1}^{2n+4i-1}$), ((2n + 4i, 4n – 4i + 2), $h_{2n+1-2i}^{2n+4i}$), (h_{2i}^{4n}, (4n +1, 2i))}. It is clear that $|D_4| = 6\left(\frac{n-1}{2}\right)$.

Define $D = D_1 \cup D_2 \cup D_3 \cup D_4$. Clearly $|D| = \frac{1}{2}(9n^2 + 6n - 3)$. We claim that D is an edge dominating set for G.

For any i, $1 \le i \le \frac{n-1}{2}$, for any j, $1 \le j \le \frac{n+2i-3}{2}$, consider the three edges ((4i – 3, 2j), (4i – 2, 4j)), ((4i – 2, 4j), (4i – 2, 4j +1)) and ((4i – 2, 4j), h_{2j}^{4i-3}). Clearly these three edges are adjacent to ((4i – 2, 4j), (4i – 1, 2j)) ∈ D_1. Similarly, the two edges ((4i – 3, 2j), (4i – 2, 4j +1)) and (h_{2j}^{4i-3}, (4i – 2, 4j +1)) are adjacent to ((4i – 2, 4j + 1), (4i – 1, 4j +2)) ∈ D_1.

Now consider the three edges ((4i, 4j + 1), (4i, 4j +2)), ((4i, 4j + 1), (4i + 1, 2j +1)) and ((4i, 4j + 1), h_{2j+1}^{4i}). It is clear that these edges are adjacent to ((4i, 4j), (4i, 4j + 1)) ∈ D_1. Similarly, the edges ((4i, 4j + 2), (4i + 1, 2j + 1)) and ((4i, 4j + 2), h_{2j+1}^{4i}) are adjacent to ((4i – 1, 2j + 1), (4i, 4j +2)) ∈ D_1.

The argument is similar if $i = \frac{n+1}{2}$ and $\frac{n+3}{2} \le i \le n$.

Case 2: n even.

It is sufficient to exhibit an edge dominating set of cardinality $\frac{1}{2}(9n^2 + 6n - 4)$.

For $1 \le i \le \frac{n-2}{2}$, $1 \le j \le \frac{n+2i}{2}$, let D_1 = {((4i – 1, 2j – 1), (4i, 4j – 1)), ((4i, 4j – 3), (4i, 4j – 2)), ((4i + 1, 2j – 1), (4i + 2, 4j – 2)), ((4i + 2, 4j – 1), (4i + 2, 4j – 1)), ((4i + 3, 2j), (4i + 2, 4j + 1)), ((4i, 4j), (4i + 1, 2j))}. It is clear that

$$|D_1| = 6\sum_{i=1}^{\frac{n-2}{2}}\left[\frac{n+2i}{2}\right] = \frac{3}{4}(3n^2 - 6n).$$

For $i = \frac{n}{2}$, $1 \le j \le n$, let D_2 = {((4i – 1, 2j – 1), (4i, 4j – 1)), ((4i, 4j – 3), (4i, 4j – 2)), ((4i + 1, 2j – 1), (4i + 2, 4j – 3)), ((4i + 2, 4j – 2), (4i + 3, 2j – 1)), ((4i + 2, 4j – 1), (4i + 2, 4j)), ((4i, 4j), (4i + 1, 2j))}. Clearly $|D_2| = 6n$.

For $\frac{n}{2} + 1 \le i \le n - 1$, $1 \le j \le \frac{3n-2i}{2}$, let D_3 = {((4i – 1, 2j), (4i, 4j)), ((4i, 4j – 2), (4i, 4j – 1)), ((4i + 1, 2j – 1), (4i + 2, 4j – 3)), ((4i + 2, 4j – 2), (4i + 3, 2j – 1)), ((4i + 2, 4j – 1), (4i + 2, 4j)), ((4i, 4j + 1), (4i + 1, 2j))}. It is clear that

$$|D_3| = 6 \sum_{i=\frac{n}{2}+1}^{n-1} \left\lceil \frac{3n-2i}{2} \right\rceil = \frac{3}{4}(3n^2 - 6n).$$

For $1 \leq j \leq \frac{n}{2} + 1$, let $D_4 = \{((2, 4j - 3), (2, 4j - 2)), ((4n, 4j - 3), (4n, 4j - 2))\}$. Therefore $|D_4| = n + 2$.

For $1 \leq j \leq \frac{n}{2}$, let $D_5 = \{((1, 2j - 1), (2, 4j - 1)), ((1, 2j), h_{2j}^1), ((2, 4j), (3, 2j)), ((4n, 4j), (4n + 1, 2j)), (h_{2j-1}^{4n}, (4n + 1, 2j - 1)), ((4n - 1, 2j), (4n, 4j - 1))\}$. Therefore $|D_5| = 3n$.

For $1 \leq i \leq \frac{n-2}{2}$, let $D_6 = \{((4i + 2, 1), h_1^{4i+2}), ((4i + 2, 2n + 4i + 2), h_{n+2i+1}^{4i+2}), ((2n + 4i, 1), h_1^{2n+4i-1}), ((2n + 4i, 4n - 4i + 2), h_{2n-2i+1}^{2n+4i-1})\}$. Clearly $|D_6| = 2n - 4$.

Define $D = D_1 \cup D_2 \cup D_3 \cup D_4 \cup D_5 \cup D_6$. Clearly $|D| = \frac{1}{2}(9n^2 + 6n - 4)$. We claim that D is an edge dominating set for G.

The proof is similar to that of case 1. □

Lemma 6 and Theorem 1 imply the following result.

Theorem 2 Let G be $SL(n)$, $n \geq 3$. Then $\gamma'(G) = \begin{cases} \frac{1}{2}(9n^2 + 6n - 3), & n\ odd; \\ \frac{1}{2}(9n^2 + 6n - 4), & n\ even. \end{cases}$

3 A molecular graph of oxide

Oxide networks play a vital role in the study of silicate networks. Oxide network is obtained by deleting silicon atoms from a silicate network. An n-dimensional oxide network is denoted as $OX(n)$. The number of vertices and edges of $OX(n)$ are $9n^2 + 3n$ and $19n^2$ respectively. An oxide network of dimension two is shown in Figure 6.

Following section 2, we also adopt a level numbering scheme for $OX(n)$.

We now determine the edge domination number of $OX(n)$. In order to obtain a lower bound for $\gamma'(OX(n))$, we require certain subgraph of $OX(n)$, namely triangular snake.

A triangular snake is obtained from a path $v_1, v_2 \ldots v_n$ by joining the vertices v_i and v_{i+1} to a new vertex w_i, for each $i = 1, 2 \ldots n - 1$. It is denoted by T_n.

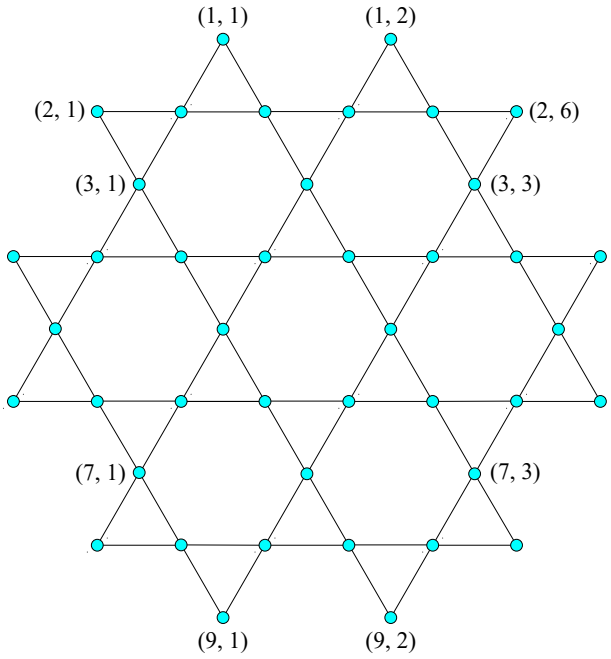


Figure 6 A oxide network *OX* (2)

Lemma 7 [12] Let G be T_n. Then $\gamma'(G) = \left\lceil \frac{n}{2} \right\rceil$.

Lemma 8 $\gamma'(OX(1)) = 3$.

Proof. It is clear that $D = \{((2, 2), (2, 3)), ((3, 1), (4, 2)), ((3, 2), (4, 3))\}$ is an edge dominating set $OX(1)$. This means that $\gamma'(OX(1)) \leq 3$. Further, for any $e \in D$, $D \setminus \{e\}$ is not an edge dominating set of $OX(1)$, implying that $\gamma'(OX(1)) \geq 3$.

Lemma 9 Let G be $OX(n)$, $n \geq 2$. Then $\gamma'(G) \geq 3n^2 + n$.

Proof. It is clear that G contains two triangular snake of size $2n + 2t$ for every t, $1 \leq t \leq n$. By Lemma 7,

$$\gamma'(G) \geq 2\sum_{t=1}^{n}\left\lceil \frac{2n+2t}{2} \right\rceil = 2\left(n^2 + \frac{n(n+1)}{2}\right) = 3n^2 + n.$$

Theorem 3 Let G be $OX(n)$, $n \geq 2$. Then $\gamma'(G) \leq 3n^2 + n$.

Proof. It suffices to exhibit an edge dominating set of cardinality $3n^2 + n$.

For $1 \leq i \leq n$, $1 \leq j \leq n + i$, let $D_1 = \{((2i, 2j - 1), (2i, 2j))\}$. Clearly

$$|D_1| = \sum_{i=1}^{n} n + i = \frac{3n^2 + n}{2}.$$

For $1 \leq i \leq n$, $1 \leq j \leq 2n - i + 1$, let $D_2 = \{((2n + 2i, 2j - 1), (2n + 2i, 2j))\}$. It is clear that

$$|D_2| = \sum_{i=1}^{n} 2n - i + 1 = \frac{3n^2 + n}{2}.$$

Define $D = D_1 \cup D_2$. Clearly $|D| = 3n^2 + n$. We claim that D is an edge dominating set for G.

For any i, $1 \leq i \leq n$, for any j, $1 \leq j \leq n + i - 1$, the four edges $((2i - 1, j), (2i, 2j))$, $((2i, 2j), (2i, 2j + 1))$, $((2i, 2j - 1), (2i + 1, j))$ and $((2i, 2j), (2i + 1, j))$ are adjacent to $((2i, 2j - 1), (2i, 2j)) \in D_1$.

For any i, $1 \leq i \leq n$, for any j, $2 \leq j \leq n + i$, the edge $((2i - 1, j - 1), (2i, 2j - 1))$ is adjacent to $((2i, 2j - 1), (2i, 2j)) \in D_1$.

The argument is similar if $n + 1 \leq i \leq 2n$.

Lemma 9 and Theorem 3 imply the following result.

Theorem 10 Let G be $OX(n)$, $n \geq 2$. Then $\gamma'(G) = 3n^2 + n$.

4 Conclusion

In this paper we have solved the edge dominating problem for certain chemical graphs. We have considered the molecular graphs of silicate and oxide. Relation between various topological indices and edge domination number of a graph is under investigation.

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The Total Relatively Prime Domination Number of Graphs

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ABSTRACT

The concept of domination in graph theory has been extensively studied and diversified into numerous variants, each imposing an additional structural or arithmetic constraint on the dominating set. This paper introduces and explores a novel variant called the **Total Relatively Prime Dominating Set (TRPDS).** *A set $S \subseteq V$ is a TRPDS if it is a total dominating set and for every pair of distinct vertices u, v in S, the greatest common divisor of their degrees is 1. The minimum cardinality of such a set is the* **Total Relatively Prime Domination Number**, *denoted $\gamma_{trpd}(G)$. We establish the value of this parameter for several fundamental graph families, including regular graphs, complete bipartite graphs, wheels, bistars, coconut trees and disjoint unions of edges. Furthermore, we provide a constructive characterization of all connected unicyclic graphs G for which $\gamma_{trpd}(G) = 2$, and identify a specific family of unicyclic graphs where this parameter is exactly 3.*

Keywords: *Dominating Set, Domination Number, Relatively Prime Dominating Set, Relatively Prime Domination Number*

AMS Subject Classification: 05C69

1 Introduction

By a graph G = (V, E) we mean a finite undirected graph without loops and multiple edges. The order and size of G are denoted by p and q respectively. A subset S of V is said to be a dominating set in G if every vertex in V– S is adjacent to at least one vertex in S. The domination number γ(G) is the minimum cardinality of a dominating set in G. Berge [2] and Ore [3] formulated the concept of domination in graphs. It was further extended to define many other dominations related parameters in graphs. In 2017, C. Jayasekaran and A. Jancy Vini [5] have introduced the concept of relatively prime domination number in graph theory. Let G be a non – trivial graph. A set $S \subseteq V$ is said to be a relatively prime dominating set if it is a dominating set and for every pair of vertices u and v in S such that (d(u), d(v)) = 1. The minimum cardinality of a relatively prime dominating set is called the relatively prime domination number and it is denoted by $\gamma_{rpd}(G)$.

A set S is a total dominating set [4] if V = N(S) and total domination number is γ_t(G) = min {|S|: S ⊆ V(G) and V = N(S)}, where N(S) is the open neighbourhood of S. A set of

vertices, S ⊆ V is said to be a Total Relatively Prime Dominating Set if every single vertex in V is adjacent to at least one vertex within S and for every pair of vertices in S such that (d(u), d(v)) = 1. The minimum cardinality of the total relatively prime dominating set is called the Total Relatively Prime Domination Number and is denoted by $\gamma_{trpd}(G)$.

In this paper, we synthesize these two ideas by introducing the Total Relatively Prime Dominating Set (TRPDS), which is a total dominating set with the additional condition that every pair of distinct vertices in the set have relatively prime degrees. The corresponding invariant, the Total Relatively Prime Domination Number $\gamma_{trpd}(G)$, is the main focus of our study. We formally defined the total relatively prime domination number and determined the exact value of $\gamma_{trpd}(G)$ for several standard graph classes, demonstrating that the parameter is well-defined and computable.

2 Total Relatively Prime Dominating Set

Definition. A set of vertices, S ⊆ V is said to be a Total Relatively Prime Dominating Set if every single vertex in V is adjacent to at least one vertex within S and for every pair of vertices in S such that (d(u), d(v)) = 1. The minimum cardinality of the total relatively prime dominating set is called the Total Relatively Prime Domination Number and is denoted by $\gamma_{trpd}(G)$.

Example. Consider the graph G given in figure 2.1 which contains two kinds of branches at v_1. Clearly, $\{v_1, v_2\}$ is a minimal dominating set and $d(v_1) = 7$ and $d(v_2) = 2$. Then, $(d(v_1), d(v_2)) = 1$. By the definition, $\{v_1, v_2\}$ is a total relatively prime dominating set and thus $\gamma_{trpd} = 2$.

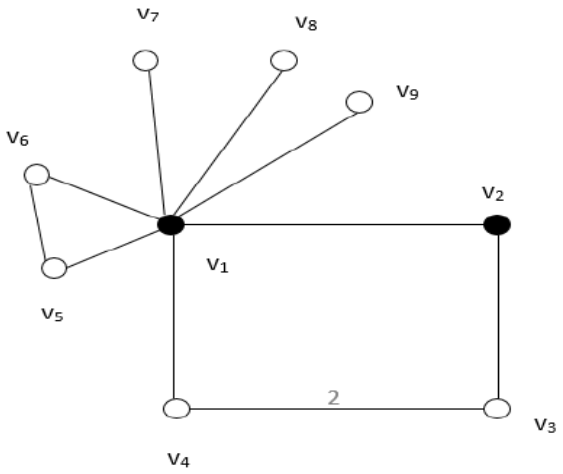


Fig 2.1

3 Results

Theorem 3.1. For a Regular graph, $\gamma_{trpd}(G) = 0$.

Proof. Consider G be a 3- Regular graph. Then, $\{v_1, v_2, v_3\}$ is the minimal total dominating set. Since, all the vertices of the graph have same degree 3, $(d(v_1), d(v_2), d(v_3)) \neq 1$. Hence, for a regular graph, $\gamma_{trpd}(G) = 0$.

Theorem 3.2. For a complete bipartite graph $K_{m,n}$, $\gamma_{trpd}(K_{m,n}) = 2$ where $(n, m+1) = 1$ and $n, m \geq 1$.

Proof. Consider a complete bipartite graph $K_{m,n}$. Here, there are two partitions of vertices, V and U. Now, number of vertices in $|V| = m$ and the number of vertices in $|U| = n$ where $n, m \geq 1$. Then, the minimum total dominating set is $\{v_1, u_1\}$ where $v_1 \in V$ and $u_1 \in U$. Here, $d(v_1) = m$ and $d(u_1) = n$. Thus, $(d(v_1), d(u_1)) = (m, n) = 1$. Therefore, the total relatively prime dominating set is $\{v_1, u_1\}$. Thus, $\gamma_{trpd}(K_{m,n}) = 2$.

Theorem 3.3. For $G = nK_2$, $\gamma_{trpd}(G) = 2n$ where $n \geq 1$.

Proof. Consider the graph nK_2 where $n \geq 1$. Now, let us label the vertex of the graph nK_2 as $\{v_1, v_2, \ldots, v_n\}$. Here, two vertices are connected by an edge. Then, the minimal total dominating set is $\{v_1, v_2, \ldots, v_n\}$. Here, $d(v_1) = 1$, $d(v_2) = 1$, …, $d(v_n) = 1$. Thus, $(d(v_1), d(v_2)) = (d(v_2), d(v_3))$, …, $(d(v_{n-1}), d(v_n)) = 1$. Therefore, $\gamma_{trpd}(G) = 2n$.

Theorem 3.4. For $G = K_n \cup K_{n+1} + v_1u_1$, $\gamma_{trpd}(G) = 2$ where $n>2$.

Proof. Consider two complete graphs K_n and K_{n+1} where $n>2$. Here, K_n has the vertices set $v = \{v_1, v_2, \ldots, v_n\}$ and K_{n+1} has the vertex set $u = \{u_1, u_2, \ldots, u_n\}$. Now, the both the graphs are not adjacent to each other. Let us join both the vertices v_1 and u_1 from the graphs K_n and K_{n+1}. Then, $G = K_n \cup K_{n+1} + v_1u_1$. Here, the total dominating set is $\{v_1, u_1\}$. Now, $d(v_1) = n+1$ and $d(u_1) = n+2$. Thus, the total relatively prime dominating set is $\{v_1, u_1\}$. Hence, $\gamma_{trpd}(G) = 2$.

Theorem 3.5. For a Wheel graph W_m, $\gamma_{trpd}(W_m) = 2$ if $m \neq 3n$ and $n \geq 1$

Proof. Consider a wheel graph W_m, where $m \neq 3n$ and $n \geq 1$. Now, the total dominating set is $\{v, u_1\}$. Then, $d(v) = m$ where $m \neq 3n$ and $n \geq 1$ and $d(u_1) = 3$. Then, $(d(v), d(u_1)) = 1$. Thus, the total relatively prime dominating set is $\{v, u_1\}$. Thus, $\gamma_{trpd}(W_m) = 2$.

Theorem 3.6. For a Bistar graph $B_{m,n}$, $\gamma_{trpd}(B_{m,n}) = 2$, if $(m, n) = 1$.

Proof. Let $B_{m,n}$ be a bistar graph which has two vertex sets, v and u and both the vertex sets are adjacent to each other. Let the vertex set, v contains ‘n’ number of vertices and u contains n number of vertices. All the vertices in the set, v is connected to a common point v and the vertices in the set u, is connected to a common point u. Then, both the common vertex, u and v are adjacent to each other. Now, $d(v) = m$ and $d(u) = n$. Then, $\{u,v\}$ is the minimal total

relatively prime total dominating set and also (d(v), d(u)) = (m+1, n+1) = 1. Hence, $\gamma_{trpd}(B_{m,n}) = 2$.

Theorem 3.7. For a coconut tree graph $CT_{m,n}$, $\gamma_{trpd} = 2$ if it is one of the following graphs:

(i). $CT_{2,n}$ where n>1

(ii). $CT_{3,2n}$ where n≥1.

Proof. Let $CT_{m,n}$ be a coconut tree graph with two sets of vertices m and n. Here, the vertices present in the set, n are adjacent to either any of the terminal vertex present in the set, m.

Case 1: m = 2 and n>1.

Consider the vertex set, V = {v_1, v_2}. Then, the vertices in the vertex set, n is adjacent to v_1. Here, {v_1, u_1} be the minimal total dominating set and $u_1 \in$ n. Here, $d(v_1) = n+1$ and $d(u_1) = 1$. Clearly, $(d(v_1), d(u_1)) = 1$. Then, {v_1, u_1} is the total relatively prime dominating set. Hence, $\gamma_{trpd}(CT_{(2,n)}) = 2$.

Case 2: m = 3 and n is a multiple of two.

Let V = {v_1, v_2, v_3} and n be the set in which the number of vertices is of two multiple. Here, the vertices in the vertex set, n is adjacent to v_1. Then, {v_1, v_2} is the minimal total dominating set. Thus, $d(v_1) = n+1$ and $d(v_2) = 2$. Therefore, {v_1, v_2} is a total relatively prime dominating set. Hence, $\gamma_{trpd}(CT_{(3,2n)}) = 2$.

Theorem 3.8. For a connected unicyclic graph G, $\gamma_{trpd}(G) = 2$ if and only if G is one of the graphs:

(i). $C_{3(v1)}(nP_2, 0, 0)$ where n is odd

(ii). $C_{3(v1)}(P_2, mP_2, 0)$ where m = 2n+1 and n≥1

(iii). $C_{3(v1)}(K_{1,m}, 0, 0)$ where m ≠ 3n+2 and n≥0

(iv). $C_{4(v1)}(nP_2, 0, 0, 0)$ where n is odd

(v). $C_{4(v1)}(nP_2, (n+1)P_2, 0, 0)$ where n≥1

Proof. Let G be a connected unicyclic graph with cycle C_n.

Case 1: n=3

Let $v_1v_2v_3v_1$ be the cycle C_3. If $d(v_i) \geq 3$; $1 \leq i \leq 3$, then $\gamma_{trpd}(G) \geq 3$. Hence, at most two vertices, say v_1 and v_2 can have degree ≥ 3.

Subcase 1. 1. $d(v_1) \geq 3$ and $d(v_2) = 2$

In this case, $d(v_3) = 2$. Since, G is a unicyclic graph, the branches at v_1 are trees other than branches which contain the cycle C_3. If all the branches are P_2, then G is $C_{3(v1)}(nP_2, 0, 0)$ where n is the number of P_2's at v_1. If $d(v_1) = n+2$ and $d(v_2) = 2$. Since, n is odd, $(d(v_1), d(v_2)) = 1$. Any minimum total relatively prime dominating set has both the vertices v_1 and v_2. Hence, $\gamma_{trpd}(G) = 2$.

Subcase 1. 2: $d(v_1) = 3$ and $d(v_2) \geq 4$.

In this case, $d(v_3) = 2$. If all the branches at v_2 are odd in number, then, $\{v_1, v_2\}$ is a total relatively prime dominating set of G where v_1 and v_2 are adjacent to each other. Here, G is $C_{3(v1)}(P_2, mP_2, 0)$ where $m = 2n+1$ and $n \geq 1$. Then, $\gamma_{trpd}(G) = 2$.

Subcase 1. 3: $d(v_2) = 2$ and $d(v_3) = 2$

In this case, a $K_{1, m}$ graph is attached with the vertex v_1. Then, $d(v_1) = 3$. Here, $m \neq 3n+2$ and $n \geq 0$. Then, $d(u) = m+1$. Then, $\{u, v_1\}$ is a total relatively prime dominating set of G where u and v_1 are adjacent to each other. Here, G is $C_{3(v1)}(K_{1, m}, 0, 0)$ where $m \neq 3n+2$ and $n \geq 0$. Then, $\gamma_{trpd} = 2$.

Case 2: $n = 4$

Let $v_1v_2v_3v_4v_1$ be the cycle, C_4.

Subcase 2. 1:

Let the vertices v_1 and v_2 be adjacent to each other. Since, G is a connected unicyclic graph, the branches at v_1 are trees other than the branch which contains the cycle, C_4. Here, the branches at v_1 are odd in number. Hence, $G = C_{4(v1)}(nP_2, 0, 0, 0)$ where n is odd number of P_2's at v_1. Clearly, $\{v_1, v_2\}$ is a minimal total dominating set. Here, $d(v_1) \geq n + 2$ and $d(v_2) = 2$. Then, $\{v_1, v_2\}$ is a total relatively prime dominating set. Thus, $\gamma_{trpd}(G) = 2$.

Subcase 2. 2:

Let the vertices v_1 and v_2 be adjacent to each other. Since, G is a connected unicyclic graph, the branches at v_1 and v_2 are trees other than the branches which contain the cycles, C_4. Here, the branches at v_1 and v_2 are of n and n+1 in number where $n \geq 1$. Then, $G = C_{4(v1)}(nP_2, (n+1)P_2, 0, 0)$ where $n \geq 1$. Clearly, $\{v_1, v_2\}$ is a minimal total dominating set. Then, $d(v_1) = n+2$ and $d(v_2) = n+3$. Thus, $\{v_1, v_2\}$ is a total relatively prime dominating set. Hence, $\gamma_{trpd}(G) = 2$.

Theorem 3.9. For a connected unicyclic graph $G = C_{3(v1)}(nP_2, (n+1)P_2, (n+2)P_2)$ has $\gamma_{trpd}(G) = 3$ if n is odd.

Proof. Let $v_1v_2v_3v_1$ be the cycle, C_3. Let the vertices v_1 and v_2 be adjacent to each other. Since, G is a connected unicyclic graph, the branches at v_1, v_2 and v_3 are trees other than the branch which contains the cycle, C_3. Here, the branches at $v_1 = n$, $v_2 = n+1$and $v_3 = n+2$ where n is odd. Hence, $G = C_{3(v1)}(nP_2, (n+1)P_2, (n+2)P_2)$ where n is odd number of P_2's at v_1, v_2 and v_3. Clearly, $\{v_1, v_2, v_3\}$ is a minimal total dominating set. Here, $d(v_1) \geq n + 2$, $d(v_2) \geq n+3$ and $d(v_3) = n+4$. Now, $(d(v_1), d(v_2)) = (d(v_1), d(v_3)) = (d(v_2), d(v_3)) = 1$. Then, $\{v_1, v_2, v_3\}$ is a total relatively prime dominating set. Thus, $\gamma_{trpd}(G) = 3$.

Conclusion

This paper introduced the Total Relatively Prime Domination Number $\gamma_{trpd}(G)$, a new graph invariant combining total domination with the condition that all vertices in the dominating set have pairwise relatively prime degrees. Exact values were established for regular graphs, complete bipartite graphs, wheels, bistars, coconut trees, and disjoint unions of edges. A complete characterization of connected unicyclic graphs with $\gamma_{trpd}(G)=2$ was provided, along with a family achieving $\gamma_{trpd}(G)=3$. The study demonstrates that this parameter is well-defined and computable, laying the foundation for further exploration of arithmetic-constrained domination parameters.

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Biogenic Synthesis of Nickel Oxide Nanoparticles via Citrus limon Leaf Extract

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ABSTRACT

The growing interest in sustainable nanomaterials has inspired research into environmentally benign synthesis approaches. In the present investigation, both conventional and a green synthesis of NiO nanoparticles using Citrus limon leaf extract as natural reducing and stabilizing agents have been carried out for an eco-friendly, cost-effective, and nontoxic alternative to traditional chemical methods. Characterization was done by XRD, FESEM, and FTIR. XRD confirmed the cubic crystalline nature, and thereby the formation of the pure NiO phase, FESEM analysis revealed a rice-like morphology for the conventionally synthesized NiO nanoparticles, while citrus limon leaf extract mediated NiO Nanoparticles exhibited an agglomerated porous morphology, FTIR confirmed the presence of Ni–O bonds in the range of 418–405 cm^{-1}. This green approach supports sustainable nanotechnology by offering an eco-friendly and cost-effective route for nanoparticle synthesis.

Keywords: *Citrus limon, cubic nature, NiO NPs, phytochemicals.*

1. Introduction

Nanoscience has evolved into a transformative discipline, underpinning innovations across catalysis, energy storage systems, environmental clean-up technologies, optoelectronic devices, and biomedical engineering. Within the broad class of metal oxide nanomaterials, nickel oxide (NiO) stands out due to its wide bandgap (3.6–4.0 eV), intrinsic p-type conductivity, remarkable thermal robustness, and versatile electrochemical behavior. These attributes make NiO a promising candidate for applications such as supercapacitors, gas-sensing platforms, photocatalytic reactors, solar energy conversion, and antimicrobial formulations [1–4]. The functional performance of NiO nanoparticles (NPs) is highly dependent on key physicochemical variables including particle size, morphology, and surface chemistry thereby necessitating synthetic approaches capable of fine-tuning these characteristics [5]. Traditional fabrication routes for NiO NPs, including sol-gel synthesis, controlled precipitation, hydrothermal processing, and thermal decomposition, can produce phase-pure and crystalline materials [6–8]. However, these techniques frequently rely on hazardous reagents, elevated temperatures, or energy-intensive conditions. Increasing environmental awareness and the demand for sustainable manufacturing strategies have shifted

attention toward green synthetic methodologies. These environmentally conscious approaches leverage plant extracts, microbial systems, or natural biopolymers as benign reducing, stabilizing, and capping agents [9–11].

Among these eco-friendly strategies, plant-assisted nanoparticle synthesis has gained momentum owing to its operational simplicity, scalability, and the presence of bioactive metabolites such as flavonoids, alkaloids, terpenoids, and phenolics that can participate in nanoparticle nucleation and growth [12,13]. Numerous botanical extracts, including those from neem, aloe vera, tea leaves, and citrus species, have enabled the controlled generation of various metal and metal oxide nanostructures with improved stability and tailored dimensions [14–16]. *Citrus limon*, in particular, contains abundant phytochemicals such as citric acid, ascorbic acid, flavonoids, and essential oils, which function as natural chelators and stabilizers capable of influencing crystal development and overall nanoparticle morphology [17,18]. Recent reports highlight that *Citrus limon*-based green synthesis can enhance both the structural and functional attributes of metal oxide NPs such as ZnO, CuO, and Fe_3O_4 often producing smaller crystallite dimensions, better dispersibility, and biofunctional surface groups derived from plant metabolites [19–21]. Nonetheless, studies exploring the biosynthesis of NiO nanoparticles using *Citrus limon* leaf extract remain relatively scarce, despite the potential of citrus phytochemicals to modulate nucleation kinetics and surface interactions during particle formation.

The present work addresses this gap by synthesizing NiO nanoparticles using a conventional chemical precipitation route and a complementary green method employing Citrus limon leaf extract. The resulting materials were systematically characterized through X-ray diffraction, Fourier-transform infrared spectroscopy, and scanning electron microscopy to elucidate differences in structural features, surface functionalities, and morphological attributes. By linking the observed characteristics to the respective synthesis pathways, this study underscores the influence of plant-derived biomolecules in directing nanoparticle formation and highlights the environmental benefits of biosynthetic approaches. These insights establish a foundation for future applications of biogenic NiO nanomaterials in catalytic, energy-related, and biomedical domains.

2. Materials and Methods

2.1. Conventional Synthesis of NiO nanoparticles

Nickel oxide nanoparticles were prepared by dissolving 2.908 g of nickel nitrate hexahydrate ($Ni(NO_3)_2 \cdot 6H_2O$) in 100 mL of distilled water and 20 mL of ethanol. This formed a greenish blue solution that was stirred for 1 hour. In a separate beaker, 6.4 g of NaOH was dissolved in

100 mL of distilled water. The latter solution was subsequently added dropwise to the nickel nitrate solution, turning the color to light green. The pH was kept at 12 during the slow addition of NaOH. The mixture was then stirred for an additional 2 hours to complete the reaction. Then, the product was washed five times with distilled water and twice with ethanol to remove impurities from the prepared sample. The product was treated by ultrasonication aimed at improving the stability of the particles. Later, the powder was dried at 150 °C for 5 hours to obtain a bright green color, then calcined at 500 °C for 2 hours in order to get pure black nickel oxide nanoparticles. Powder samples were calcined and ground to a fine powder.

2.2. Preparation of *Citrus limon Leaf* extract

The leaves of *Citrus limon* leaf were washed with distilled water, shade-dried for 14 days to remove excess water content, and finally ground into fine powder. Approximately 5 g of the powdered leaves were mixed with 100 mL of distilled water and then heated at 60°C with the help of a magnetic stirrer for 20 minutes. The mixtures were then stirred continuously for another 1 hour for the complete extraction of bioactive compounds. After stirring, the solution was separately filtered by Whatman filter paper and the obtained extract were collected and stored at 4°C for further use in the green synthesis process.

2.3. Green synthesis of NiO using *Citrus limon Leaf* extract

Nickel oxide nanoparticles were synthesized with the help of *Citrus limon* leaf extract. At first, nickel nitrate hexahydrate ($Ni(NO_3)_2 \cdot 6H_2O$) of 2.908 g was combined with 100 mL of distilled water and 20 mL of ethanol, and the mixture was stirred for 2 hours yielding a greenish-blue solution. The colour changed to light green when 40 mL of the citrus leaf extract was gradually added. Then 6.4g of NaOH which was dissolved in 100 mL of water was added slowly while maintaining the pH at 12, resulting in a yellowish green solution. The solution was stirred for another 2 hrs, washed 5 times with distilled water and 2 times with ethanol, and ultrasonicated to improve the quality of the nanoparticles. The product was dried at 150 °C for 5 hrs to get a black powder and then calcined at 500 °C for 2 hrs to obtain pure black NiO nanoparticles which were subsequently ground into a fine powder.

3. Results and Discussion

3.1. X-Ray Diffraction

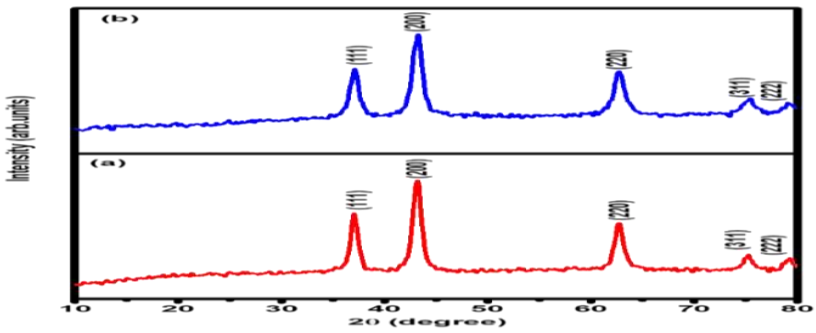


Fig 1. X-Ray diffraction pattern of (a) conventionally synthesized NiO NPs and (b) *Citrus limon* leaf extract mediated NiO NPs.

In this work, we synthesized nickel oxide nanoparticles using both conventional methods and a *Citrus limon* leaf extract-mediated green synthesis approach.The structural characteristics and crystallinity of the synthesized samples were investigated using the XRD pattern, as shown in Fig. 1. The diffraction peaks for the conventionally synthesized NiO sample were at 2θ values 37.05°, 43.24°, 62.73°, 75.20°, and 79.06° corresponding to crystal planes (111), (200), (220), (311) and (211), respectively. Peaks corresponding to the synthesized NiO using *Citrus limon* leaf extract were at 37.15°, 43.25°, 62.72°, 75.32°, and 79.20° corresponding to the crystal planes (111), (200), (220), (311) and (211), respectively. Sharp and well-defined peaks in the XRD patterns confirmed that the NiO nanoparticles have excellent crystallinity with phase purity. Calculated lattice parameters were 4.1884Å for conventionally synthesized NiO and 4.1899Å for *citrus limon* leaf mediated extract, respectively. The green-synthesized NiO shows a slight change in lattice parameter values because of minor lattice strain and surface effects which result from the phytochemical residues present in *Citrus limon* leaf extract. These consistent lattice parameter values indicate the successful formation of a single-phase cubic NiO nanoparticles in these samples. Both the samples were matched to the standard JCPDS/ICDD card no. 01-078-0423 and it confirmed that the nanoparticles have a cubic NiO structure with NaCl-type arrangement belonging to space group Fm-3m.

3.1.1. Crystallite size

The crystallite size of synthesized NiO nanoparticles was calculated using Debye-Scherrer equation,

$$\mathbf{d} = \frac{0.89\lambda}{\beta cos\theta} \quad \mathbf{nm} \qquad (1)$$

Where:

d = crystallite size (in nanometres, nm)

λ = wavelength of the X-ray used (typically 0.15406 nm for Cu Kα radiation)

β= full width at half maximum (FWHM) of the diffraction peak (in radians)

θ = Bragg diffraction angle (in degrees)

The average crystallite sizes of conventionally synthesized nickel oxide nanoparticles and *Citrus limon* leaf-extract mediated nickel oxide nanoparticles were found to be 17.99 nm, and 17.70 nm respectively, indicating a slight reduction in particle size due to the influence of the phytochemical constituents present in the plant extract.

3.2. Fourier Transform Infrared Spectroscopy

Fourier-transform infrared spectra of the two samples between biomolecular extract and nickel oxide are presented in (Fig. 2). All the samples have a broad O–H stretching vibration band at (3566–3465 cm^{-1}), which is consistent with surface hydroxyls and adsorbed water. The weak absorption band near 2947 cm^{-1} observed in the conventionally synthesized NiO sample is attributed to C–H stretching vibrations.The samples of NiO had broad absorption bands at about 1631 cm^{-1} and 1383-1361 cm^{-1}, which could be attributed to the stretching and bending vibrations of -OH groups adsorbed on the catalyst surface due to an atmosphere. The absorption band observed in the 1035–1001 cm^{-1} region is attributed to C–O or C–N stretching vibrations arising from residual organic species.The NiO samples exhibit the characteristic metal-oxygen lattice vibrations in the range of 418-405 cm^{-1}, further confirming the successful formation of nickel oxide nanoparticles.

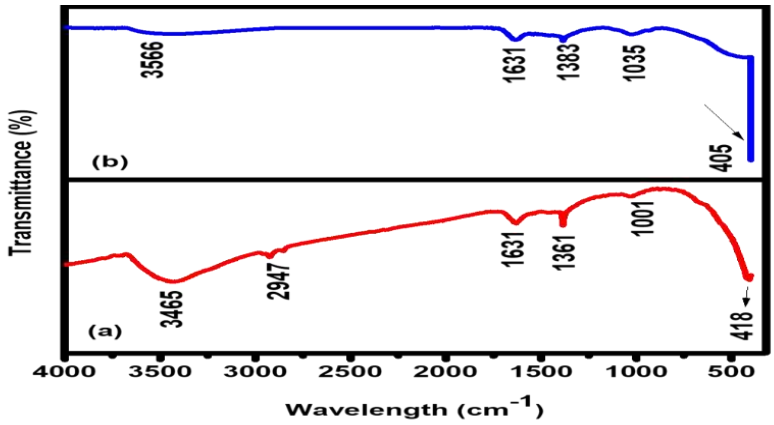


Fig 2. FT-IR spectrum of (a) conventionally synthesized nickel oxide NPs and (b) *Citrus limon* leaf extract mediated nickel oxide NPs.

3.3. Scanning Electron Microscopy

3.3.1. Conventionally synthesized NiO NPs

The surface morphology of the synthesized nanoparticles was analyzed by scanning electron microscopy. The SEM images (Fig. 3a, b) of conventionally synthesised nickel oxide

nanoparticles show densely packed, rice-like structures with an aggregated surface morphology, indicative of the formation of even particles with excellent surface roughness, typical of rice-like materials in the 300–400 nm submicron range.

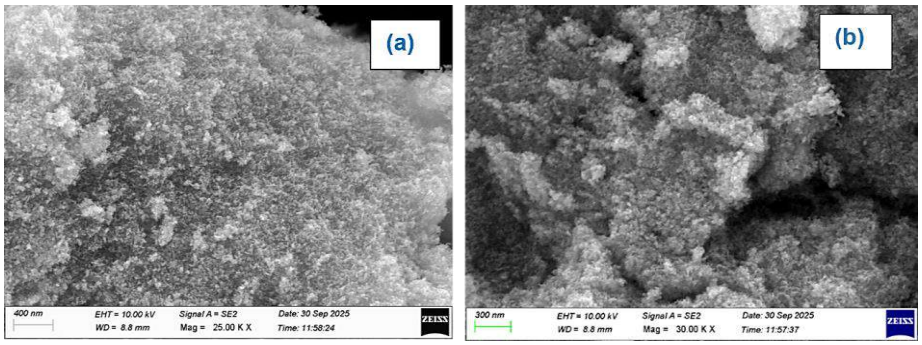


Fig 3. SEM images of conventionally synthesized NiO NPs at different magnifications (a) at 400 nm and (b) 300 nm.

3.3.2. *Citrus limon* leaf mediated NiO NPs

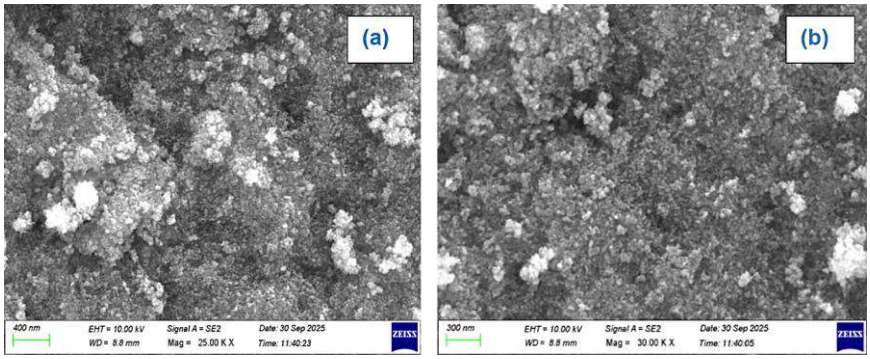


Fig 4. SEM images of *Citrus limon* leaf extract mediated NiO NPs at different magnifications (a) at 400 nm and (b) 300 nm.

The SEM images (Fig. 4a, b) of *Citrus limon* leaf extract mediated NiO nanoparticles at 400 nm and 300 nm reveal that the particles are not uniformly dispersed but are rather heavily aggregated and clustered together to present a porous-looking surface morphology. Such aggregation could be due to the strong interparticle interactions and biomolecules from the *Citrus limon* leaf extract acting as capping and stabilizing agents. In general, the morphology suggests the successful preparation of nanostructured NiO with a porous and irregular surface that could improve surface activity and catalytic properties.

4. Conclusion

In the present work, nickel oxide nanoparticles were obtained through two distinct routes such as a conventional precipitation technique and a phytochemically driven synthesis employing *Citrus limon* leaf extract. X-ray diffraction patterns confirmed that all products crystallized in

a well-defined cubic NiO phase and corresponded closely with the reference JCPDS/ICDD file no. 01-078-0423. Notably, the nanoparticles produced via the plant-assisted method exhibited a marginally reduced crystallite dimension relative to those produced chemically, suggesting that the phytoconstituents in the extract modulate nucleation and growth during particle formation. Complementary FTIR measurements substantiated the presence of Ni–O lattice vibrations and revealed additional spectral features attributable to organic groups originating from plant-derived molecules that act as natural capping agents.

Taken together, these observations show that the green synthesis route yields NiO nanoparticles with structural features comparable to their chemically derived counterparts, while simultaneously offering a more sustainable and resource-efficient fabrication strategy. The effective role of *Citrus limon* extract as both a reducing and stabilizing medium underscores its potential for producing environmentally benign NiO nanomaterials. These findings lay the groundwork for further exploration of such biogenic NiO nanoparticles in catalytic, functional, and biomedical domains.

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Solanum nigrum leaf extract synthesis of Cu-HAp nanocomposites: comprehensive structural, morphological and compositional properties

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ABSTRACT

The comprehensive characterization results demonstrate that leaf extract from Solanum nigrum (SN) functions as an effective bio-reducing agent for synthesizing highly crystalline copper-Hydroxyapatite (Cu-HAp) nanocomposites with precisely controlled morphological features and chemical composition. The resulting nanocomposites display excellent structural stability, homogeneous morphology, and ideal copper incorporation levels. Through X-ray diffraction (XRD) analysis, the successful synthesis of both hydroxyapatite (HAp) phase and copper (Cu) nanocomposite was verified. Energy-dispersive X-ray (EDX) spectroscopy detected calcium, phosphorus, oxygen and copper elements with atomic ratios consistent with copper-substituted HAp. The Cu concentration was found to be approximately 4wt%, confirming effective integration while maintaining the structural integrity of HAp. Field emission scanning electron microscopy (FESEM) images showed uniformly distributed rod-like shaped nanoparticles ranging in size from 300nm to 1μm (specifically 1μm, 500nm, 400nm, and 300nm). Fourier-transform infrared spectroscopy (FTIR) analysis identified characteristic phosphate vibrational band at 1100, 1033, 947, 605, 567 and 476 cm^{-1}, along with hydroxyl stretching peaks at 3573 cm^{-1}.

Keywords: *Copper- Hydroxyapatite (Cu-HAp), Green synthesis, Nanocomposites, Solanum nigrum (SN).*

1. Introduction

The development of multifunctional nanocomposites using environmentally sustainable synthesis routes has become a critical focus in modern material science, especially for biomedical applications. HAp, being the principal mineral constituent of natural bone and dental tissue, stands out as one of the most biocompatible materials [1]. Cu-HAp nanocomposites have shown exceptional promise owing to copper's established importance in various biological mechanisms, including collagen production, wound healing and bone metabolism [2]. Traditional synthesis methods raise environmental issues and may introduce hazardous contaminants that restrict their use in biomedical fields. The increasing need for environmentally responsible and sustainable fabrication techniques has prompted researchers to investigate biological systems, especially plant-based extracts, as eco-friendly alternatives for nanocomposite production. The bioactive molecules present in these extracts can efficiently

reduce metal ions while simultaneously inhibiting particle clustering, resulting in well-regulated nanoparticles formation with improved biological properties. Rich in phytochemicals, SN leaf extract provides an excellent foundation for the environmentally friendly fabrication of Cu-HAp nanocomposites [3]. The structural stability, morphological features, and compositional homogeneity of the synthesized nanocomposites is essential. Thorough characterization using XRD analysis elucidates the crystalline phases and structural alternations resulting from copper integration into the hydroxyapatite matrix. Morphological examination via electron microscopy techniques offers valuable information regarding surface properties and composite organization [4]. This study delivers a detailed investigation of the green synthesis of Cu-HAp nanocomposites utilizing SN leaf extracts as both a natural reducing and stabilizing agent. The research emphasizes comprehensive structural characterization through XRD to examine phase development and crystalline quality, compositional evaluation via EDX spectroscopy, morphological assessment using FESEM to analyze particle features and dispersion, and FTIR spectroscopy to verify successful synthesis and chemical incorporation [5]. Additionally, the environmentally sustainable nature of this synthesis methodology addresses ecological considerationswhile potentially improving the biocompatibility of the final materials through the integration of beneficial phytochemical compounds derived from the plant extract.

2. Materials and methods

2.1 Chemicals and reagents

All reagents utilized in this investigation were of analytical grade and employed without additional purification steps. Calcium nitrate tetrahydrate ($Ca(NO_3)_2.4H_2O$), ammonium dihydrogen phosphate ($NH_4H_2PO_4$), ammonia solution (NH_3), *Solanum nigrum* (SN) and copper nitrate trihydrate ($Cu(NO_3)_2.\ 3H_2O$) were obtained from Hi Media. Fresh SN leaves were gathered from Kanyakumari for extract formulation, and double distilled water was employed consistently throughout all synthesis procedures.

2.2 Synthesis of *Solanum nigrum* extract assisted of Cu-HAp nanocomposite

30 grams of fresh SN leaves were thoroughly washed with double distilled water to eliminate dust particles and impurities, followed by air- drying at room temperature for 5 days. The dried leaves were then subjected to boiling in 500 ml of double distilled water at 80ºC for 1 hour under constant stirring. The obtained brownish solution was allowed to cool to room temperature and subsequently filtered using what man No. 1 filter paper to eliminate plant residue. The prepared leaf extract was preserved at 4ºC under refrigeration for subsequent applications. Calcium nitrate tetrahydrate (0.8M) and copper nitrate trihydrate (0.2M) were co-

dissolved in 100 ml of double distilled water to create a combined metal salt solution. A separate solution of ammonium dihydrogen phosphate (0.06M) was prepared in 50 ml of double distilled water. The SN leaf extract (50 ml) was introduced in to the combined metal salt solution with continuous agitation at room temperature. A colour transition from blue to blue-greenish was observed, signifying the interaction between phytochemicals constituents and metal ions. The mixture underwent stirring for 30 mins to achieve complete chelation of metal ions with the bioactive compounds in the leaf extract. The phosphate solution was gradually added dropwise into the metal-extract mixture over 30 mins while maintaining vigorous agitation. The pH was continuously monitored and adjusted to 12 using 10 ml of NH_3 solution to establish optimal conditions for HAp formation. Throughout this addition, a characteristic colour shift to a bluish-green precipitate was observed, confirming the formation of Cu-incorporated HAp. The precipitate underwent 4 washing cycles with double distilled water and once wash with ethanol to eliminate impurities, and the pH was neutralized. The washed precipitate was oven-dried at 150ºC for 6 hours, and the resulting dried bluish-green powder was ground using a mortar and pestle to achieve fine particles. The dried powder subsequently underwent calcination at 700ºC for 2 hours to eliminate organic residues and enhance crystallinity. The calcination temperature was carefully optimized to ensure complete removal to organic content while maintaining the HAp Structure and Cu integration, as illustrated in Figure 1 [6, 7].

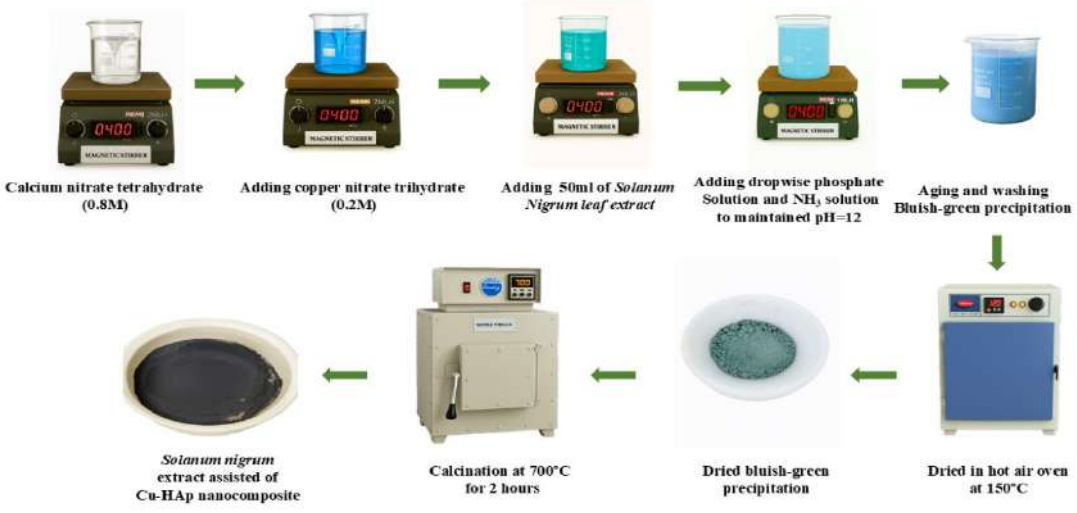


Figure 1. Schematic diagram of the synthesis of *Solanum nigrum* extract assisted of Cu-HAp nanocomposite.

2.3 Characterization

The Cu-HAp nanocomposites synthesized using SN extract assistance underwent comprehensive characterization to examine their structural properties, elemental composition, morphological features, and chemical integration. XRD was conducted using an XPERT-PRO powder diffractometer with CuKα radiation, scanning across a 2θ range of 20º- 80º. Elemental composition was determined through EDX spectroscopy analysis. Morphological characteristics were investigated via FESEM utilizing a Zeiss EVO18 instrument. Functional group identification was performed through FTIR spectroscopy employing the KBr pellet method using a Bruker IFS48 spectrometer.

3. Result and discussion

3.1 X-ray diffraction analysis

Figure 2 illustrates the XRD patterns of Cu-HAp nanocomposites synthesized using SN leaf extract. The diffraction pattern of the control sample displays characteristic peaks corresponding to well-crystallized HAp with a hexagonal crystal system with space group $P6_3/m$. The major diffraction peaks are detected at 2θ values of 26.08º (002), 28.36º (102), 29.28º (210), 32.07º (211), 33.07º (300), 34.23º (202), 39.91º (310), 40.05º (221), 42.11º (311), 42.97º (302), 44.44º (400), 45.53º (203), 46.94º (222), 49.78º (213), 50.58º (321), 52.28º (402), 53.45º (004), 57.25º (313), 63.23º (502) and 64.24º (304), demonstrating excellent correspondence with standard JCPDS no 09-0432 for stoichiometric HAp and CuO JCPDS no 48-1548. As shown in figure 2, the CuO diffractogram reveals diffraction peaks at the 2θ values of 35.46º (002), 38.23º (111), 48.53º (202), 51.73º (112), 56.21º (021), 58.42º (202) and 61.24º (113). Ideal copper incorporation was confirmed by the preservation of the characteristic hydroxyapatite phase with minimal lattice distortion, indicating successful substitution of Cu^{2+} ions into the calcium sites. The incorporation of Cu-HAp structure through the SN leaf extract-mediated synthesis process induces alternations in the XRD patterns [8]. The diffraction peaks of SN leaf extract- assisted with Cu-HAp samples exhibit shifts toward higher 2θ values relative to pure HAp and CuO. The most notable shifts occur in the prominent reflections, ranging from 0.1º to 0.5º. These positive shifts suggest crystal lattice contraction, which is consistent with the replacement of larger Ca^{2+} ions by smaller Cu^{2+} ions within the Hap framework. XRD analysis demonstrates excellent phase purity across all synthesized samples, with minimal secondary phases of CuO-containing compounds. This confirms successful incorporation of Cu into the HAp structure without separate phases formation. The absence of impurity peaks validates the efficacy of the SN-mediated synthesis methodology in producing Cu-HAp. The average crystalline size was determined using the Debye - Scherrer equation D

= Kλ/(β cosθ). The SN-mediated Cu-HAp synthesis approach effectively controls crystallite size, yielding a value of 18 nm with corresponding microstrain (ε) of 6.7026, providing quantitative assessment of the structural modifications induced by Cu integration into the Hap framework. Excellent structural stability can be attributed to the successful incorporation of copper ions into the hydroxyapatite lattice without disrupting the fundamental apatite framework, thereby maintaining both crystallographic integrity and phase stability.The reduced crystallite dimensions achieved through this environmentally friendly synthesis route demonstrate the effectiveness of SN leaf extract-mediated Cu-HAp nanocomposites fabrication. The bioactive compounds present in SN leaf extract substantially influence the crystallization mechanism.Organic capping agents prevents excessive crystal growth by providing heterogeneous nucleation sites and regulating growth kinetics [9].

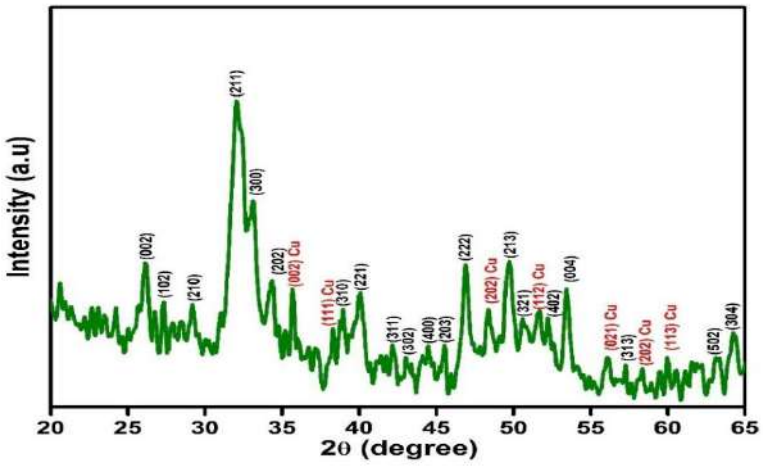


Figure 2. XRD patterns of*Solanum nigrum* extract assisted of Cu-HAp nanocomposite.

3.2 Energy dispersive X-ray analysis

EDX spectroscopy was utilized to examine the elemental composition and chemical stoichiometry of the SN leaf extract-mediated Cu-HAp nanocomposites. The EDX spectrum verified the presence of all anticipated elemental components, including calcium (Ca), phosphorous (P), oxygen (O) and copper (Cu), confirming successful integration of Cu ions into the HAp matrix via the green synthesis approach. Quantitative elemental analysis indicates that calcium and phosphorus constituted the primary elements, with oxygen present in substantial proportions corresponding to the hydroxyl and phosphate groups within the HAp structure [10]. The calculated Ca/P molar ratio was found to be 1.70, which exceeds the stoichiometric values of 1.67 for pure HAp. This elevated Ca/P ratio indicates the formation of a calcium-enriched HAp phase, potentially attributed to excess calcium ions on the

nanocomposite surface or the development of calcium-deficient phosphate phases during the bio-mediated synthesis process. Such deviation from the ideal stoichiometric ratio is frequently observed in biologically synthesized HAp and is typically associated with enhanced bioactivity and superior osteoconductivity. The EDX analysis additionally revealed distinct copper peaks, verifying successful doping of Cu^{2+} ions into HAp lattice, facilitated by the phytochemical components present in the leaf extract that functioned as chelating and reducing agents. The homogeneous distribution of copper across the nanocomposite matrix, as demonstrated by elemental mapping, confirmed the effectiveness of the green synthesis approach in achieving uniform metal incorporation without phase separation [11]. The comprehensive EDX analysis thus validated the formation of compositionally enriched Cu-HAp nanocomposites with a Ca/P ratio of 1.70, establishing their potential suitability for applications where calcium-rich HAp phases demonstrate enhanced biological performance, as illustrated in Figure 3 and Table 1.

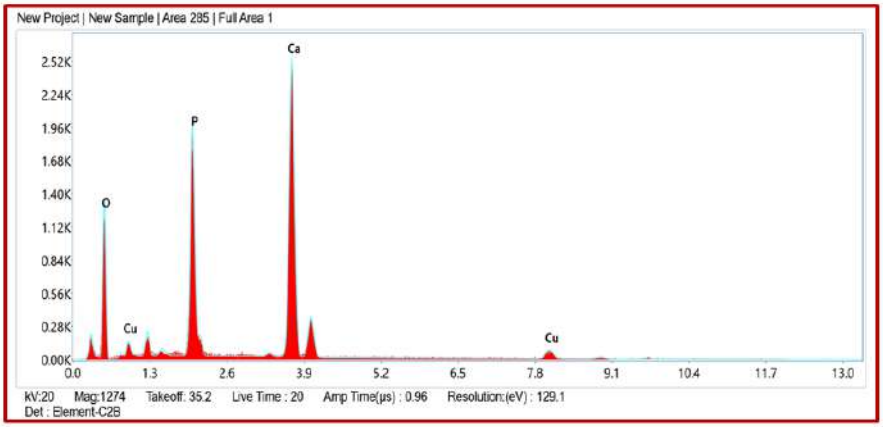


Figure 3. EDXspectrum of*Solanum nigrum* extract assisted of Cu-HAp nanocomposite.

Elements	Atomic (%)	Ca/P
Ca	24.52	1.70
P	16.82	
O	54.47	
Cu	4.19	

Table 1. The elements and Ca/P ratio of the synthesized samples

3.3 Field emission scanning electron microscopy analysis

The FESEM micrographs of Cu-Hap synthesized using SN leaf extract as a bio-reducing agent revealed distinct morphological features compared to conventionally prepared HAp. FESEM analysis was conducted at various magnifications to thoroughly assess the surface morphology

and structural attributes of the synthesized Cu-HAp nanocomposites. At 1µm magnification, the SEM micrographs displayed well-distributed microparticles, featuring a heterogeneous surface with interconnected porous networks. The overall architecture demonstrated successful integration of Cu into the HAp matrix through the leaf extract-mediated green synthesis approach. Upon increasing the resolution to 500nm, the morphological, characteristics become more apparent, exhibiting rod-like nanostructures with Cu submicron particles embedded within the HAp framework [12]. At 400nm magnification, individual submicron particles assemblies were distinctly visible, displaying rod-like morphologies. The interface between the Cu and HAp phases showed intimate contact, indicating strong interaction facilitated by bioactive compounds from the leaf extract that functioned as both reducing and capping agents. Further magnification at 300nm provided detailed visualizationof the nanostructures surface characteristics, revealing crystalline facets and grain boundaries of the HAp structure decorated with Cu-HAp are illustrated in Figure 4 [13].The sample exhibited a broad particle size distribution ranging from 300 nm to 1 µm, with an average particle size of 38 -72 nm. The precisely controlled morphology, evidenced by uniform particle dimensions and reproducible shape, was superior to conventional precipitation methods, demonstrating the effectiveness of the synthesis approach.The SEM analysis across multiple magnifications collectively validated the successful synthesis of Cu-HAp nanocomposites with favorable morphological, characteristics, demonstrating the effectiveness of the green synthesis approach in producing nanostructured materials with controlled and enhanced surface properties.

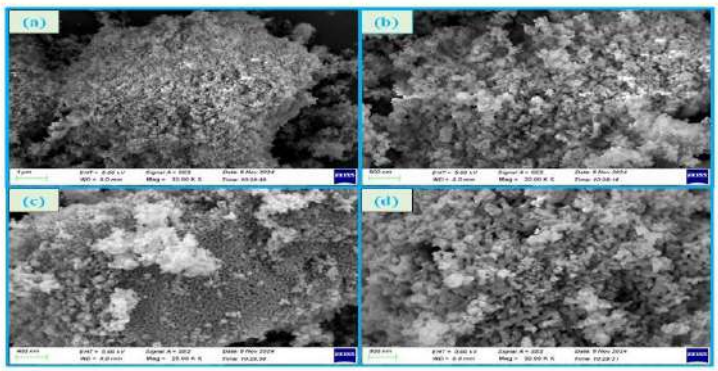


Figure 4. FESEM images of*Solanum nigrum* extract assisted of Cu-HAp nanocomposite showing the distribution of agglomerated scale bar and magnification details (a) 1µm, 10.00 K × (b) 500 nm, 20.00 K× (c) 400 nm, 25.00 K× (d) 300 nm, 30.00 K×

3.4 Fourier transform infrared spectroscopy analysis

The FTIR spectrum of Cu-substituted HAp nanocomposites synthesized using SN leaf extract exhibits characteristic vibrational bands corresponding to the phosphate and hydroxyl groups within the HAp structure. The principal absorption bands are presented in Figure 5 and Table 2. A sharp peak at 3573 cm^{-1} corresponds to the O-H stretching vibration mode of structural hydroxyl group located in the hexagonal channels of HAp. An absorption peak at 2931 $cm^{-1}$is attributed to C-H asymmetric stretching vibrations of alkyl groups in organic compounds. Additionally, the band observed at 1651 cm^{-1}represents the bending mode of water molecules. A weak peak at 1436 cm^{-1}corresponds to the asymmetric stretching mode of CO_3^{2-} ion present in organic compounds containing carbonyl and hydroxyl groups that function as reducing agents, facilitating Cu incorporation into the HAp structure [14]. Strong bands at 1100 cm^{-1}, 1033 $cm^{-1}$are assigned to the asymmetric stretching vibrations of PO_4^{3-} groups. A medium intensity peak at 947 cm^{-1} corresponds to the symmetric stretching vibration mode of PO_4^{3-} groups. The band observed at 643 cm^{-1}represents the librational mode of OH^-. Sharp peaks at 605 cm^{-1} and 567 $cm^{-1}$are associated with the asymmetric bending vibrations mode of O-P-O bonds in phosphate groups. The peak at 476 cm^{-1} corresponds to the symmetric bending vibration mode of the PO_4^{3-} group [15]. FTIR analysis validates the successful synthesis of Cu-HAp nanocomposites using SN leaf extract while maintaining the fundamental HAp structure with systematic modifications resulting from Cu incorporation.

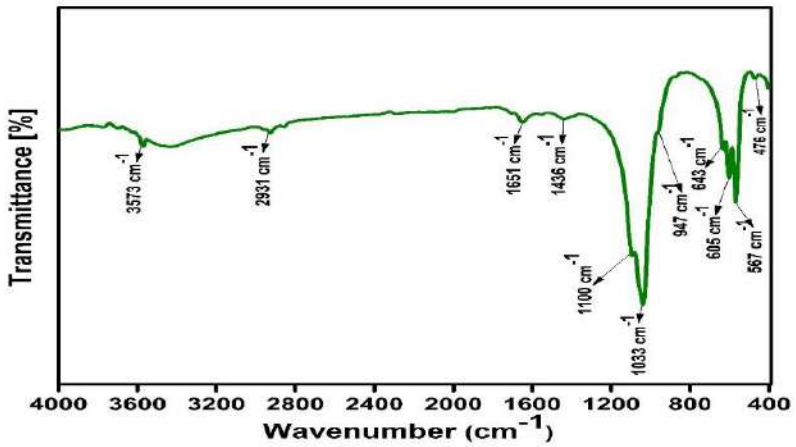


Figure 5. FTIR analysis of*Solanum nigrum* extract assisted of Cu-HAp nanocomposite showing characteristics phosphate and hydroxyl vibration bands.

Solanum nigrum extract assisted of Cu-HAp nanocomposite (cm^{-1})	Functional group
3573	OH^- stretching mode
2931	C-H asymmetric stretching vibrations mode (ν)
1651	H-O-H bending mode of water molecules
1436	Asymmetric stretching mode of CO_3^{2-} (ν_3)
1100	Asymmetric stretching mode of PO_4^{3-} (ν_3)
1033	Asymmetric stretching mode of PO_4^{3-} (ν_3)
947	Symmetric stretching mode of PO_4^{3-} (ν_1)
643	OH^-librational mode
605	Asymmetric bending mode of PO_4^{3-} (ν_4)
567	Asymmetric bending mode of PO_4^{3-} (ν_4)
476	Symmetric bending mode of PO_4^{3-} (ν_2)

Table 2. Shows the peak position and functional groups of the synthesized samples

4. Conclusion

The present investigation successfully demonstrates an eco-friendly and sustainable approach for fabricating Cu-HAp nanocomposites utilizing SN leaf extract as a natural reducing and capping agent. Structural characterization confirms the preservation of the distinctive HAp phase with effective Cu doping, while morphological investigations demonstrate the development of nano-sized particles with regulated dimensions and homogeneous dispersion. Compositional evaluation verifies the stoichiometric integration of Cu within the Calcium, phosphorus phase, validating the efficacy of the leaf extract-mediated synthesis in generating high-quality nanocomposites. Morphology examination revealed uniformly distributed rod-like nanoparticles, and chemical analysis identified hydroxyl stretching and phosphate vibration bands that authenticate the HAp phase formation.

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Pressure Dependence of Metallization in Silver Halides and Metal Selenides (AgCl, AgBr, ZnSe AND CdSe)

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ABSTRACT

The high pressures provoke metallization in silver halides and metal selenides provides important observations into their structural, electronic under certain conditions. The electronic band structure, charge density of states, semiconductor to metal metallization and phase transition of cubic structured zinc blende type silver halides and metal selenides are investigated using the full potential linear muffin-tin orbital (FP-LMTO) method. The equilibrium lattice constant, pressure dependence of bulk modulus and the phase transition pressure are studied from the electronic total energy calculations. When the increase of pressure, there is improved overlie between the wave functions of the adjacent atoms and produces the widths of the valence and empty conduction bands increase. These changes lead to the tightening and concluding of band gaps (metallization).

Keywords: *Electronic Band Structure, Electron Density of States, metallization, phase transition*

1.Introduction

Under very high pressure, the atoms get closer together and their properties get changed. Materials like AgCl, AgBr, ZnSe, and CdSe are semiconductors, but when pressure increases, their structure and energy levels change [1,2]. Whether a solid is an insulator, conductor or semiconductor, is determined by the energy band structure, the arrangement of electrons with respect to these bands and the width of forbidden bands. The N valence electrons will fill in pairs only lower half of the energy levels of the band. Then electrons in the valence band easily acquire additional energy to move to the higher unoccupied energy levels within the same band without crossing any energy gap. The additional energy is in the form of kinetic energy, and the moving electrons constitute an electric current. An unoccupied band into which electrons can pass is termed as ‘conduction band’. In metals, the valence band itself is also the conduction band. The electrons in the valence band would not move within the band because there are no unoccupied levels in this band. They can, however, move to the higher empty band provided they get the required energy E_g to cross the forbidden band. An electric field cannot give this amount of energy to an electron in the solid. Thus no electron acquires additional kinetic energy

in the electric field. Therefore, there will be no electric current and the solid will be an insulator. In semiconductor, the width of the energy gap is small, at ordinary room temperatures, a small proportion of electrons in the valence band have sufficient kinetic energy of thermal motion to cross the narrow energy gap and enter the conduction band above it. These electrons are sufficient to permit a limited amount of current to flow when an electric field is applied. Because of this, their band gap becomes smaller, and at a certain pressure they start behaving like metals. This study is based on the electronic band structure and density of states of silver halides and metal halides using the Full-Potential Linear Muffin -Tin Orbital (FP-LMTO) Method to explore their behaviour under different pressures [3,4].

2. Method of Calculation

Using the Full-Potential Linear Muffin-Tin Orbital (FP-LMTO) method, the electronic band structures of AgCl,AgBr,ZnSe and CdSe can be correctly calculated. The crystal structure of each material is rocksalt for AgCl and AgBr, Zinc-blende for ZnSe and Wurtzite for CdSe is used to develop the potential and energy bands [5,6]. The FP-LMTO method develop these compounds are wide-band gap at ambient conditions. When pressure is applied, the FP-LMTO band structures shows continuous band expanding, reduction of the energy gap and final overlap of the valence and conduction bands, representing metallization. In the FP-LMTO framework, applying external (hydrostatic) pressure primarily modifies the band structures and DOS of AgCl, AgBr, ZnSe, and CdSe through volume reduction, which enhances orbital overlap and changes hybridization. Although the figures present are at ambient pressure, the expected pressure trends are well understood and can be summarized. Within FP-LMTO, pressure is introduced by reducing the lattice constant and re-optimizing the self-consistent potential. This leads to:Increased overlap between neighboring atomic orbitals, Broader energy bands (larger dispersion), Shifts in band edges and redistribution of the density of states,Pressure-dependent changes in band gaps and, at sufficiently high pressure, possible electronic or structural phase transitions. Relation connecting lattice constant and reduced volume is given by

$$a = ao(Vo/V)^{1/3}$$

ao – lattice constant at *ambient* pressure [7,8].

*V/V*o – reduced volume

Relation connecting pressure and volume is given byMurnaghan's equation of state

$$P = 1.5B_0 \left[(V_0/V)^{7/3} - (V_0/V)^{5/3}\right] \left[1 + 0.75 (B_0^1 - 4) \{(V_0/V)^{2/3} - 1\}\right]$$

Relation connecting pressure and energy gap is given by [9]

$$Eg(P) = Eg(0) - KP$$

where

K- pressure coefficient of band gap.

Eg(P) -band gap at *ambient* pressure

Eg(0)-band gap at pressure

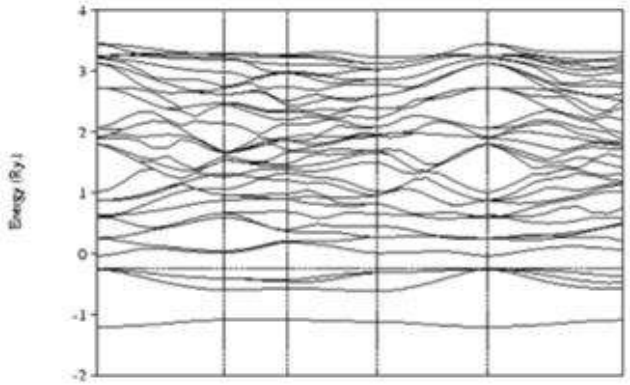


Fig 2.1. Band structure of Zinc selenide at ambient pressure

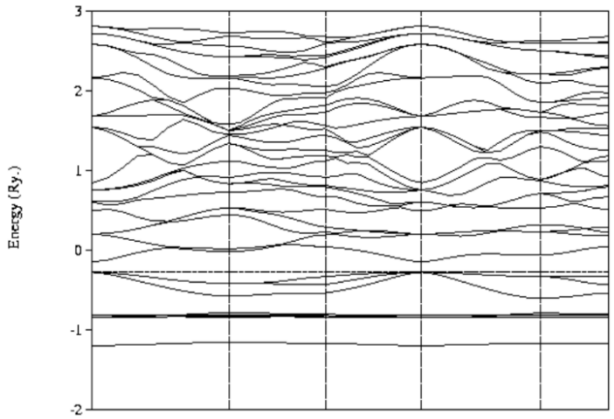


Fig 2.2. Band structure of cadmium selenide at ambient pressure

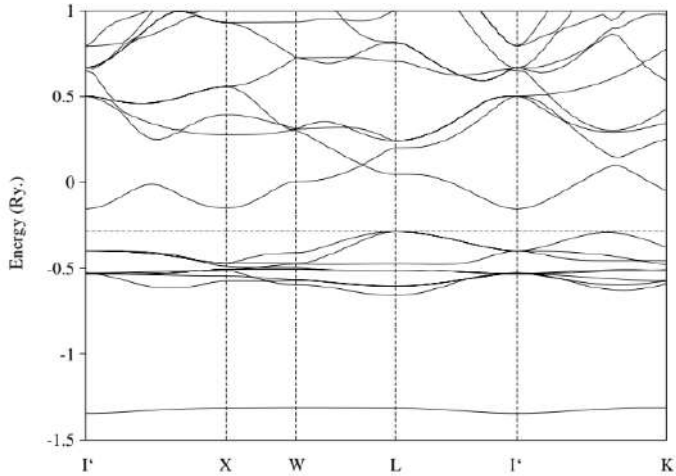


Fig.2.3. Band structure of silver chloride at ambient pressure

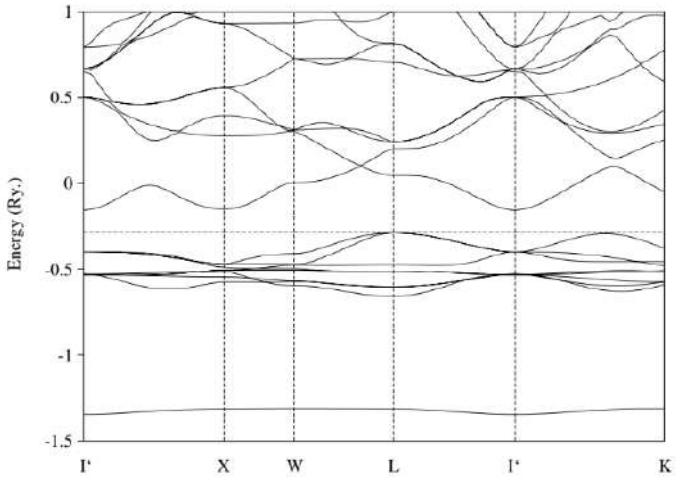


Fig.2.4. Band structure of silver bromide at ambient pressure

3. Band structure

Both AgCl and AgBr are indirect-gap ionic semiconductors at ambient pressure. Under compression, the Ag-4d states interact more strongly with halogen p states, enhancing p–d hybridization. Valence bands broaden and move upward in energy. Conduction band minima generally shift downward, leading to band-gap narrowing. The electronic configurations of Ag, Cl and Br are [Kr] $4d^{10}5s^1$ (Z = 47), [Ne] $3s^23p^5$ (Z = 17) and [Ar] $3d^{10}4s^24p^5$ (Z = 35) respectively. The valence electronic configurations chosen in our calculation are $5s^14d^{10}$ for Ag, $3s^23p^5$ for Cl and $4s^24p^5$ for Br. Throughout the calculation there are 18 valence electrons for silver chloride and silver bromide. This corresponds to nine bands in valence band [9]. ZnSe and CdSe have a direct band gap at Γ at ambient pressure. With increasing pressure, the conduction band minimum at Γ shifts upward or downward depending on the relative s–p coupling, but overall the band gap decreases. Enhanced interaction between cation d states (Zn-3d or Cd-4d) and anion p states causes p–d repulsion, pushing the valence band maximum upward. Band dispersion increases, reflecting stronger covalent bonding under compression.

4. Density of States

The density of states is defined as the number of electronic states present in a unit energy range. The number of orbitals per unit energy range is also called the density of states. As electron can occupy two spin states there are two quantum states for a single electron. Therefore, density of states for this case would be given by figures 3.1 to 3.4 respectively. DOS peaks become broader and less sharp due to increased bandwidth. Ag-d dominated states shift slightly toward the Fermi level, increasing their contribution near the valence band maximum. At sufficiently high pressure, FP-LMTO calculations typically predict gap closure and eventual pressure-induced metallization, often preceding or accompanying the known B1 → B2 (NaCl → CsCl) structural transition. The Density of States (DOS) of silver chloride, silver bromide, ZnSe and

CdSe indicates how many electron states are available at each energy level. In silver chloride and silver bromide, the valance band primarily comes from the halogen atoms, p-orbitals mingled with silver d-orbitals, while the conduction band comes mostly from silver s and p orbitals [9]. We now discuss the distribution of electrons among the allowed energy levels and determine the Fermi energy, total energy and the density of states. This creates a large energy gap among them, which makes these materials insulators at normal conditions [1,2].

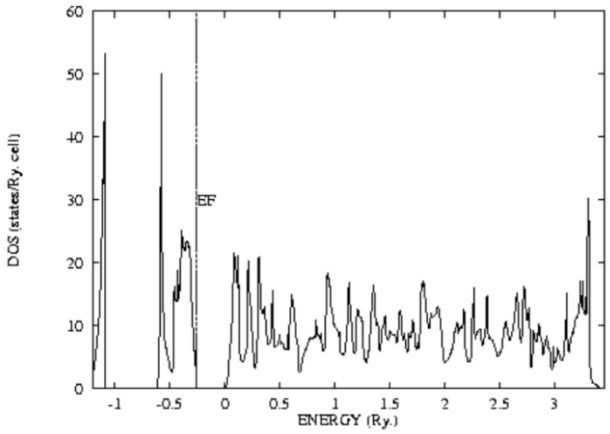


Fig.3.1. DOS of Zinc selenide at normal pressure

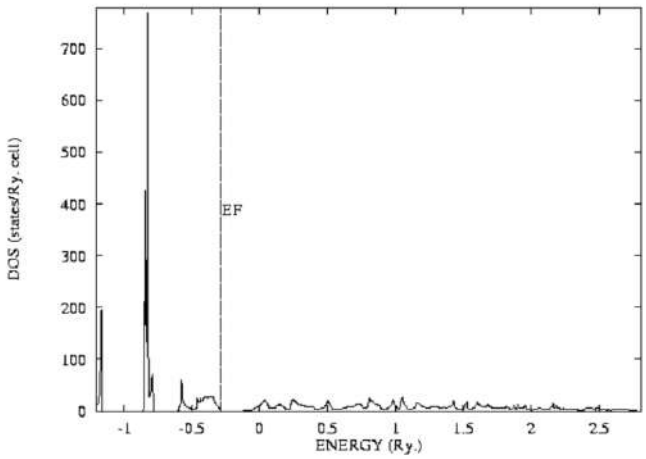


Fig.3.2. DOS of cadmium selenide at normal pressure

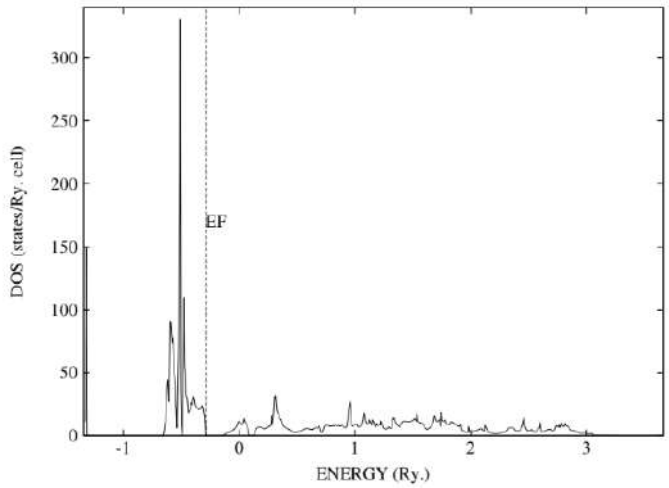


Fig.3.3. DOS of silver chloride at normal pressure

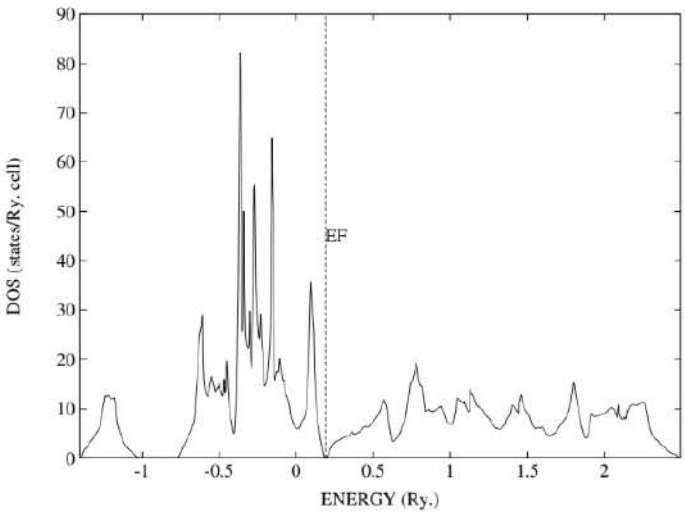


Fig.3.4. DOS of silver bromide at metallization

5. Ground State and its properties

In their ground state, silver chloride and silver bromide have a NaCl cubic structure and act as insulators caused by strong ionic bonding. ZnSe has a zinc-blende structure, and CdSe generally has a wurtzite structure, both are semiconductors and mostly covalent bonding. All four materials are non-metallic in their ground state, and their primary properties, structure, bonding, and band gap, stay unchanged at normal temperature and pressure. FP-LMTO total-energy calculations reliably capture both the sequence of pressure-induced phases and transition pressures, in close agreement with experimental and established theoretical studies.Comparison of metallizationand phase transition are given below

	Metallization		Phase transition	
Silver halide	P_M (Mbar)	$(V/V_0)_M$	P_T (Mbar)	$(V/V_0)_T$
AgCl	1.588	0.476	0.221	0.793
AgBr	1.393	0.488	0.183	0.808

Compound	Metallization		Phase transition	
	P_M Mbar	$(V/V_o)_M$	P_T Mbar	$(V/V_o)_T$
ZnSe	0.709	0.6860	0.1160	0.942
CdSe	0.663	0.6313	0.0312	0.967

6. Conclusion

In the present investigation, when a metal particle having bulk properties is reduced in size to a few hundred atoms, the density of states in the conduction band changes dramatically. The pressure dependent band structures and density of states of these materials are computed and the results are used to study the metallization under high pressure. The electron density of states in the conduction band is equal to that for free electrons. As a result the widths of the valence and empty conduction bands increase. These changes lead to the narrowing and closing of band gaps in these materials (metallization). These materials (silver chloride and silver bromide) clearly illustrate how pressure can strongly modify the electronic behaviour of ionic and semiconductor solids (zinc selenide and cadmium selenide)[9]. Phase purity and single-phase behavior are assumed only within the ambient-pressure stability range of each compound. These FP-LMTO outputs like band dispersion, DOS broadening, hybridization trends, charge delocalization, and Fermi-level DOS provide explicit, first-principles evidence that increased pressure enhances wavefunction overlap, broadens bands, and ultimately drives metallization.

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Structural and Optical Analysis of Zn-Doped Nio and Nio–Cr_2O_3 Nanocomposites Using Hydrothermal Synthesis for Electrochemical Applications

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ABSTRACT

Zn-doped NiO nanoparticles and NiO–Cr_2O_3 nanocomposites were successfully synthesized using hydrothermal synthesis method. Their structural, morphological and optical properties were successfully characterized and also investigated. Powder X-ray diffraction (PXRD) confirmed that the formation of cubic NiO with successful Zn incorporation and the composite formation of NiO–Cr_2O_3 without any impurity phases. Raman and Photoluminescence studies showed that defect-related vibrational and emission characteristics. The combined results highlight Zn-doped NiO and NiO–Cr_2O_3 nanocomposites as promising candidates for applications in optoelectronics, photo catalysis, sensing, and mainly for energy storage devices.

Keywords: *NiO-Cr2O3 nanocomposites, hydrothermal synthesis, PXRD, Photoluminescence, emission.*

1. **Introduction**

Transition metal oxides have gained a significant attention due to their excellent electrical, optical, thermal, and electrochemical characteristics [1,2]. Among them, Nickel Oxide (NiO) is a P-type semiconductor with a wide band gap (~3.6 eV), making it suitable for sensors, photocatalysis, supercapacitors, and optoelectronics [3,4]. Doping and nanocomposite formation are effective strategies to improve its intrinsic properties [5,6]. For Zn-doping, the ionic radius mismatch between Zn^{2+} and Ni^{2+} ions induce lattice distortion and strain, leading to the generation of defect states such as nickel vacancies and oxygen interstitials. These defects play a key role in defect chemistry by increasing hole concentration, thereby enhancing the p-type conductivity of NiO. Substitutional doping modifies the host lattice at the atomic level, directly tuning the electronic structure and charge carrier density. In contrast, the incorporation of Cr_2O_3 primarily results in composite or heterostructure formation, where the fundamental distinction lies in the creation of interfaces rather than lattice substitution. The NiO/Cr_2O_3 heterojunction facilitates efficient charge transfer across the interface, suppresses

charge recombination, and provides additional active sites, leading to improved catalytic and electrochemical behaviour [7,8].

2. Materials and Methods

2.1 Chemicals

Analytical graded (Sigma Aldrich) purchased Nickel (II) nitrate hexahydrate ($Ni(NO_3)_2 \cdot 6H_2O$), zinc nitrate hexahydrate ($Zn(NO_3)_2 \cdot 6H_2O$), chromium(III) nitrate ($Cr(NO_3)_3$), sodium hydroxide (NaOH), ethanol, and double-distilled water were used without further purification.

2.2 Synthesis of Zn-doped NiO nanoparticles

Stoichiometric solutions of nickel nitrate (0.5M in 50 ml) and zinc nitrate (0.5M in 50 ml) were prepared independently and then mixed thoroughly. Precipitation was induced using NaOH to maintain pH 10. The mixture was subjected to hydrothermal treatment at 150 °C for 16 hours. The precipitate was washed, dried, and calcined at 400 °C to obtain Zn-doped NiO.

2.3 Synthesis of NiO–Cr_2O_3 Nanocomposites

Initially, a NiO precursor (1 g) was synthesized. Chromium nitrate (0.5M in 100 ml) was then mixed with this precursor, followed by hydrothermal treatment under similar conditions. The resulting product was calcined at 500 °C to yield the NiO–Cr_2O_3 composite.

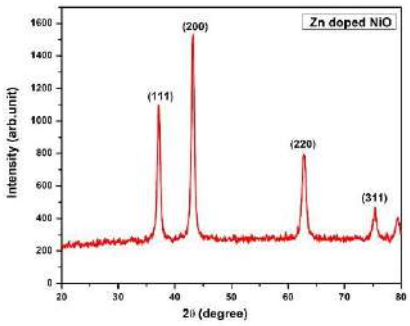
3. Structural Analysis

3.1 PXRD Analysis

The structural characterization of the Zn-doped NiO nanoparticles and NiO–Cr_2O_3 nanocomposites was investigated by recording the powder X-ray diffraction (PXRD) spectra using X-ray diffractometer. The crystal grain size can be quantitatively estimated using the Scherrer equation and the diffraction peak broadening in the XRD curves.

$$D = 0.9\,\lambda / \beta \cos\theta$$

where λ is the wavelength of the Cu- K_α radiation [1.54060 Å], β is the full width half maximum of the diffraction line and θ is the angle of diffraction. PXRD confirmed peaks corresponding to (111), (101), (220), and (311) planes for Zn-doped NiO (JCPDS No. 78-0429 for pure NiO, JCPDS No.63-3358 for Zn doped NiO). NiO–Cr_2O_3 displayed peaks of both oxides, confirming composite formation (JCPDS No.38-1479 for Cr_2O_3). Crystallite sizes calculated using the Scherrer formula ranged between 20–35 nm. Similar PXRD behaviour has been reported by Das and Roy, who observed peak broadening and slight peak shifts in Zn-incorporated NiO due to lattice strain and reduced crystallite size [4]. Likewise, Li et al. documented that NiO–Cr_2O_3 nanocomposites typically exhibit distinct diffraction patterns of both components, confirming composite formation, consistent with the results obtained in this study [8].



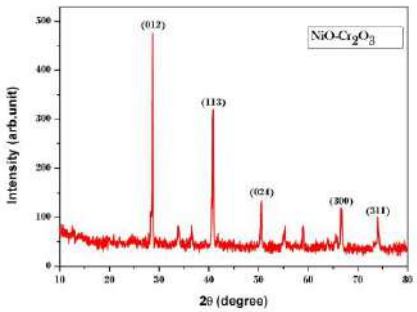
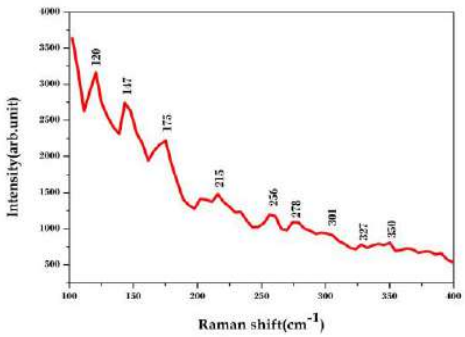


Fig. 1: PXRD pattern of Zn-doped NiO **Fig. 2: PXRD Pattern of NiO-Cr_2O_3 Nanocomposites**

3.2 Raman Spectroscopy

NiO–Cr_2O_3 exhibited Cr–O modes. Raman spectra of Zn-doped NiO showed characteristic Ni–O vibrational modes at 152, 244, 476, 1066, and 1414 cm^{-1}, indicating lattice distortions induced by Zn incorporation. Additional peaks in NiO–Cr_2O_3 corresponded to Cr–O stretching modes, confirming successful composite formation and structural coupling between the phases. Similar Raman modes associated with defect-induced Ni–O vibrations in Zn-doped NiO have been reported by Wang and Zhao, who attributed peak shifts to lattice strain and defect formation [7]. Additionally, Prakash et al. documented Cr–O vibrational features in NiO–Cr_2O_3 nanocomposites, supporting the interpretation of composite-related Raman enhancements observed in this work [6].



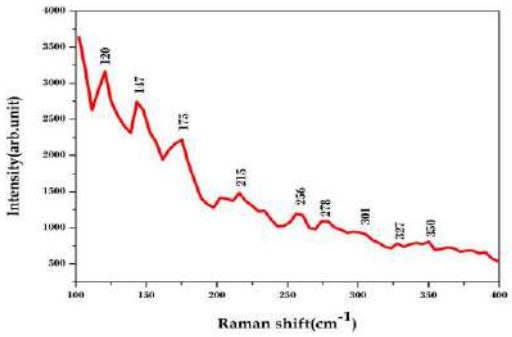


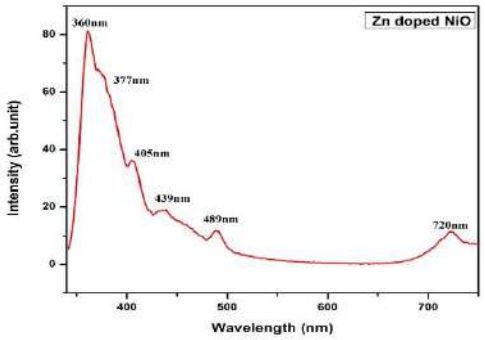
Fig. 3: Raman Spectra of Zn doped NiO **Fig. 4: Raman Spectra of NiO-Cr_2O_3 Nanocomposites**

4. Optical Analysis

4.1 Photoluminescence

The PL emission spectrum of Zn-doped NiO exhibited peaks at 360, 377, 405, 449, 489, and 720 nm, corresponding to excitonic transitions and deep-level defects such as oxygen vacancies, zinc substitutional sites, and lattice distortions [5]. NiO–Cr_2O_3 nanocomposites

showed broader and more intense emissions, attributed to interfacial defects and enhanced electron–phonon coupling. Chen et al. similarly reported that Zn-doping in NiO introduces multiple defect-related PL bands due to enhanced oxygen vacancy concentration [5]. Furthermore, Kumar and Singh observed broad-band emission in NiO-based composites resulting from heterogeneous interfaces, which aligns with the increased PL intensity seen in the NiO–Cr_2O_3 system [2].



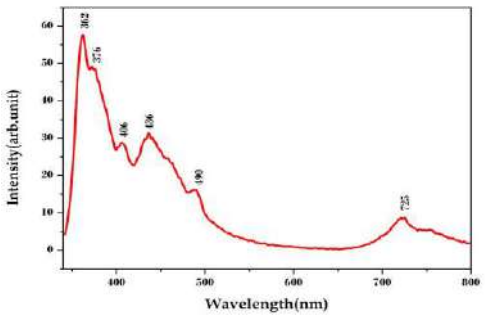


Fig. 5: PL emission of Zn-doped NiO Fig. 6: PL emission of NiO-Cr_2O_3 Nanocomposites

5. Summary and Conclusion

Zn-doped NiO nanoparticles and NiO–Cr_2O_3 nanocomposites were successfully synthesized using a hydrothermal route. PXRD confirmed phase purity and controlled crystallite size, while Raman and PL studies revealed significant defect-related features and interfacial vibrational modes. The optical responses of both materials highlight their strong potential for use in optoelectronic, photocatalytic, and sensing applications. Incorporation of Zn and Cr_2O_3 significantly improves the structural integrity and optical behavior of NiO, thereby providing effective routes to enhance material performance for advanced technological applications.

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Eco-Friendly Synthesis of Activated Carbon Nanoparticles from Cocoa Bean pod husk: Study Structural, Optical, and Photocatalytic property

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ABSTRACT

Activated carbon nanoparticles (ACNPs) were synthesized from agricultural waste (cocoa bean pod husk) using a cost-effective and environmentally friendly method. Structural, morphological, elemental, and photocatalytic studies were carried out for the prepared samples. XRD analysis confirmed the successful formation of nanosized cocoa bean–derived activated carbon with a predominantly amorphous structure containing minor graphitic domains. SEM images revealed that the ACNPs possess a highly porous, rough, and irregular surface morphology with visible micropores and mesopores. UV–Visible analysis showed a strong absorption peak at 467 nm, and the optical band gap was estimated to be 2.66 eV, indicating semiconducting behaviour. EDAX analysis confirmed that the material is primarily composed of carbon, indicating successful carbonization of the biomass precursor. Photocatalytic studies demonstrated that the cocoa bean ACNPs efficiently degrade methylene blue dye, highlighting their potential for environmental remediation applications.

Keywords: *Activated carbon nanoparticles, Cocoa been pod husk, Chemical activation, Optical band gap, Photocatalytic degradation, Methylene blue.*

1. Introduction

In the current global scenario, there is increasing emphasis on producing renewable and sustainable materials from waste due to their low cost and environmental benefits [7,9]. Activated carbon can be prepared from cocoa bean pod husk, an agricultural waste material rich in cellulose, hemicellulose, and lignin. Owing to its eco-friendly nature and abundant availability, cocoa bean husk serves as an excellent precursor for the preparation of activated carbon [1,8].

Activated carbon nanoparticles (ACNPs) have wide applications in environmental and energy-related fields, including water purification, catalysis, and energy storage [2,11]. ACNPs exhibit high charge storage capacity and rapid ion transport due to their nanoscale architecture, which enhances electron transfer efficiency [10,13]. These properties make them promising candidates for next-generation energy storage devices.

Additionally, carbon-based nanomaterials are generally considered biocompatible and relatively less toxic compared to many metal-based nanoparticles [3,9]. This makes them suitable for biomedical applications such as drug delivery, imaging, and biosensing [9]. The present study

focuses on the preparation of ACNPs from cocoa bean pod husk and confirms the successful formation of carbon nanoparticles. Utilizing biomass waste for ACNP production helps reduce agricultural residue burning, a major source of environmental pollution. Instead of being discarded, these wastes are converted into value-added nanomaterials, supporting circular economy practices and green chemistry principles [7,12].

2. Material and Method

Activated carbon nanoparticles (ACNPs) were synthesized from cocoa bean pod husk (Theobroma cacao), a naturally available, renewable, and eco-friendly biomass precursor. The synthesis method was selected based on sustainability, cost-effectiveness, and efficiency in achieving high surface area, porosity, and adsorption capacity. The overall process included pre-treatment, carbonization, chemical activation, washing, and drying.



Cocoa Bean Pod Husk

2.1 Materials

Biomass Precursor

Cocoa bean pod husks were collected directly from local farmers.

Chemical Reagents

- Potassium hydroxide (KOH) pellets (activating agent)
- Diluted hydrochloric acid (HCl, 0.1–1 M)
- Distilled water

Apparatus and Equipment

- Muffle furnace (up to 1000 °C)
- Hot air oven (up to 100 °C)

- Mortar and pestle or mechanical grinder
- Crucibles

Method

Pre-treatment and Sun drying

Cocoa bean pod husk was washed with water to remove soil and surface contaminant, then cut into small pieces. Bio mass sample was spread evenly on a tray and Sun dried for 10-14 days under the direct sunlight. The sample was uniformly dried until they became brittle and completely moisture free. The dry weight was measured to facilitate yield and conversion efficiency calculation.

Carbonization

The dried sample was subjected to thermal carbonization to convert the organic matter into carbon rich biochar. The dried samples was loaded into crucible. It was placed in a muffle furnace heated at a controlled rate of 5-10°c/min, maintained at 800°c for 2 hour. After carbonization the sample was allowed to cool gradually until it reaches room temperature.

Chemical activation with KOH as activating agent

The chemical activation is important step to enhance the porosity, surface area and adsorption capability for the carbonized material.

Grinding

The carbon biochar was finely ground using a motor and pestle to enhance uniform particle size and increase surface area for the sample

Impregnation

The powder sample was mixed with KOH in a 1:3 mass ratio (biochar: KOH) for 1g of biochar was mixed with 3g of KOH pellets add enough distilled water to soak for 6-12 hour which was left undisturbed.

Washing and Neutralization

After activation the sample was roughly washed with diluted HCl to remove the residue alkaline and inorganic compounds. The sample was washed until the pH is 7, confirmed neutrality and removal of soluble impurities.

Drying and Storage

The Neutralized sample was dried in a hot air oven at 100°c for 3 to 4 hours until completely moisture free. The finally dried sample mass was recorded to evaluate the overall yield of cocoa bean activated carbon.

3. Characterization Techniques

The structural, morphological, optical, and elemental properties of the synthesized cocoa bean pod husk–derived activated carbon nanoparticles (ACNPs) were analyzed using the following characterization techniques:

X-ray Diffraction (XRD)

XRD analysis was performed to determine the crystalline structure, phase composition, and average crystallite size of the synthesized activated carbon nanoparticles.

Scanning Electron Microscopy (SEM)

SEM was employed to examine the surface morphology, particle distribution, and porous structure of the prepared ACNPs.

UV–Visible Spectroscopy (UV–Vis)

UV–Vis spectroscopy was used to investigate the optical absorption behavior of the samples and to estimate the optical band gap energy using the Tauc plot method.

Energy Dispersive X-ray Analysis (EDAX)

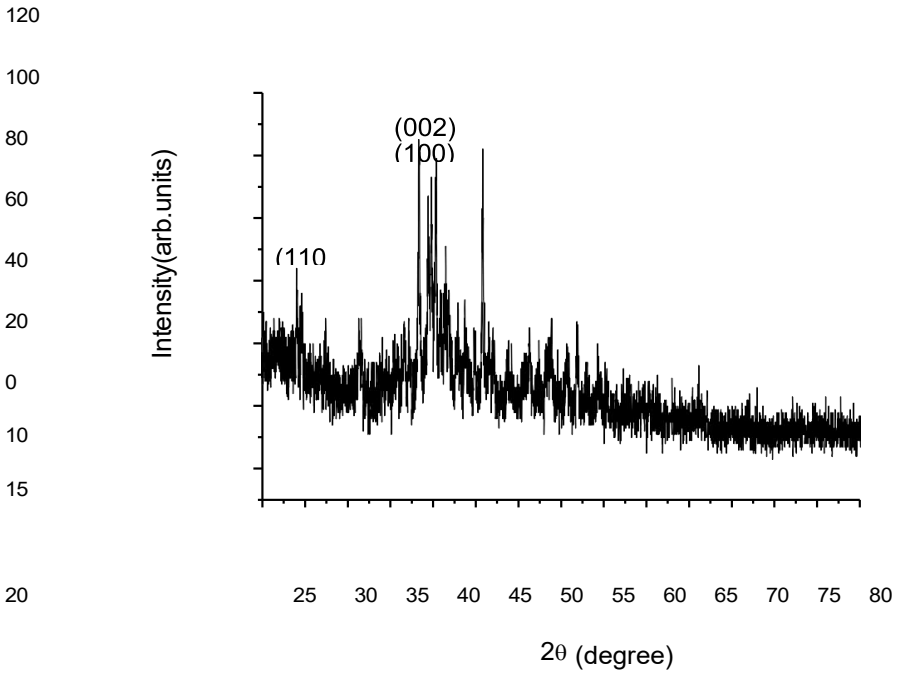
EDAX analysis was carried out to determine the elemental composition and confirm the presence of carbon as the primary constituent of the synthesized material.

Photocatalytic Degradation Studies

Photocatalytic experiments were conducted to evaluate the dye degradation efficiency of the ACNPs under light irradiation using methylene blue as a model pollutant.

3. 4. 1 X-Ray Diffraction

X-ray diffraction (XRD) analysis was carried out to investigate the crystalline nature and structural characteristics of the synthesized cocoa bean–derived activated carbon nanoparticles (ACNPs). The XRD pattern was recorded using Cu-Kα radiation (λ = 1.5406 Å) over a suitable 2θ range.

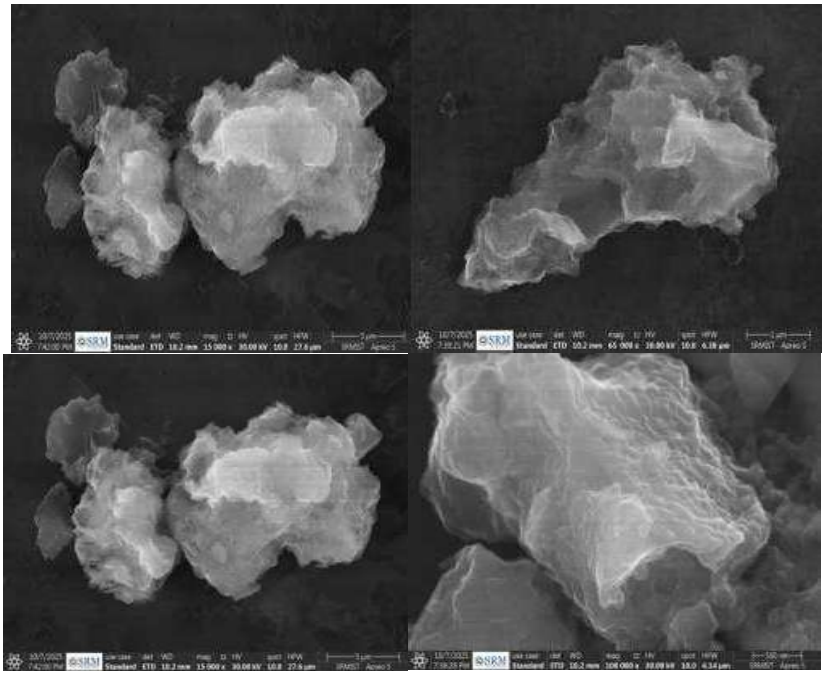


4. 2 Scanning Electron Microscope (Sem)

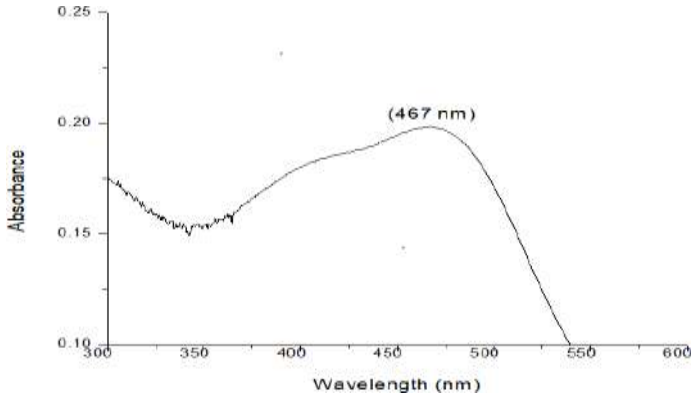
SEM images of the cocoa bean pod husk–derived activated carbon nanoparticles (ACNPs) reveal a highly porous and non-uniform surface morphology. The micrographs show the formation of well-developed porous networks, indicating that the activated carbon particles possess irregular shapes with agglomerated nanoclusters.

The chemical activation process plays a crucial role in pore development by partially removing the carbon framework, thereby generating a large number of micro- and mesopores. The surface appears rough and wrinkled, which may be attributed to the increased number of surface defects and active sites created during activation.

The presence of numerous microcavities enhances the adsorption capacity of the material by providing abundant active sites for dye molecules. Furthermore, the porous architecture facilitates effective light penetration, which is essential for photocatalytic dye degradation applications. Overall, SEM analysis confirms the successful formation of a highly porous nanostructured activated carbon material suitable for environmental remediation applications.



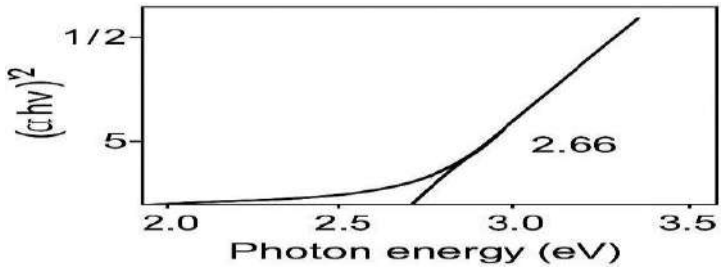
4.3 UV–Visible Analysis and Band Gap Determination



The UV–Visible absorption spectrum of the cocoa bean–derived activated carbon nanoparticles (ACNPs) was recorded in the wavelength range of 300–600 nm to investigate their optical properties. The spectrum exhibits a prominent absorption peak at 467 nm, indicating strong light absorption in the visible region.

The observed absorption in the visible range suggests the presence of π–π* transitions associated with conjugated carbon structures and possible defect-induced energy states within the carbon framework. The enhanced visible light absorption behaviour may be attributed to the presence of surface functional groups, structural defects, and partial graphitic domains formed during the carbonization and activation processes.

The strong absorption at 467 nm confirms the material's ability to interact effectively with visible light, which is a crucial requirement for photocatalytic dye degradation applications. This optical behaviour supports the band gap value obtained from the Tauc plot and demonstrates the suitability of the synthesized ACNPs for environmental remediation under visible light irradiation.



The optical band gap of the cocoa bean–derived activated carbon nanoparticles (ACNPs) was determined using UV–Visible spectroscopy. The band gap energy was estimated from the Tauc plot assuming a direct allowed transition. From the linear portion of the plot, the band gap energy was calculated by extrapolating the straight-line region to intersect the photon energy axis. The estimated optical band gap value was found to be 2.66 eV.

The relatively narrow band gap indicates that the synthesized ACNPs can effectively absorb visible light, making them suitable for photocatalytic dye degradation applications. The enhanced light absorption behaviour may be attributed to the presence of defect states and partial graphitic domains within the carbon structure. Thus, the UV–Visible analysis confirms that the prepared activated carbon nanoparticles exhibit promising optical properties for environmental remediation applications.

4. 4 Energy Dispersive X-ray Analysis (EDAX)

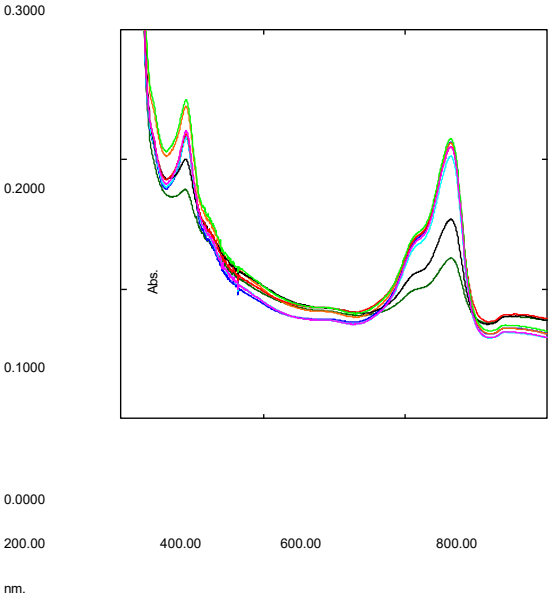
Energy Dispersive X-ray Analysis (EDAX) was performed to determine the elemental composition of the synthesized cocoa bean–derived activated carbon nanoparticles (ACNPs). The EDAX spectrum exhibits a strong and dominant peak corresponding to carbon (C), confirming that the material is primarily composed of carbon.

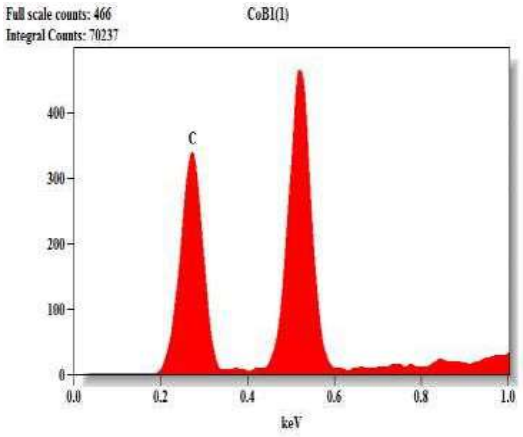
The intense carbon peak indicates successful carbonization of the cocoa bean pod husk biomass. Minor peaks, if present, may be attributed to trace elements or residual impurities originating from the precursor material or activation process. However, the absence of significant impurity peaks demonstrates the high purity of the prepared activated carbon.

The EDAX results validate the effective removal of non-carbonaceous components during carbonization and chemical activation. Overall, the analysis confirms the successful synthesis of carbon-rich activated carbon nanoparticles suitable for environmental and photocatalytic applications.

4. 5 Photocatalytic Degradation

Photocatalytic activity refers to the ability of a material (photocatalyst) to accelerate a chemical reaction in the presence of light. When the photocatalyst is irradiated with light energy equal to or greater than its band gap energy, electron–hole pairs are generated. These charge carriers migrate to the surface and participate in redox reactions.





In dye degradation studies (e.g., methylene blue or methyl violet):

1. Light irradiation excites electrons (e^-) from the valence band (VB) to the conduction band (CB), leaving behind holes (h^+).
2. The photogenerated electrons react with dissolved oxygen (O_2) to form superoxide radicals ($\bullet O_2^-$).
3. The holes react with water or hydroxide ions (OH^-) to produce hydroxyl radicals ($\bullet OH$).
4. These reactive oxygen species (ROS) degrade organic dye molecules into smaller, harmless products such as CO_2 and H_2O.

The photocatalytic efficiency is typically evaluated by:

$$\text{Degradation (\%)} = C0 - Ct/Co \times 100$$

Using 0.01 g of cocoa bean pod husk–derived activated carbon nanoparticles achieved complete degradation of 100 mL of methylene blue solution within 85 minutes.

4. Conclusion

Eco-friendly activated carbon nanoparticles (ACNPs) were successfully synthesized from

cocoa bean pod husk through carbonization followed by chemical activation. XRD analysis confirmed the polycrystalline nature of the prepared ACNPs. UV–Vis spectroscopy revealed characteristic absorption peaks, and the Tauc plot indicated the semiconducting behavior of the material. SEM analysis demonstrated a highly porous surface morphology, while EDAX confirmed the predominant presence of carbon. Owing to its high porosity and favorable structural properties, cocoa bean pod husk–derived ACNPs exhibit promising potential for dye degradation applications.

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Growth and Characterization of L-Threonine coordination complexes for Device Fabrication

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ABSTRACT

This study establishes the pivotal influence of metal cation engineering on modulating the structural, optical, and electrical properties of L-threonine–based crystalline materials. Sodium (Na^+) and magnesium (Mg^{2+}) complexes were synthesized in a 1:1 stoichiometric ratio through an optimized slow-evaporation method, enabling a systematic comparison of their structure property relationships. Single-crystal analysis reveals two distinct crystallographic architectures directed by the nature of the metal cation. The Na^+ complex adopts a highly anisotropic 2D layered structure (a = 13.611 Å, b = 5.792 Å, c = 1.738 Å), where the large, monovalent cation promotes extensive hydrogen-bonded networks acting as an ionic scaffold. Conversely, the Mg^{2+} complex forms a rigid 3D coordination framework (a = 5.255 Å, b = 13.02 Å, c = 7.822 Å), driven by strong coordinate covalent bonding between the small, divalent cation and ligand sites. These structural divergences manifest directly in their optical behaviour: the 2D Na^+ complex exhibits a narrower band gap (5.6 eV) relative to the 3D Mg^{2+} framework (5.9 eV), attributed to higher electron delocalization across layered planes.

***Keywords**: L-Threonine; Sodium; Magnesium; Coordination complex; Crystal growth.*

1. Introduction

Conventional crystal growth techniques often enhance specific empirical properties, leading to optimized product quality, greater application efficiency, cost-effectiveness, and improved usability. Among the essential characteristics for developing high-grade crystals are physicochemical and Nonlinear Optical (NLO) properties, which are crucial for use in devices such as light emitters, dosimeters, photonics, electro-optical components, and semiconductors [1]. Current research focuses on producing nonlinear photonic crystals with properties like a lower UV cutoff, broader transmittance range, greater nonlinearity, higher damage threshold, and suitable thermal and mechanical properties. To achieve these, pure organic and inorganic materials have been combined, with recent emphasis on organic crystals due to their lower cost, faster nonlinear response across frequencies, and higher optical damage threshold [2, 3]. However, organic crystals are limited by volatility, low thermal stability, and weak mechanical properties [4]. To address these limitations, organometallic crystals, introduced in the 1960s for optoelectronic applications, combine the advantages of organic and inorganic crystals. These materials are created by integrating inorganic distorted polyhedrons with asymmetric organic molecules [1]. This design imparts high optical nonlinearity, mechanical flexibility, temporal and thermal stability, and enhanced transmittance compared to purely organic or

inorganic crystals. Additionally, organometallic materials offer unique metal-ligand and intra-ligand charge transfer, making them highly suitable for NLO applications [5].

Synthesis and characterization of amino acid crystal was found in the report with different solvents such as methonal and ethonal and the synthesis process of slow cooling method. In this paper we report the growth of L-Threonine with Sodium and Magnesium single crystal at the room temperature and analyzed the structural and optical behaviour. It provides the method of the synthesis, properties, growth parameters, and significant characteristics of the crystals. The novelty of the present work lies in the systematic investigation of how different metal cations influence the crystal structure and resulting optical properties of L-threonine coordination complexes. While earlier studies have mainly focused on the synthesis or isolated characterization of amino acid–based crystals, the current study provides a direct comparative analysis of Na^+ and Mg^{2+} complexes grown under identical conditions. This approach reveals clear correlations between metal-ion–directed structural architecture (2D layered vs. 3D framework) and functional properties such as band gap and optical behavior. Such an explicit structure–property relationship has not been previously reported for L-threonine complexes and offers new insights for designing amino acid–based materials for device fabrication.

2. Experimental Details

2.1. Growth Kinematics

The material processing on the crystal growth of metal complex involves high purity starting materials. All the chemicals such as L-Threonine ($C_4H_9NO_3$), Sodium Acetate Anhydrous (CH_3COONa) and Magnesium Acetate Tetrahydrate ($(CH_3COO)_2 Mg{\cdot}4H_2O$) were used directly without purification. The laboratory grade deionised water was used as the solvent.

The preparation of saturated solution is a combined process of solution preparation and crystal growth, optimized for a synthesis process. In reaction mixture preparation, 1:1 molar ratio of L-Threonine to the respective metal acetate was used. The precise masses were dissolved directly in 25 ml of deionized water in a 100 ml.

- For Sodium Complex: L-Threonine (2.98 g) + Sodium Acetate (2.05 g) in 25 ml H_2O.
- For Magnesium Complex: L-Threonine (2.98 g) + Magnesium Acetate Tetrahydrate (5.36 g) in 25 ml H_2O.

A magnetic stir bar was added, and the flask was placed on a hotplate stirrer. The mixture was heated to 50-60°C with constant stirring at ~300 rpm for 6 hours. This extended period ensured complete dissolution and promoted the molecular-level interaction necessary for complex formation in solution. The hot, clear solution was promptly filtered using a pre-warmed funnel and Whatman No. 1 filter paper. The filtered flask was loosely sealed with perforated parafilm to allow for controlled evaporation. Crystals of the metal complexes typically appeared within 10-15 days.

2.2. Growth of Sodium Acetate Complex of L-Threonine

The synthesis aimed to directly grow the L-Threonine Sodium Acetate complex crystal. The 1:1 molar ratio in 25 ml of water, was designed to force the co-crystallization of both components into a new molecular complex. The growth of Na^+ and L-Threonine crystals with

the stoichiometric 1:1 ratio and concentrated volume in a conical flask were specific optimizations to yield the distinct complex as the primary crystalline phase, which was confirmed by the subsequent single-crystal XRD analysis revealing a novel layered structure.

2.3. Growth of Magnesium Acetate Complex of L-Threonine

Similarly, the L-Threonine Magnesium Acetate complex was synthesized directly. The use of a stoichiometric 1:1 ratio in 25 ml of water was critical. By employing a synthesis condition that favors the formation of a pure coordination polymer phase. The conical flask setup provided an ideal environment for the slow concentration of the solution, facilitating the nucleation and growth of the robust, blocky crystals of the 3D framework structure.

After the growth period (10-15 days), well-formed crystals were observed at the bottom of the conical flasks. The mother liquor was carefully decanted, and the crystals were manually retrieved using non-metallic tweezers to prevent damage. Crystals were briefly rinsed with a few drops of a cold 1:1 water: acetone mixture to remove surface impurities without dissolving them.

2.4. Characterization

The grown crystals were subjected to the characterization such as single crystal X-ray Diffraction (XRD), linear and non-linear optical studies and Fourier Transform Infrared (FTIR) studies. Single crystal X-ray diffraction analysis was carried out using a Bruker AXS diffractometer with MoKα (λ=0.7170 **Å**) radiation to identify the lattice parameters. The optical absorbance spectrum of the crystal was recorded in the spectral range between 200-1200 nm using the ELICO model UV spectrophotometer. Optical band gap of the grown crystals are estimated from the following relation:

$$Eg = hc / \lambda$$

3. Results and Discussion

3.1. Visual Observation and Morphological Study of Grown Crystals

The synthesis of L-Threonine metal complexes via slow evaporation yielded high-quality single crystals suitable for characterization. A distinct morphological difference was observed between the two compounds, indicative of their underlying structural anisotropy.

The L-Threonine Sodium Acetate complex crystallized as thin, plate-like crystals. This habit is characteristic of materials with strongly layered structures, where crystal growth proceeds much more rapidly in two dimensions compared to the third. The plate face corresponds to the large a-b plane, while the short c-axis (1.738 Å) defines the thin dimension of the plate. This observation aligns with the well-documented phenomenon where anisotropic bonding forces manifest in crystal habit.

In contrast, the L-Threonine Magnesium Acetate complex formed more blocky, prismatic crystals. This equant morphology suggests relatively isotropic growth rates in all three crystallographic directions, which is consistent with its three-dimensional framework structure were strong, directional coordinate covalent bonds form in a more balanced network throughout the lattice. Similar correlations between coordination polymer formation and blocky crystal habits have been noted in other coordination systems.

3.2 Single crystal X-Ray Diffraction Analysis

XRD analysis confirmed the crystalline nature of both complexes and provided quantitative structural parameters that elucidate the fundamental architectural differences between them. Both compounds crystallize in the orthorhombic crystal system, but with vastly different lattice parameters and dimensionalities.

Table 1: Crystallographic Parameters of L-Threonine Metal Complexes

Parameter	L-Threonine Sodium Acetate	L-Threonine Magnesium Acetate
Crystal System	Orthorhombic	Orthorhombic
a (Å)	13.611	5.255
b (Å)	5.792	13.02
c (Å)	**1.738**	7.822
α=β=γ	90°	90°
Unit Cell Volume (Å³)	137.1	535.2

The most striking feature is the extreme anisotropy of the Sodium complex, characterized by a very long a-axis (13.611 Å) and an exceptionally short c-axis (1.738 Å). This c-axis length is commensurate with the thickness of a single molecular layer, unambiguously confirming a monolayer-like, 2D layered structure. The long a-axis accommodates the L-Threonine and acetate moieties within the sheet.

Conversely, the Magnesium complex exhibits more balanced lattice parameters and a significantly larger unit cell volume. The absence of an extremely short axis and the substantial cell volume are characteristic of a three-dimensional coordination polymer. This signifies a complete reconstruction of the crystal packing, driven by the different coordination chemistry of Mg^{2+} compared to Na^{+}. The Mg^{2} ion, with its high charge density, favours a well-defined octahedral coordination geometry, acting as a structural node that propagates connectivity in three dimensions, as observed in similar coordination compounds.

3.3 FTIR Spectroscopic Analysis

FTIR spectroscopy was employed to confirm the chemical identity of the complexes and to investigate the nature of the metal-ligand interactions. The spectra of both complexes showed characteristic vibrational modes of the L-Threonine and acetate ions, with key shifts indicating successful complexation and differences in the bonding environment.

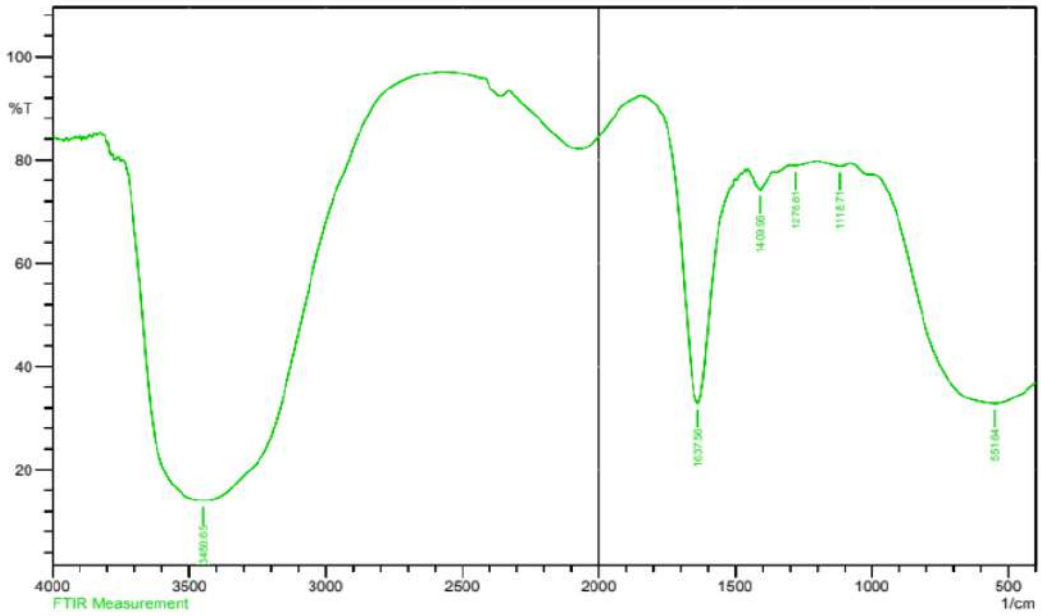


Fig. 1. FTIR spectra of L-Threonine Sodium Acetate

The FTIR Fig.1 shows features consistent with L-threonine in its carboxylate (salt) form and with sodium acetate present, plus hydrogen-bonding/water. The broad strong band centered near **~3400 cm⁻¹** is from O–H and N–H stretching. The **absence of a sharp C=O band near 1700 cm⁻¹** and instead a strong band at **~1638 cm⁻¹** indicates the carboxyl group is present as **COO^- (asymmetric stretch)** rather than protonated COOH. The band at **~1401 cm⁻¹** corresponds to the **symmetric COO^- stretch**. Peaks in the 1200–1000 cm^{-1} region can be assigned to C–N/C–O stretching modes the **1119 cm⁻¹** is consistent with C–O stretching of the threonine side-chain, and ~1278 cm^{-1} can include C–N stretching or C–O contributions. The weak feature around **~615 cm⁻¹** is from skeletal/out-of-plane bending vibrations.

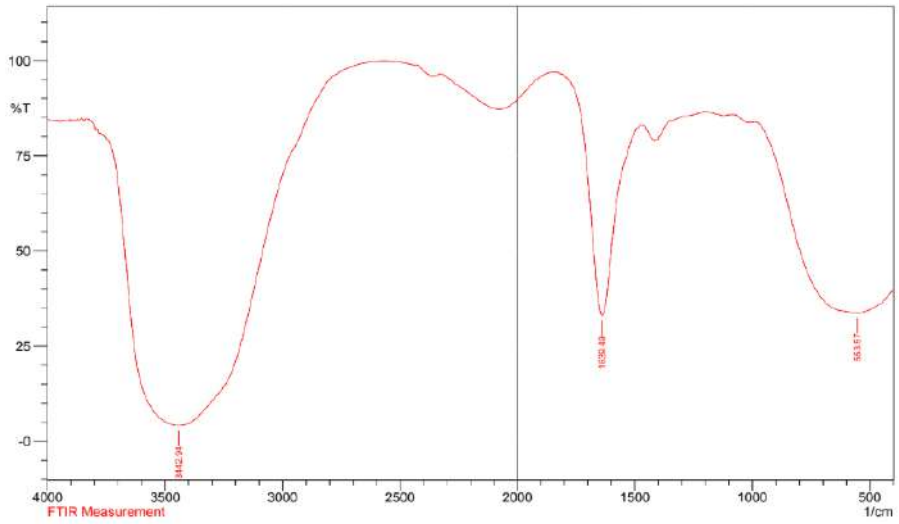


Fig. 2. FTIR spectra of L-Threonine Magnesium Acetate

The FTIR spectrum of **L-Threonine Magnesium Acetate** in fig. 4.2 exhibits characteristic absorption bands confirming the formation of a coordination complex between L-threonine and magnesium acetate. A **broad band around ~3400 cm⁻¹** corresponds to the overlapping **O–H stretching** vibrations of the threonine side-chain hydroxyl group and **N–H stretching** vibrations from the amino group, indicating strong hydrogen bonding and coordination with Mg^{2+}. The **strong band near ~1635 cm⁻¹** is attributed to the **asymmetric stretching vibration of the carboxylate group (COO^-)**, while the **band at ~1400 cm⁻¹** represents the **symmetric COO^- stretch.** The separation between these two peaks confirms that the carboxylate group is coordinated to the magnesium ion rather than existing as a free acid. Bands in the region **1270–1120 cm⁻¹** arise from **C–N and C–O stretching vibrations**, suggesting interaction between the amino and hydroxyl groups with the metal center. The **band near 550–600 cm⁻¹** corresponds to **Mg–O stretching vibrations**, confirming the formation of a magnesium–oxygen coordination bond.

3.4 UV-Visible Spectral Analysis

UV-Vis spectroscopy was used to probe the electronic structures and estimate the optical band gaps of the synthesized complexes. The absorption spectra revealed significant differences in transparency and electronic transition energies, directly linked to their structural disparities.

Both complexes are transparent in the visible region but absorb strongly in the UV-C range due to $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$ transitions within the organic ligands. However, the onset of absorption and the spectral profile differ markedly.

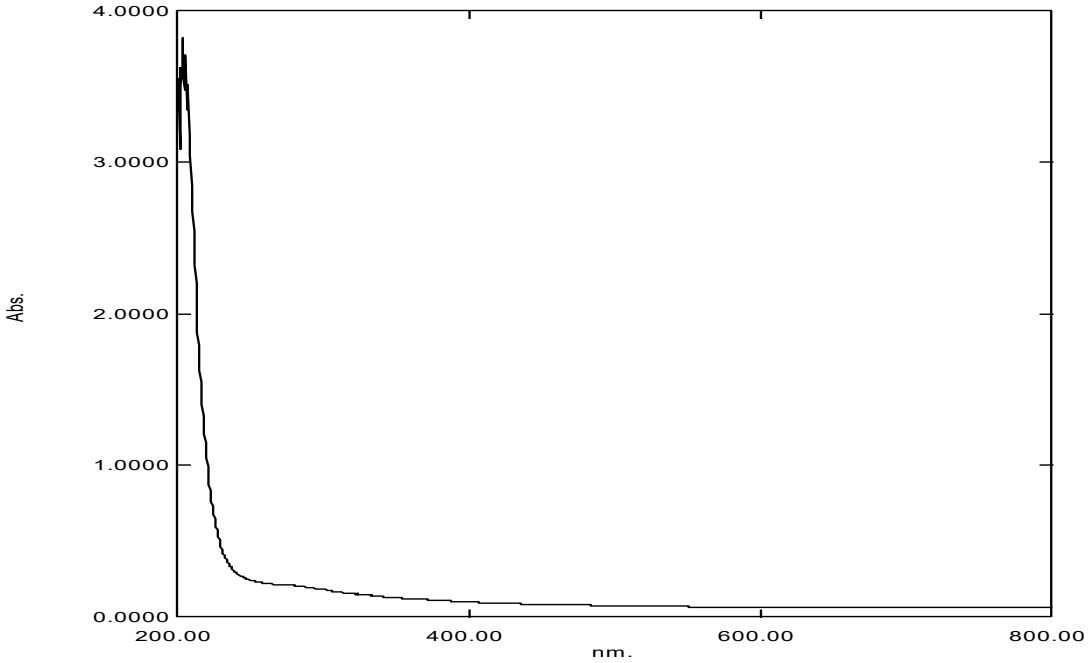


Fig. 3. UV absorbance spectra of L-Threonine Sodium Acetate

The L-Threonine Sodium Acetate complex exhibited an absorption onset at approximately 220 nm, corresponding to an estimated optical band gap of 5.6 eV. Its absorption edge was broad and relatively unstructured shown in Fig. 3.

The L-Threonine Magnesium Acetate complex showed a blue-shifted absorption onset at 210 nm in fig.4, indicating a wider optical band gap of 5.9 eV. The absorption rise was sharper, suggesting more defined electronic states.

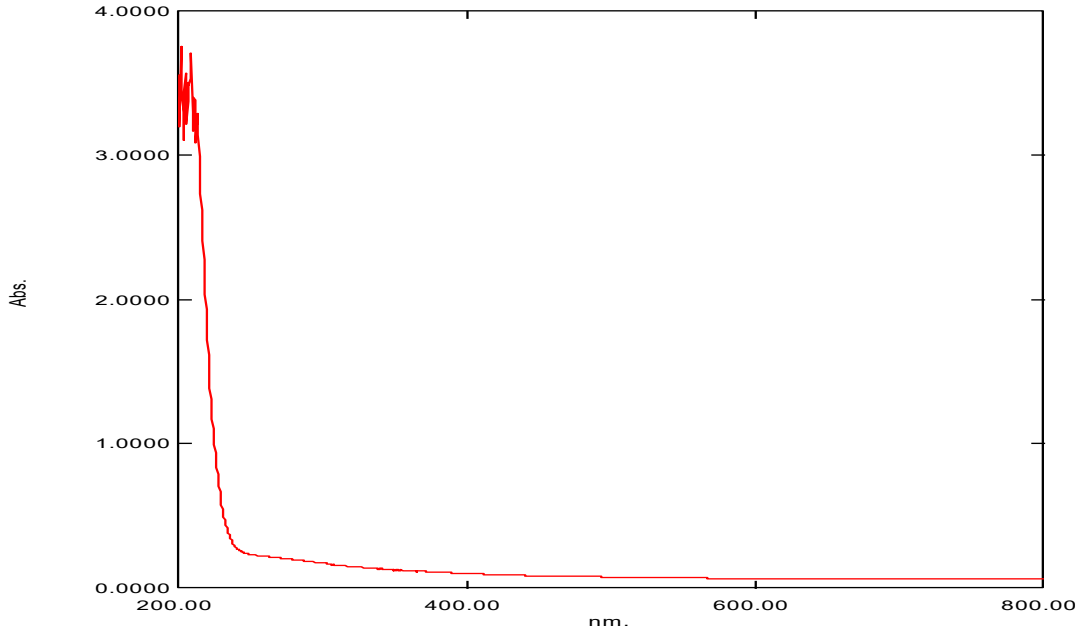


Fig. 4. UV absorbance spectra of L-Threonine Magnesium Acetate

The red-shifted absorption and narrower band gap in the Sodium complex. In Magnesium complex, with its strong, localized Mg-O bonds, confines electronic states and limits delocalization, resulting in a wider band gap. This inverse relationship between structural dimensionality and band gap has been observed in other molecular crystal systems, where lower-dimensional structures often exhibit smaller band gaps due to enhanced intermolecular interactions. The results demonstrate that the metal cation can effectively tune the optical properties of the material by dictating its crystal packing.

The Na^+ ion, with its large ionic radius and low charge density, acts as a passive ionic template. Its flexible coordination sphere promotes the formation of a 2D layered structure, where the dominant interactions are weaker ionic and hydrogen bonds. This layered architecture allows for greater π-orbital overlap and electron delocalization within the sheets, which directly manifests as a reduced optical band gap (5.6 eV) observed in the UV-Vis analysis. Conversely, the small ionic radius and high charge density of the Mg^{2+} ion make it a highly active structural node. Its strong, directional, and geometrically specific (octahedral) coordinate covalent bonds force the assembly of a dense, rigid 3D framework. This structure localizes electronic states and limits delocalization, resulting in the observed wider band gap (5.9 eV). Therefore, the metal cation does not just doping a host lattice; it defines the very lattice itself, and the resulting optical properties are a direct consequence of this metal-directed crystal engineering.

3.5. Implications for Device Fabrication

The tailored properties of these metal-organic complexes suggest promising pathways for specific device applications. The improved optical transparency in the visible region and the tunable band gap, particularly the wider gap of the Mg^{2+} complex, suggest potential for nonlinear optical (NLO) applications, as proposed for similar semiorganic crystals. The structural integrity of the 3D framework could also lend mechanical stability to NLO devices.

Furthermore, the superior and tunable dielectric properties indicate their usefulness in microelectronics and capacitor applications. The Mg^{2+} complex, with its giant dielectric constant, could be explored for use in high-capacitance density components, albeit likely in low-frequency or energy storage applications where high loss can be managed. The Na^+ complex, with its more balanced dielectric constant and lower loss, might be better suited for gate dielectric or high-frequency capacitor applications where low energy dissipation is critical. This ability to select a metal cation to strategically tune a material for either high-performance/high-loss (Mg^{2+}) or moderate-performance/low-loss (Na^+) scenarios provides a

powerful and versatile design strategy for fabricating specialized electronic components from bio-compatible, metal-organic materials.

4. Conclusion

This study demonstrates that metal cation engineering plays a key role in controlling the structural and functional properties of L-threonine–based crystals. A systematic comparison of Na^+ and Mg^{2+} complexes synthesized by slow evaporation reveals two distinct architectures: a 2D layered Na^+ structure and a 3D coordination Mg^{2+} framework. These structural differences directly influence their optical behavior, with the Na^+ complex showing a slightly lower band gap and enhanced electron delocalization. Overall, the findings establish clear structure–property relationships and highlight the potential of metal-directed crystal design for advanced optical materials.

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Biogenic Synthesis of Zno Nanoparticles Utilizing *Vitex Negundo* Leaf Extract and Development of Pmma-Zno Nanocomposites: A Sustainable Approach for Advanced Functional Materials

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ABSTRACT

This investigation centers on the development of functional PMMA-ZnO nanocomposites through the integration of green-synthesized (Vitex negundo) zinc oxide nanoparticles (ZnO NPs) into a poly (methyl methacrylate) (PMMA) matrix. This green synthesis approach provides a sustainable substitute for traditional methods, leveraging phytochemicals in the leaf extract to reduce and stabilize the nanoparticles. A range of spectroscopic and microscopic techniques, including XRD, FTIR, UV-Vis spectroscopy, SEM, and EDX, were employed to characterize the ZnO nanoparticles, which were found to exhibit a hexagonal wurtzite crystal structure These analyses confirmed the successful polymer-nanoparticle interaction, and uniform dispersion within PMMA. The nanocomposites synthesized in this study are poised to make a positive impact on the development of sustainable nanomaterials, with potential applications in both industrial and biomedical sectors.

Keywords: *Polymethyl methacrylate, Vitex negundo, Zinc Oxide.*

1. Introduction

Nanotechnology is a groundbreaking discipline of the 21st century, allowing for the manipulation of matter at the smallest scales to create materials with extraordinary characteristics and capabilities. Due to their remarkable physicochemical properties, including high surface-to-volume ratios, quantum confinement effects, and increased reactivity, metal oxide nanoparticles have become a focal point of research, presenting opportunities for innovative applications. [1,2]. The unique combination of a wide band gap, high exciton binding energy, and robust stability in ambient environments has positioned ZnO nanoparticles as a key area of research, leveraging their potential for various applications. Owing to their unique features, ZnO nanoparticles are applicable in diverse fields such as gas sensing, photocatalysis, UV protection, antimicrobial treatments, optoelectronics, and biomedical applications [3].

In recent years, green synthesis, or biogenic synthesis, has emerged as a sustainable and environmentally friendly alternative to conventional nanoparticle production methods. *Vitex*

negundo L (VN), a member of the Verbenaceae family, is a medicinal plant with a long history of traditional use, valued for its anti-inflammatory, analgesic, antimicrobial, and antioxidant properties. With a high content of bioactive compounds, such as flavonoids, phenolic acids, and alkaloids, the leaves of this plant offer a promising approach for the eco-friendly synthesis of metal oxide nanoparticles. [4,5]. In addition to aiding in the reduction of metal precursors, these phytochemicals naturally cap and stabilize the resultant nanoparticles, frequently giving the produced materials additional functional qualities.

Hybrid composites are being developed by combining ZnO nanoparticles with polymer matrices, allowing for the synergistic integration of the advantages of both materials and enhancing the overall functionality of the nanoparticles. Poly (methyl methacrylate) (PMMA) stands out as an ideal matrix material for ZnO nanoparticles due to its remarkable optical transparency, resistance to weathering, and ease of processing, making it an attractive choice for various applications. [6,7]. The synergistic properties of PMMA-ZnO composites—such as increased mechanical strength, improved thermal stability, UV protection, antimicrobial activity, and altered optical properties—exceed the capabilities of the individual components. [8].

Research on the green synthesis of ZnO nanoparticles using VN leaf extract has primarily focused on exploring their antimicrobial, photocatalytic, and anticancer activities. For instance, studies have shown that VN-mediated ZnO nanoparticles exhibit significant antibacterial activity [9] and can degrade organic pollutants like methylene blue [10]. In a separate line of research, ZnO nanoparticles have been incorporated into PMMA matrices using chemical methods, such as atomic layer deposition [7]and chemical synthesis [11,12], for various applications. However, the combination of biogenic ZnO nanoparticles derived from VN extract with a PMMA polymer matrix remains unexplored. Our work bridges this gap, combining the benefits of green synthesis with the versatility of PMMA to create advanced nanocomposites with enhanced properties. This study seeks to explore the potential of *Vitex negundo* (VN) leaf extract-mediated green synthesis of ZnO nanoparticles and their integration into PMMA matrices, with the ultimate goal of developing advanced composite materials with improved properties and functionality.

2. Materials and methods

2.1 Chemicals

The experiment employed analytical-grade reagents without additional purification. Merck Chemicals supplied the necessary chemicals, including zinc acetate dihydrate, sodium

hydroxide, polymethyl methacrylate, dichloromethane, and ethanol. Fresh VN leaves were sourced from Kanyakumari for extract preparation, and double-distilled water was consistently used.

2.2 Preparation of *Vitex negundo* Leaf Extract

10g of dried VN leaf powder was combined with 200mL of distilled water and heated at 60°C for 30 minutes with constant stirring. The mixture was then cooled, filtered through Whatman No. 1 filter paper, and stored in a refrigerator at 4°C.

2.3 Green Synthesis of ZnO Nanoparticles

The synthesis involved preparing a 0.5M zinc precursor solution (zinc acetate dihydrate) by dissolving the zinc salt in distilled water. The zinc precursor solution was mixed with *Vitex negundo* leaf extract through dropwise addition under constant stirring at room temperature, and the pH was adjusted to 9 by adding a sodium hydroxide (NaOH) solution. The mixture was stirred for 2-6 hours, washed, dried at 120°C, and calcinated at 400°C for 2 hours. [13].

2.4 Preparation of green synthesis PMMA-ZnO Composite

PMMA (1g) was dissolved in 20mL of dichloromethane, while ZnO nanoparticles (10mg/mL) synthesized via green method were mixed in chloroform through ultrasonication. The ZnO dispersion was added to the PMMA solution, and the mixture was kept onto glass petri dishes and dried at 140°C for 8 hours.

Table 1. Comparison of the present work with previously reported green synthesis of ZnO NPs and PMMA-ZnO composites

Plant Source / Synthesis Route	Precursor	Crystallite Size (nm)	PMMA Composite	Reference
Azadirachta indica (biogenic)	Zinc nitrate	39–74	Absent	[14]
Nigella sativa(biogenic)	Zinc nitrate hexahydrate	35	Absent	[15]
ZnO/PMMA – atomic layer deposition (chemical route)	Zinc chloride	~10–30	Present (chemical ZnO)	[7]
PMMA/ZnO nanocomposite films (chemical precipitation)	Zinc acetate (chemical)	~20–50	Present (chemical ZnO)	[8]
Vitex negundo leaf / biogenic with PMMA composite	Zinc acetate dihydrate (biogenic)	28.3 (ZnO); 23.5 (composite)	Present (biogenic ZnO)	Present study

3. Results and Discussion

3.1 X-Ray Diffraction

The XRD analysis of VN leaf extract with ZnO and VN leaf extract with PMMA-doped ZnO nanocomposite is presented in Figure 1. The diffraction pattern of VN-ZnO in Figure 1(a) exhibits peaks at 2θ values centered at 31.29° (100), 34.85°(002), 36.42°(101), 47.77°(102), 56.19°(110), 62.01°(103), 66.61°(200), 67.41°(112), and 68.22°(201), and Figure 1(b) PMMA-VN-ZnO disclosed the diffraction peaks 2θ centered at 31.48° (100), 34.91°(002), 36.75°(101), 47.86°(102), 56.64°(110), 62.14°(103), 66.78°(200), 67.62° (112), and 68.45°(201), the pattern matches the hexagonal wurtzite structure of ZnO, as confirmed by the JCPDS No. 36-1451 [10] reference data. The XRD pattern in Figure 1(b) reveals a subtle shift in the 2θ values, providing evidence of PMMA binding with the ZnO nanoparticles. This alteration in peak position can be attributed to the interplay of three interdependent mechanisms at the ZnO-PMMA interface. Firstly, lattice microstrain arises from local atomic displacements induced by differential thermal contraction between the inorganic ZnO lattice [16] and the organic PMMA chains during drying and calcination [17]. Secondly, interfacial stress is generated by the mechanical constraint exerted by the surrounding polymer matrix on the embedded nanocrystals, distorting the Zn-O bond lengths and modifying the interplanar d-spacings [18,19]. Thirdly, polymer confinement effects occur as PMMA chains adsorbed on the nanoparticle surface restrict grain growth and impose compressive or tensile stress on the crystallite periphery [20]. The observed positive 2θ shift across all diffraction planes in PMMA-VN-ZnO relative to VN-ZnO suggests a net compressive microstrain, which reduces the interplanar spacing according to Bragg's law, displacing peaks toward higher angles. Using the Scherrer equation (Eq. 1), the crystallite size of the nanoparticles was calculated.

$$D = K\lambda / \beta \cos \theta \qquad (1)$$

where

k - a constant (0.94),

λ - the wavelength of the X-ray,

β -the full width at half maximum (FWHM) of the peak, and

θ -the diffraction angle.

The crystallite size for VN- ZnO and VN-PMMA-ZnO was estimated to be 28.3 and 23.5 nm, respectively [11]. The presence of PMMA can influence the growth kinetics of nanoparticles, either by modifying the surface energy or providing alternative diffusion pathways[12]. This could explain the reduced size of PMMA-ZnO nanoparticles compared to green-synthesized ZnO nanoparticles.

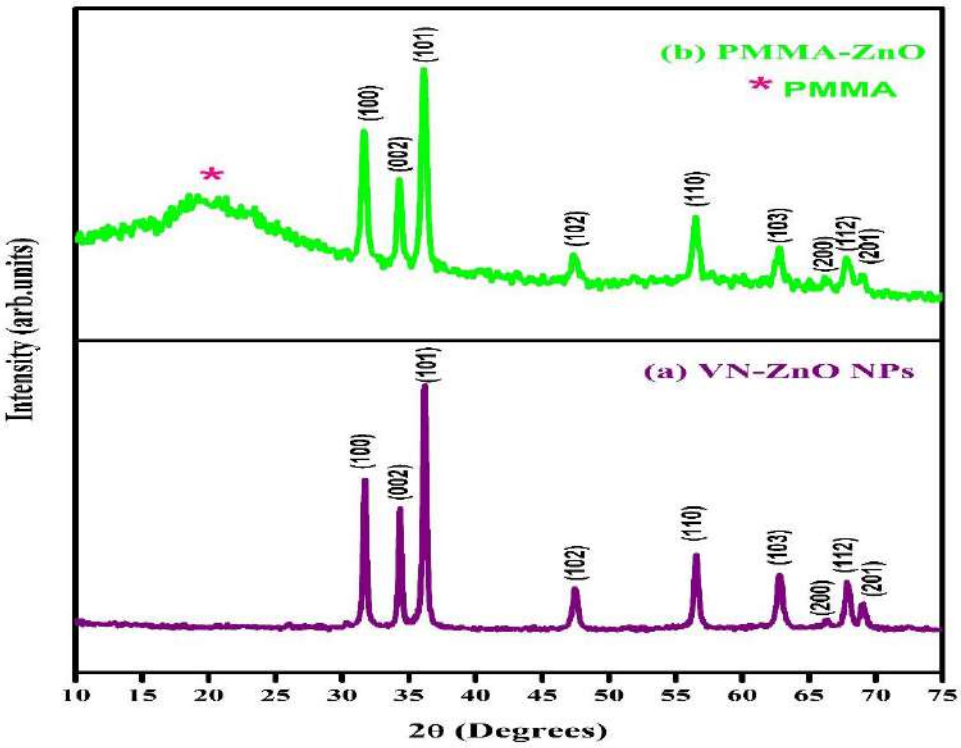


Figure 1. XRD spectra of *the Vitex negundo* synthesised ZnO NPs and leaf extract PMMA-ZnO NPs

3.2 Fourier Transform Infrared Spectroscopy (FTIR)

FTIR spectroscopy was employed to investigate the surface functional groups of green-synthesized ZnO nanoparticles and their interactions with PMMA in the doped ZnO nanocomposite, using VN leaf extract as a bio-reducing agent. The VN-ZnO and PMMA-ZnO nanocomposites were recorded in the range of 4000 cm^{-1} to 400 cm^{-1}. Figure. 2 compares the green-synthesized NPs and PMMA-doped green-synthesized NPs. The interaction between PMMA and ZnO nanoparticles involves hydrogen bonding and other interfacial interactions. The surface hydroxyl groups (Zn-OH) on ZnO interact with ester oxygen atoms of PMMA [21], causing a shift and broadening of the O-H stretching band from 3437 cm^{-1} in VN-ZnO to 3487 cm^{-1} in VN-PMMA/ZnO. New C-O bending (1214 cm^{-1}) and NO_3 symmetric stretching (835 cm^{-1}) bands appear in the nanocomposite, indicating new interfacial bonding environments [22, 23]. These changes confirm that PMMA chains are chemically anchored to the ZnO surface, resulting in improved dispersion and stability. The bands corresponding to various stretching modes, as depicted in Table 2, indicate the functional groups involved in reducing zinc ions to ZnO.

Table 2 shows the Peak position and functional group of synthesized ZnO NPs and the Extract with ZnO NPs

Peak Position (cm^{-1})		Functional Groups
VN-ZnO NPs	VN-PMMA/ZnO	
3437	3487	O-H Stretching
2918	2938	Asymmetric and symmetric CH_3 stretching
-	1779	C-O stretching of PMMA
1665	-	C=C Stretching
1421	1484	C-H bending
-	1214	C-O bending
1129	-	C-O stretching
-	835	NO_3 symmetric stretching
714	-	C-H bending
451	475	Zn-O stretching

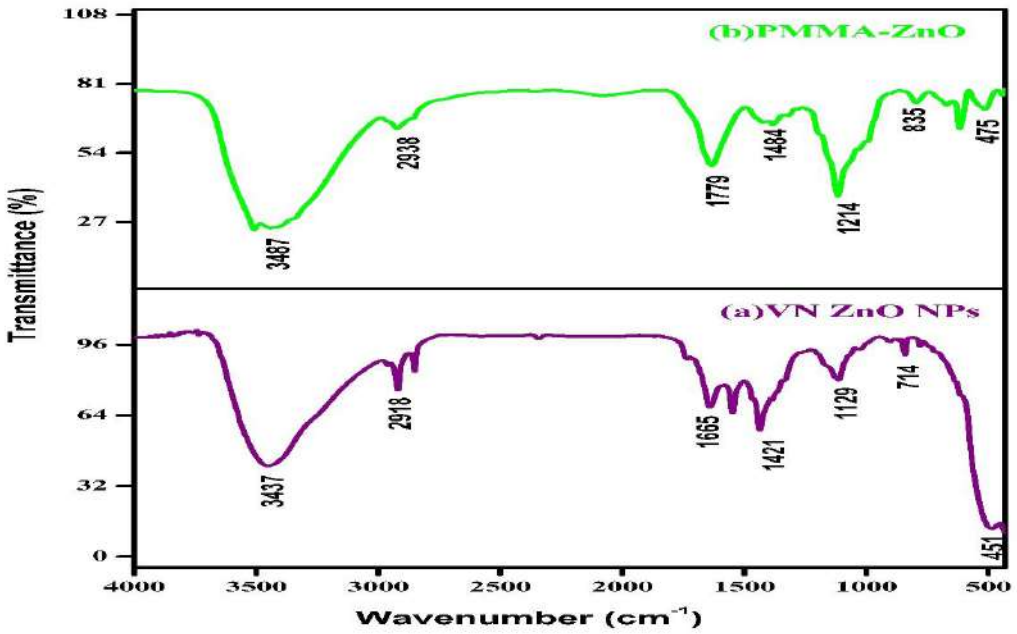


Figure.2. FTIR spectrum of *the Vitex negundo* synthesised ZnO NPs and VN-PMMA-ZnO NPs

3.3 UV-Visible Spectroscopy (UV-Vis)

UV-Visible spectroscopy analysis, presented in Figure 3, reveals distinct optical properties between pure *Vitex negundo* (VN)-synthesized ZnO NPs and the PMMA-ZnO

nanocomposite. Environmentally friendly synthesized ZnO exhibit a sharp absorption edge at ~373 nm, accompanied by high absorption intensity, indicating good crystallinity and a uniform electronic structure, which is characteristic of zinc oxide semiconductors [24]. Conversely, the PMMA-ZnO nanocomposite exhibits a red-shifted absorption edge at ~380 nm and a broader absorption profile, due to the heterogeneous nature of the composite with ZnO particles embedded in the organic matrix of PMMA [25].

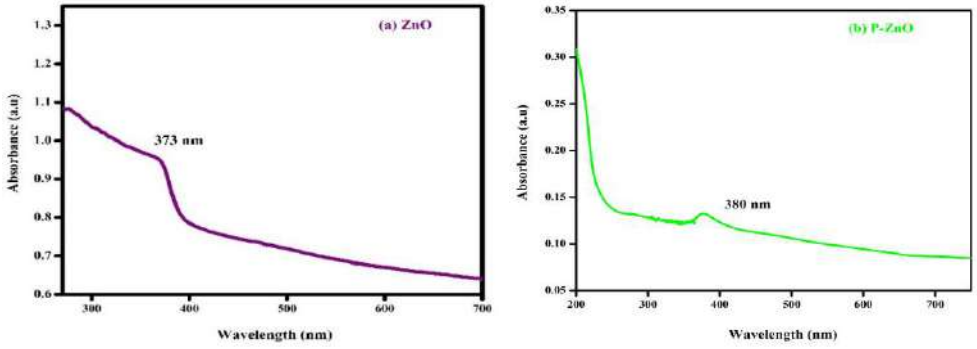


Figure. 3. UV-Visible analysis of *the Vitex negundo* with ZnO NPs and *Vitex negundo* PMMA-ZnO NPs

3.4 Scanning Electron Microscope Analysis (SEM)

SEM analysis reveals the surface morphology of *Vitex negundo*-synthesized ZnO nanoparticles and VN-PMMA-ZnO nanocomposite. Figure 4(a), Green-synthesis ZnO nanoparticles exhibit a uniform morphology with spherical to quasi-spherical particles, narrow size distribution, and minimal agglomeration, indicating good dispersion [26]. In contrast, Figure 4(b) shows that the PMMA-ZnO nanocomposite exhibits ZnO nanoparticles embedded in a continuous PMMA matrix, characterized by larger aggregate structures and a complex surface morphology, where polymer-covered ZnO particles appear as smooth areas with clusters of ZnO particles [27].

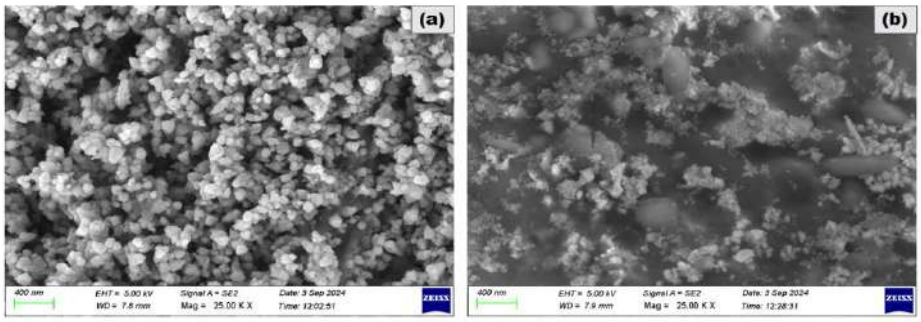


Figure. 4. SEM analysis of *the Vitex negundo* synthesised ZnO NPs and *Vitex negundo* PMMA-ZnO NPs

3.5 Energy Dispersive X-ray Analysis (EDX)

EDX analysis, as shown in Figure 5, was used to determine the elemental composition of the ZnO nanoparticles synthesized using *Vitex negundo* and the corresponding PMMA-ZnO nanocomposites. VN-synthesized ZnO display peaks for zinc and oxygen only in Figure 5(a), indicating a stoichiometric composition without contamination. In Figure 5(b) PMMA-ZnO nanocomposite spectrum shows an additional prominent carbon peak, indicating organic material incorporation, and the zinc and oxygen peak intensities due to dilution by the organic matrix and potential surface coverage by the polymer phase [17,18].

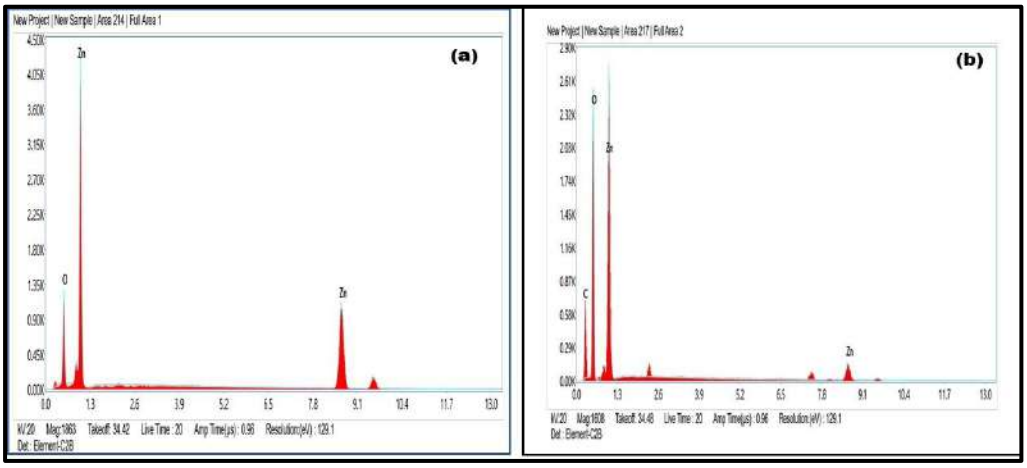


Figure. 5. EDX analysis of *the Vitex negundo* synthesised ZnO NPs and VN-PMMA-ZnO NPs

3.6 Comparison with Recent Literature

The present study findings are corroborated by recent research on Phyto mediated ZnO synthesis and ZnO-polymer nanocomposites. Aseen et al. (2024) [28]and Veena et al. (2018) [29] reported similar results on VN-mediated ZnO nanoparticles, including hexagonal wurtzite structure, spherical morphology, and Zn-O stretching frequencies. Kowsalya et al. (2025) [30] demonstrated the anticancer efficacy of VN-ZnO nanoparticles, while Sneha Asaha (2025) [31] showed broad-spectrum antibacterial and anticancer activity. Rehner et al. (2025) [32] reported enhanced antibacterial activity in chemical synthesis PMMA-ZnO nanocomposites with uniform ZnO dispersion. These studies validate the VN-mediated synthesis route, ZnO structure, and functional properties of the PMMA-ZnO nanocomposite.

4. Conclusion

This investigation demonstrates the efficacy of VN leaf extract in the biosynthesis of zinc oxide nanoparticles and their subsequent integration into PMMA matrices, yielding novel functional nanocomposites. Among these, biogenic synthesis methods provide an alternative ecologically

friendly pathway to conventional chemical methods by utilizing natural phytochemicals. XRD, FTIR, UV-Visible spectroscopy, SEM, and EDX characterizations were performed. The VN-ZnO nanoparticles had a crystallite size of 28.3 nm, which decreased to 23.5 nm upon formation of the VN-PMMA-ZnO nanocomposite. FTIR spectroscopy confirmed the role of functional groups in nanoparticle stabilization and identified characteristic peaks that indicate polymer-nanoparticle interactions. UV-Visible analysis showed the optical properties of both materials. In contrast, the nanocomposite showed a redshifted absorption edge, attributed to the composite systems heterogeneous nature. The pure ZnO nanoparticles appeared uniformly spherical to quasi-spherical with minimal aggregation, as observed in morphological studies. In the nanocomposite, ZnO particles were evenly dispersed and embedded within the continuous PMMA matrix. EDX analysis confirmed the elemental purity of synthesized ZnO nanoparticles and further validated the incorporation of organic components into the nanocomposite. From that, the interaction of polymer-nanoparticles is successful, and the dispersion of ZnO within the PMMA matrix is uniform, and the structural integrity of the nanoparticles is maintained.

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Structural Integrity and Spectral Features of Synthesized LAAS Nonlinear Optical Single Crystals

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ABSTRACT

Pure semi organic L–arginine ammonium sulphate (LAAS) single NLO crystals are grown at ambient temperature by varying the reaction time 3, 6, 12 and 24 h. Good value, optically apparent large sized crystals are selected for performing the characterization studies. The LAAS crystals grown are analysed using p-XRD and SEM, which gives its structural morphology. The unit cell constraints of all the L–arginine ammonium sulphate crystals at different reaction times are intended by using the JCPDS Data base file no 87–2354, which recommends orthorhombic nature of the grown crystal. By Debye–Scherer's equation [$D = 0.9\lambda / \beta \cos\theta$ *], the measured crystallite size of the grown crystals is found to be in the range of 24.11 – 28.46 nm. p-XRD studies resolute the lattice factors. The grown LAAS crystal that possess 24 hr reaction time, has widespread optical transparency in the entire UV-vis. region.*

Keywords: *Ammonium sulphate; L–Arginine; NLO crystals; p-XRD; SEM; Spectral*

1. Introduction

In the current situation, NLO crystal growth plays a crucial multidisciplinary role, as high-quality single crystals are essential for advanced technologies due to their ability to respond to light, temperature, pressure and electromagnetic fields [1-6]. Organic NLO crystals are attractive for their structural flexibility, fast response and high susceptibility, but their poor mechanical and physicochemical stability limits their practical use, whereas inorganic crystals offer better stability, shorter cutoff wavelengths and stronger nonlinearities. Semi-organic crystals, formed by combining amino acids with inorganic components, provide an effective alternative with broad applications in optical information processing, data storage, sensing and medical diagnostics. Because amino acids exist in a zwitterionic state, they offer additional advantages, making these semi-organic materials highly promising for advanced NLO technologies.

L-amino acid complexes are widely used in environmental science, pharmaceuticals, manufacturing and laboratory chemicals. They also play essential roles in transamination, decarboxylation and metabolic processes in the human body. Due to its molecular chirality,

zwitterionic nature and lack of extended conjugation, L-arginine is considered an exceptional material with notable chemical properties. L-arginine, an optically active amino acid, can donate or accept protons and act as a nucleophilic reagent and its maleate crystals have already attracted significant technological interest. Recent studies show that new salts of L-arginine have been developed [7–10], and the physical properties of amino acid–based single crystals can be enhanced through carbon-based doping [11-15]. The present work attempted to grow single semi-organic nonlinear optical crystals of L-arginine ammonium sulphate (LAAS) using the slow evaporation technique [16,17].

Although several reports are available on amino acid based semi-organic nonlinear optical crystals, systematic studies on the influence of reaction time on the structural and optical properties of L-arginine ammonium sulphate (LAAS) crystals are very limited. In the present work, LAAS single crystals are grown by varying the reaction time (3, 6, 12 and 24 h) under identical growth conditions. A comparative investigation of crystallinity, optical transparency and band gap variation as a function of reaction time is reported for the first time. The study clearly demonstrates that prolonged reaction time significantly improves crystalline perfection and optical performance, highlighting the optimized growth condition for NLO applications.

2. Materials and Methods

2.1. Materials employed

All those chemicals used for the synthesis of L–arginine ammonium sulphate is purchased from E. Merck product. So, it is used without further purification. For crystal growth, solvent used is the double distilled water.

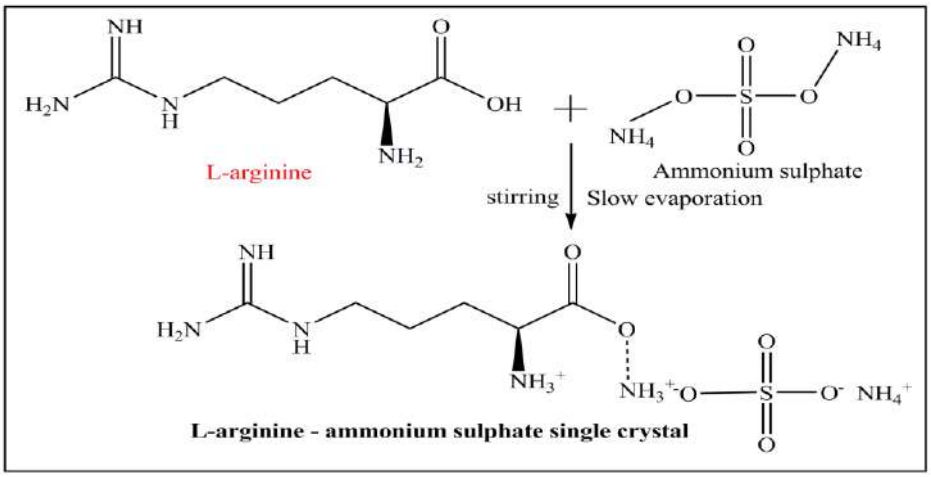


Fig. 1. Synthesis of L-arginine-ammonium sulphate single crystal

2.2. Growth of LAAS single crystal

In the present study, three distinct time parameters are involved: reaction time, stirring time and crystal growth time. Reaction time refers to the duration for which the equimolar

solution of L-arginine and ammonium sulphate is continuously stirred to ensure complete chemical interaction and homogeneity. The stirring time is the same as the reaction time and is maintained at 3 h, 6 h, 12 h and 24 h using a heater cum magnetic stirrer at 200 rpm. After completion of the reaction, the homogeneous solution is allowed to undergo slow evaporation at room temperature without further agitation. The beaker is covered with a lid perforated with holes. The time taken for the formation of well-defined single crystals through evaporation is referred to as the crystal growth time, which is approximately 10 – 12 days for all samples. Thus, the growth time is kept constant, while only the reaction (stirring) time is varied to study its influence on crystal properties. Good quality NLO crystal of large size is chosen for analysis. Synthesis of L–arginine–ammonium sulphate (LAAS) single NLO crystal is schemed out in the Figure 1 and the pictorial image of the grown single NLO crystals of LAAS at different reaction time are shown in the Figure 2.

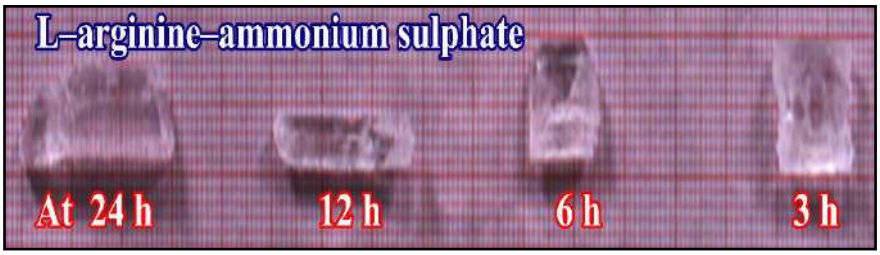


Fig 2. Pictorial image of the grown LAAS single NLO crystals at different reaction times

2.3. Characterization studies

The synthesized single crystals are characterized using powder XRD, UV–Vis. spectroscopy and SEM analysis. Powder XRD is performed using a Bruker AXS D8 diffractometer with Cu Kα radiation at STIC, CUSAT. Optical transmittance spectra of L-arginine doped ammonium sulphate crystals are recorded in DMF at room temperature over the range 200 – 1100 nm [18,19]. SEM analysis using a JEOL JSM-6390LV system revealed surface morphology and crystallite size of the LAAS crystals.

3. Results and Discussions

3.1. *p-XRD* Analysis

X-ray diffraction confirmed the purity and unit cell parameters of LAAS NLO crystals, with sharp intense peaks across all reaction times indicating a well-defined microcrystalline structure with a uniform phase [22,23,24]. Prominent peaks at 16.9°, 22.8°, 28.5° and 29.2° correspond to the regular monomeric arrangement of a quaternary ammonium compound in planar conformation. Based on the JCPDS file No. 87–2354, the crystals are confirmed to possess an orthorhombic structure with only slight variations in lattice parameters across reaction times. The lattice parameters and crystal volumes for each reaction time are

summarized in Table 1. By applying the values of diffraction angle (θ) and FWHM (β) in Debye–Scherer's equation [$D = 0.9\lambda / \beta\cos\theta$], the crystalline size (D) can be calculated. The calculated crystallite size of the grown crystals is found to be in the range of 24.11 – 28.46 nm. It is found that by increasing the reaction time, the thickness and the value of particle size increases, which causes highest degree of crystalline nature of the sample.

Parameters	L-arginine-ammonium sulphate crystal for different reaction times			
	3hr	6hr	12hr	24hr
a (Å)	7.712	7.713	7.711	7.72
b (Å)	10.623	10.598	10.58	10.59
c (Å)	6.061	6.061	6.057	6.032
V $(Å)^3$	494.6	495.53	494.14	493.13

Table 1. Lattice parameters of the grown crystals for different reaction times

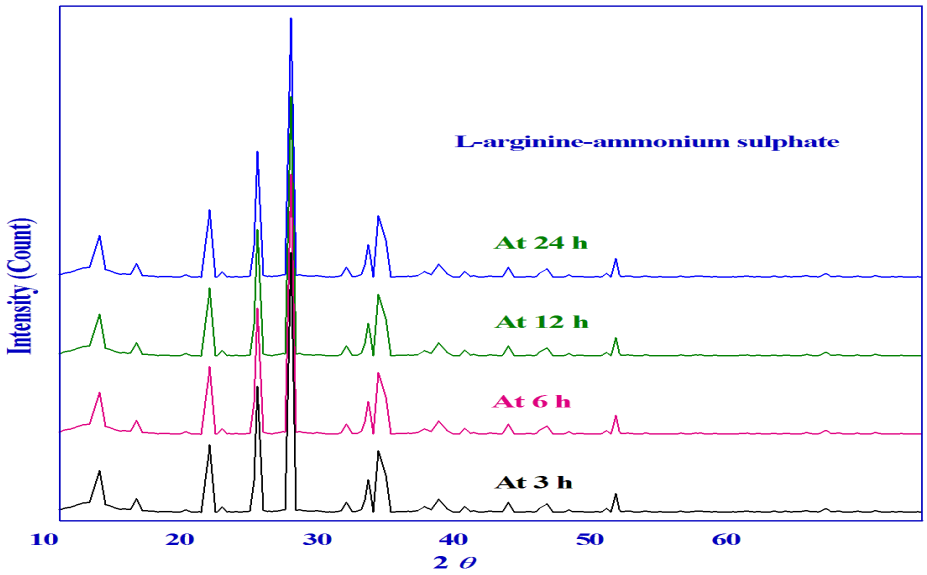


Fig. 3. X-ray diffractograms of L–arginine-ammonium sulphate

3.2. Ultra Violet–*vis.* spectral analysis

The UV–Visible transmittance spectra of the crystals grown at different reaction times are shown in Figure 4, and the results indicate that transmittance increases with increasing reaction time. Among all samples, the 24-hour crystal exhibits the highest optical transmittance. The energy band gap values of the L-arginine ammonium sulphate (LAAS) crystals are calculated using Tauc's relation by plotting $(\alpha h\nu)^2$ versus hν, as shown in Figure 5. The indirect band gap is determined by extrapolating the linear portion of the plot to the hν

axis. The results show that the energy band gap decreases as the reaction time increases. Some crystals with relatively low band gap values are also observed.

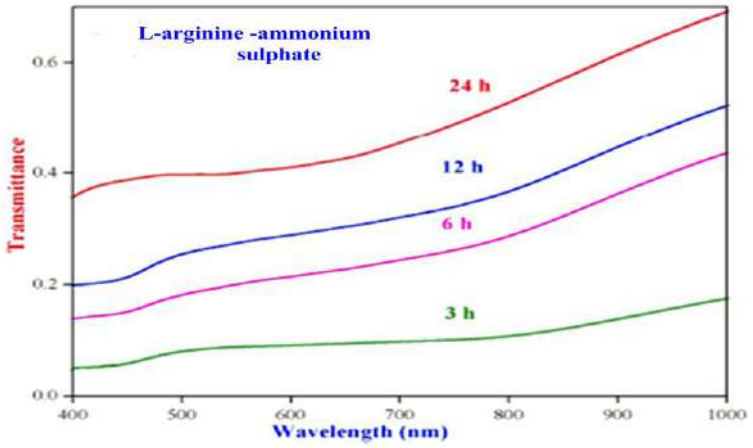


Fig 4. UV–Vis. spectra of L-arginine-ammonium sulphate with different reaction time

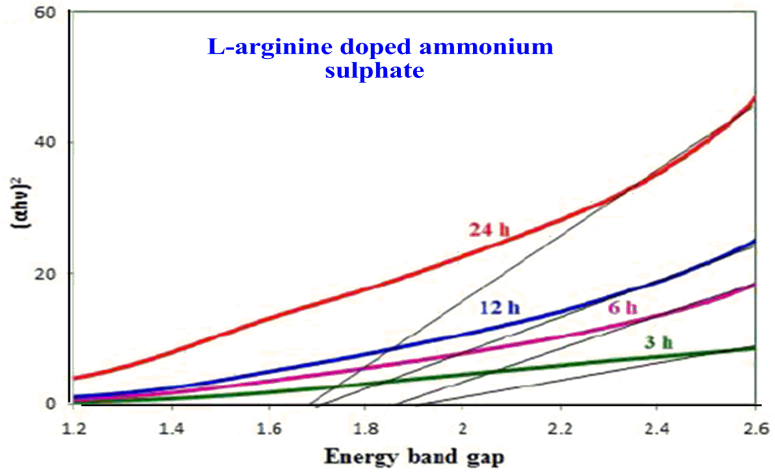


Fig.5 Energy band gap values of L-arginine- ammonium sulphate for different reaction time

3.3. Scanning Electron Microscope (SEM) analysis

SEM analyses the surface morphology and particle size of L–arginine doped ammonium sulphate crystal systems. SEM under various magnified images with 15 kV accelerating voltage and its photographs have been depicted in Figure 6. The SEM analysis shows consistent crystal matrix with consistent phase separation, with different morphology. A frequently detached huge layer by layer spider shells like form morphology (Figure 6a) owns 50 µm particle size, an unevenly broken insignificant powerful fragment of ice–rock like structure (Figure 6b) owns 10 µm particle size, the group of coral reef like external morphology (Figure 6c) with 5 µm particle size and an unevenly fractured huge crack like with miniature haze like structure morphology (Figure 6d) in deep water by dint of 2 µm particle size are

perceived for L–arginine nobbled ammonium sulphate system at 3 h reaction time which specifies that the experiential SEM morphology illustrates entirely different surface structures.

The crystallite size obtained from p-XRD corresponds to the coherently diffracting domain size, which lies in the nanometer range (24–28 nm). In contrast, SEM provides information on surface morphology and particle agglomeration, resulting in observed particle sizes in the micrometer range. Therefore, the particle sizes observed in SEM images represent clusters of many crystallites rather than individual crystallites. Hence, the XRD and SEM results are complementary and not contradictory.

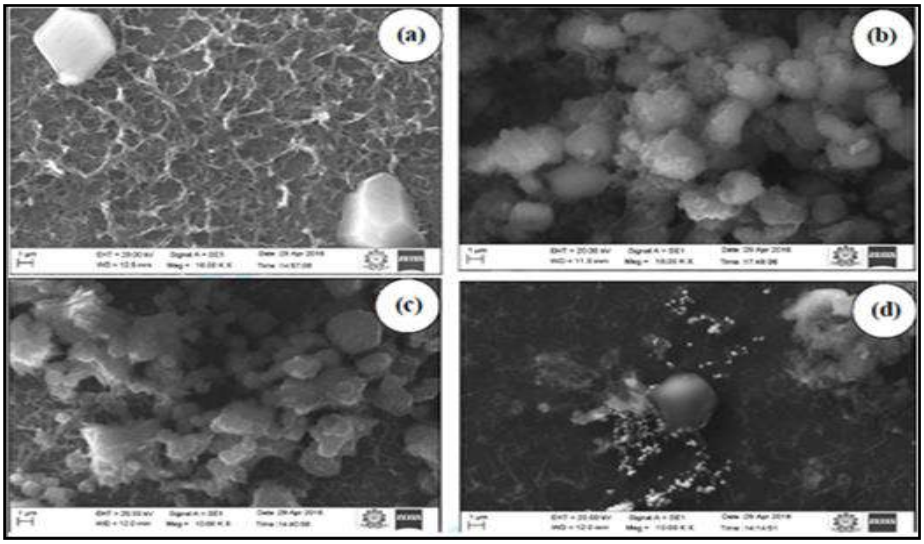


Fig 6. SEM images of L-arginine- ammonium sulphate for different reaction time

4. Conclusion

This investigation, reported the production, advancement of original semi-organic crystal of L-arginine-ammonium sulphate (LAAS) NLO crystal at ambient temperature in aqueous medium. Synthesized solitary crystals are full-fledged by slow-evaporation technique at ambient temperature in different response times (3h, 6h, 12h and 24 h). The grown single crystals have been characterized by p-XRD, UV-Vis. spectra and SEM analyses. X-ray diffraction analysis confirmed the purity and unit cell parameters of the synthesized L-arginine ammonium sulphate system. The crystals exhibit an orthorhombic structure with negligible variations in lattice parameters, indicating that the overall crystal structure remains unaffected. The presence of sharp, well-resolved peaks with high intensity and a few low-intensity feeble peaks confirms the microcrystalline nature with a uniform phase. At 24 h reaction time, highly intense and well-defined 2θ peaks indicate a well-ordered crystal structure with closely packed planar moieties. The increase in reaction time enhances particle size and thickness, resulting in improved crystallinity. The optical absorption by UV-vis. is found between 200 – 1100 nm

which illustrates that the optical transmittance value increases with increasing reaction time and also the system show remarkable transmittance values at 24 h. Moreover, the indirect energy gap values are found in the range of 1.62 – 1.92 eV. The observed energy band gap values clearly demonstrate that the band gap values decrease with increasing reaction time. SEM studies illustrates that the surface morphology of the grown crystals shows entirely different structures.

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Investigation of Structural and Optical Properties of Barium Doped Zirconium Oxide Nanoparticles

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ABSTRACT

Barium-doped zirconium oxide (Ba–ZrO_2) nanoparticles were synthesized using a green synthesis method with neem leaf extract as a natural reducing and stabilizing agent. The structural and optical properties of the nanoparticles were characterized using XRD, FTIR, and UV–Diffraction spectroscopy. XRD analysis confirmed the crystalline nature and successful incorporation of barium ions into the ZrO_2 lattice with nanosized particles. FTIR spectra showed characteristic peaks corresponding to Zr–O and Ba–O bonds. UV–DRS analysis revealed an absorption peak in the visible region, and the calculated band gap showed a slight shift compared to pure ZrO_2. The modification in structural and optical properties indicates that barium doping effectively alters the electronic structure of zirconium oxide. These results suggest that Ba–ZrO_2 nanoparticles have potential applications in photocatalysis, sensors, and optoelectronic devices.

***keywords**: Nano, Metal oxide, XRD, FTIR, UV-DRS.*

1. Introduction

Nanoparticles are particles with sizes ranging from 1 to 100 nanometers. They exhibit unique optical, electrical, and mechanical properties compared to their bulk materials. Nanoparticles show high surface area, enhanced reactivity, and quantum size effects. They possess tunable optical, magnetic, and catalytic behaviors. These properties make them suitable for applications in medicine, electronics, and energy storage. They are also used in sensors, coatings, and environmental remediation. Metal oxide nanoparticles consist of metal and oxygen atoms arranged in a crystalline structure. They exhibit excellent chemical stability, catalytic activity, and electrical conductivity. Common examples include ZnO, TiO_2, and ZrO_2. Their properties depend on particle size, morphology, and synthesis method. They are widely used in photocatalysis, gas sensing, and biomedical applications. Nanoparticles can be synthesized using physical, chemical, or biological methods. The process aims to control particle size, shape, and dispersion. Common approaches include sol–gel, hydrothermal, co-precipitation, and green synthesis methods. Green synthesis uses plant extracts, microorganisms, or natural products as reducing and stabilizing agents. It is an eco-friendly, cost-effective, and non-toxic method for nanoparticle production. This approach avoids

harmful chemicals and promotes sustainable nanotechnology. Zirconium oxide (ZrO_2), also known as zirconia, is a white crystalline metal oxide with high thermal stability. It exhibits excellent mechanical strength, corrosion resistance, and ionic conductivity. ZrO_2 exists in monoclinic, tetragonal, and cubic crystal phases depending on temperature. It is widely used in ceramics, sensors, catalysts, and biomedical implants. Doping zirconium oxide with metals such as barium enhances its electrical and optical properties. The doped material shows improved crystallinity and modified band gap energy. ZrO_2 nanoparticles possess high surface area and tunable physicochemical characteristics. Their synthesis can be achieved through sol–gel or green routes using natural extracts. Overall, zirconium oxide is a multifunctional material with diverse technological applications. Introducing Ba^{2+} ions into a host nanomaterial, deliberately modify structural, electronic, optical, and surface characteristics of the host material.

2. Experimental Procedure

The green synthesis of barium-doped zirconium oxide was carried out using neem (Azadirachta indica) leaf extract as a natural reducing and stabilising agent. Fresh neem leaves were first collected, thoroughly washed with distilled water, and air-dried for several days until all moisture was removed. The dried leaves were then finely powdered, and the extract was prepared by mixing the powder with distilled water and heating it to obtain the bio-extract.

For the synthesis of barium-doped zirconium oxide, 25 g of neem leaf powder is boiled with 200 mL of distilled water and reduced to 125 mL, from which 100 mL of filtered extract is used as the green reducing and stabilising agent. 1 mole of zirconyl nitrate ($ZrO(NO_3)_{2.x}H_2O$) and 0.05 mol of barium nitrate ($Ba(NO_3)_2$) were added. The resulting mixture was magnetically stirred to ensure homogeneous mixing and subsequently heated at 70˚C to initiate the combustion process. During heating, the mixture underwent self-propagating combustion, resulting in the formation of a fine ash-like residue. The obtained product was then collected, dried, and ground. The obtained product was dried to yield a fine powder, which was then calcined at 500°C for three hours to enhance crystallinity and remove organic residues. Finally, barium-doped zirconium oxide nanoparticles were successfully obtained.



Figure 1. Schematic representation of Synthesis

3. Characterization Methods

3.1. X-Ray Diffraction

The XRD analysis of the synthesised barium-doped Zirconium Oxide (Ba–ZrO_2) nanoparticles confirmed their crystalline nature, as the diffraction peaks at the (111), (200), (220), (311), and (222) planes matched the standard face-centered cubic phase of ZrO_2 (JCPDS No. 49-1642). The pattern showed a strong peak at $2\theta = 50.897°$ corresponding to the (220) plane and a weaker peak at $2\theta = 34.780°$ for the (200) plane, indicating successful incorporation of barium into the zirconium oxide lattice. The average crystallite size calculated using the Debye–Scherrer equation was found to be 9.27 nm, and the lattice parameter for the cubic phase was determined as 5.0812 Å, reflecting slight lattice expansion due to Barium doped Zirconium Oxide.

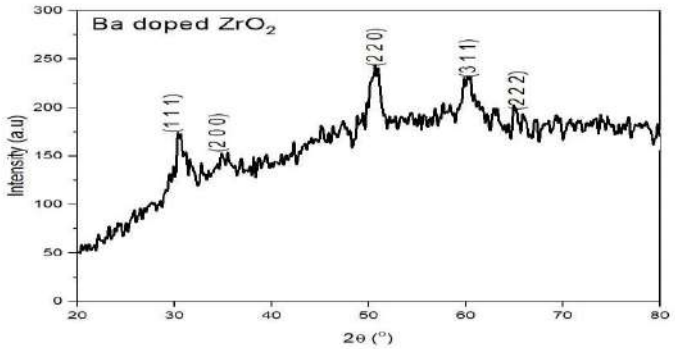


Figure 2. XRD Pattern for Barium doped Zirconium Oxide

3.2. Fourier Transform Infrared (FTIR) Spectroscopy

The FTIR spectrum of Ba-doped ZrO_2 shows a broad band around 3425 cm^{-1} and weak peaks at 3792 cm^{-1} and 3656 cm^{-1}, corresponding to O–H stretching vibrations of adsorbed water and surface hydroxyl groups. The peaks at 2919 cm^{-1} and 2343 cm^{-1} arise from C–H stretching and CO_2 vibrations, respectively, indicating residual organic and carbonate species. Bands at 1553

cm^{-1}, 1372 cm^{-1}, and 1081 cm^{-1} are attributed to C=O, C–O, and COO^- vibrations from neem extract residues used as a green reducing agent. The strong absorption peak at 436 cm^{-1} corresponds to Zr–O and Ba–O lattice vibrations, confirming the successful formation of Ba-doped zirconium oxide nanoparticles.

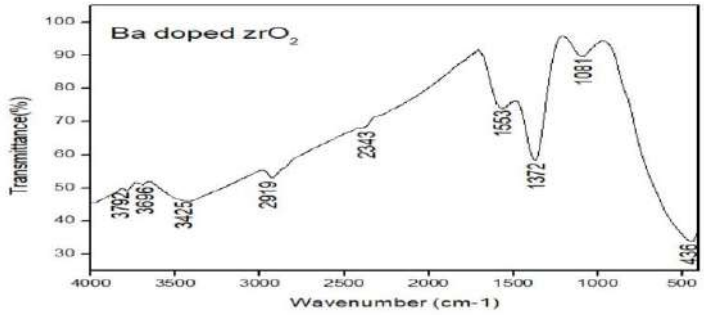


Figure 3. FTIR Spectrum of Barium doped Zirconium Oxide

3.3. UV-DRS

The optical band gap energy (Eg) of Ba-doped ZrO_2 nanoparticles was determined using the Kubelka–Munk (K–M) function, enabling analysis of the material's optical response. Using the Kubelka–Munk relation, a Kubelka–Munk plot of $[F(R)h\nu]^n$versus $h\nu$ was constructed, and extrapolation of its linear region yielded an optical band gap of 4.4837 eV, indicating a direct allowed transition. This band gap value is lower than that of bulk ZrO_2, attributed to the quantum confinement effect occurring at the nanoscale. The absorbance spectrum shows a noticeable hypsochromic shift, suggesting reduced particle size and increased band gap energy due to Barium incorporation. Similarly, the reflectance spectrum also exhibits a blue shift, confirming that Barium doping modifies the electronic structure, enhances optical activity, and increases reflectance in the visible region of Ba-doped ZrO_2 nanoparticles.

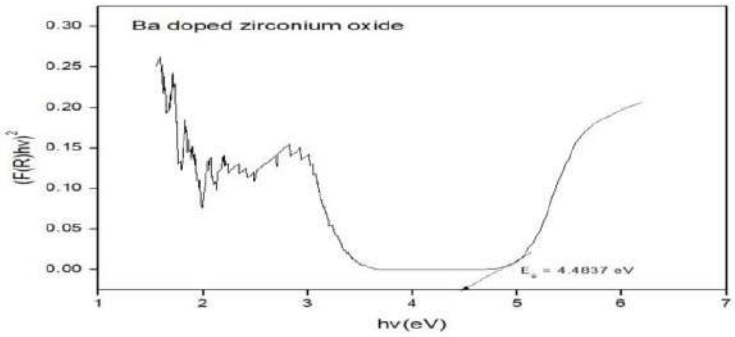


Figure 4. Kubelka Munk plot of Barium doped zirconium oxide

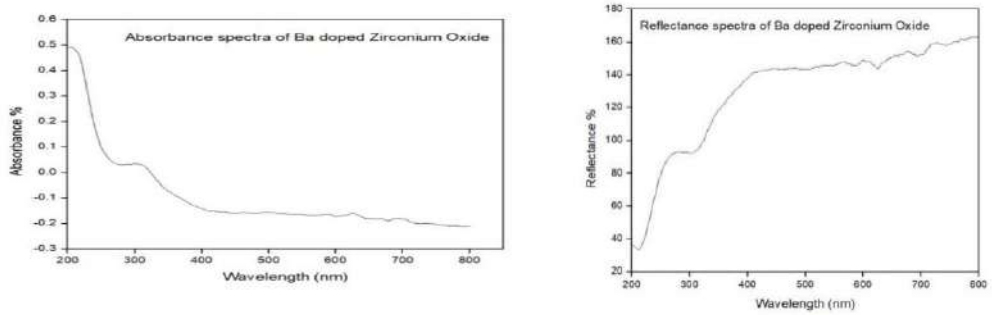


Figure 5. Absorbance and Reflectance spectra of Barium doped zirconium oxide

Conclusion

Barium-doped zirconium oxide (Ba–ZrO_2) nanoparticles were successfully synthesized by a green synthesis route using neem extract as a natural reducing and stabilizing agent. The nanoparticles obtained were white in color and characterized using various analytical techniques to explore their structural and optical properties. XRD analysis confirmed the formation of crystalline Ba–ZrO_2 nanoparticles with an average particle size of 9.27 nm, indicating successful barium incorporation into the zirconium oxide lattice. FTIR spectra verified the presence of characteristic metal–oxygen vibrations, confirming the formation of Ba–ZrO_2. The optical study using UV–DRS revealed a band gap energy of 4.4837 eV, suggesting modified optical behavior due to barium doping. In conclusion, the green synthesis approach proved to be an effective and eco-friendly method for producing Ba–ZrO_2 nanoparticles with desirable structural and optical properties, making them promising candidates for future applications in optoelectronic devices.

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Structural and Optical Properties of Zinc Oxide (ZnO) Nanoparticles

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ABSTRACT

Zinc oxide (ZnO) nanoparticles have gained significant attention due to their unique structural, electrical, and optical properties, making them promising materials for applications in optoelectronics, sensors, photocatalysis, and biomedical fields. The physical and chemical characteristics of ZnO are strongly influenced by synthesis methods, reaction parameters, and the presence of surfactants or stabilizing agents. In this study, ZnO nanoparticles were synthesized using a chemical precipitation method, where ethylene glycol and hexamethylenetetramine (HMT) were employed as structure-directing agents to modify the morphology and crystalline behavior of the nanoparticles. The synthesized samples were characterized using X-ray diffraction (XRD), Raman spectroscopy, and UV–Visible spectroscopy to investigate their structural and optical properties.

Keywords: *Structural properties, Precipitation technique, Zinc oxide.*

1. Introduction

Zinc Oxide (ZnO) is one of the most important semiconducting nanomaterials with wide applications due to its unique optical, electrical, and chemical properties [1-3]. It is a largely inert, white compound which is used very widely as a bulking agent or filler, and as a white pigment. It is found in some rubber, glass and ceramic products, and is found in the chemical industry as a catalyst. It is also used in paints as a corrosion inhibitor and for mildew control.

ZnO has a wide band gap (3.37eV) and high exciton binding energy (60meV), making it excellent for optoelectronic applications [4-6]. It can be synthesized in various nanostructures such as nanorods, nanowires, nanospheres, and thin films. It shows strong UV absorption and photoluminescence, used in UV lasers, LEDs, and sensors. Acts as a transparent conducting oxide (TCO) in solar cells and displays [7-8]. Highly chemical and thermal stable, making it useful in gas sensors, photocatalysis, and environmental purification.

2. Experimental Section

4.4 g of zinc acetate was dissolved in 100 mL of distilled water under continuous stirring until a clear solution was obtained. The pH of the solution was adjusted to 12 by the

slow addition of NaOH solution under constant stirring. The pH-maintained solution was stirred for 4 hours at 60 °C to ensure complete reaction and homogeneous mixing. After stirring, the solution was allowed to settle naturally for precipitation to occur. For the preparation of Sample II and Sample III, the above pH-maintained solution was modified by adding 10 mL of ethylene glycol along with 1 g of hexamethylenetetramine (HMT). The obtained samples were filtered, washed with distilled water, and dried. Finally, the prepared samples were subjected to structural and optical analysis.

3. Results and Discussion

3.1. XRD Analysis of ZnO Nanoparticles

The X-ray diffraction (XRD) patterns of pure ZnO nanoparticles and those synthesized with different concentrations (1g and 2g) of HMT are shown in Figure 1a-1b. All samples exhibit distinct diffraction peaks corresponding to the (100), (002), (101), (102), (110), (103), and (112) planes, which are characteristic of the hexagonal wurtzite structure of ZnO (JCPDS Card No. 36-1451). No additional peaks were observed, confirming the high phase purity of the synthesized nanoparticles. The average crystallite size is calculated using the Debye–Scherrer equation,

$$D = K\lambda / (\beta \cos \theta)$$

Where, D is the average crystallite size, K is the shape factor (usually taken as 0.9), λ is the X-ray wavelength (typically 1.5406 Å for Cu-Kα radiation), β is the full width at half maximum (FWHM) of the diffraction peak (in radians), θ is the Bragg angle. The average crystallite size was found to be 16.47 nm for pure ZnO nanoparticles, 13.37 nm for ZnO nanoparticles prepared with 1g of Hexamine respectively. Upon addition of HMT, a slight shift in peak intensity and broadening was observed, indicating a decrease in crystallite size and possible strain introduced by the surfactant molecules. The incorporation of ethylene glycol and varying amounts of HMT appears to influence the nucleation and growth process, leading to smaller and more uniformly distributed nanoparticles. These results demonstrate that the addition of HMT acts as a capping and structure-directing agent, enhancing the crystallinity and controlling particle growth during synthesis.

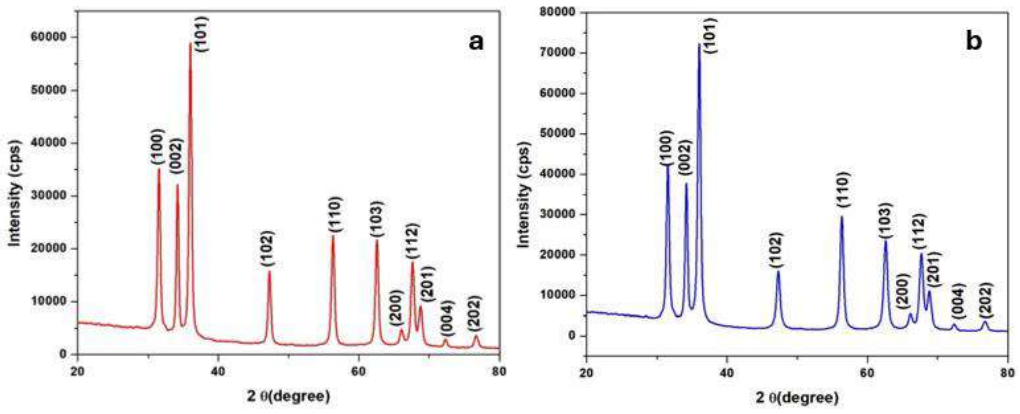


Fig. 1. XRD pattern of a) Pure zinc oxide nanoparticles b) ZnO nanoparticles prepared with 1g of hexamine

3.2. Raman Spectra Analysis of ZnO nanoparticles

Raman spectroscopy was used to further confirm the structural quality and crystalline nature of the ZnO nanoparticles (Figures 2a & 2b). The characteristic E_2 mode of ZnO, typically observed around 437 cm^{-1}, is evident in all samples, confirming the wurtzite phase. The intensity of this peak slightly varies with the addition of HMT, suggesting changes in particle size and surface disorder.

For the samples prepared with 1 g of HMT, the Raman peaks become sharper, indicating improved crystallinity and reduced lattice defects. Additional weak bands observed in the higher frequency region could be attributed to multi-phonon processes or minor surface defects introduced by the organic additives. The absence of any impurity-related modes reaffirms the structural purity of the synthesized ZnO nanoparticles.

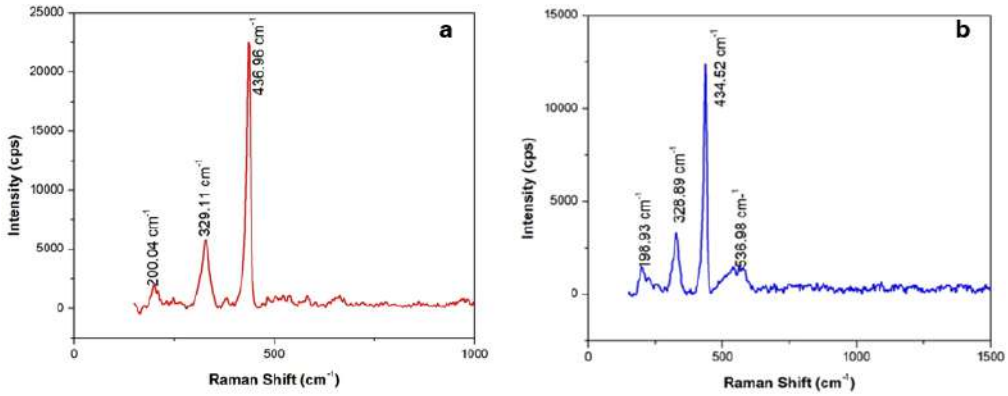


Fig. 2. Raman Spectrum of a) ZnO nanoparticles b) ZnO nanoparticles prepared with 1g Hexamine

3.3. UV Vis-Analysis for Zinc Oxide nanoparticles:

The optical properties of the ZnO nanoparticles were analyzed using UV–Visible spectroscopy (Figures 3a &3b). The absorption spectra show strong absorption edges in the UV region, characteristic of ZnO semiconductors. The absorption edge for pure ZnO nanoparticles was observed near 364.20 nm, corresponding to a band gap energy of approximately 3.4 eV, calculated using the formula,

$$E_g = \frac{hc}{\lambda e} \text{ eV}$$

Upon incorporation of ethylene glycol and HMT, a slight blue shift in the absorption edge was noted, which can be attributed to the quantum confinement effect resulting from reduced particle size and increased bandgap of 3.46 eV for ZnO nanoparticles prepared with 1g of Hexamine respectively. The samples synthesized with 1 g of HMT exhibit sharper absorption features, indicating better dispersion and uniformity. These observations are consistent with the XRD results, confirming that HMT influences the nucleation rate and stabilizes the nanoparticle surfaces.

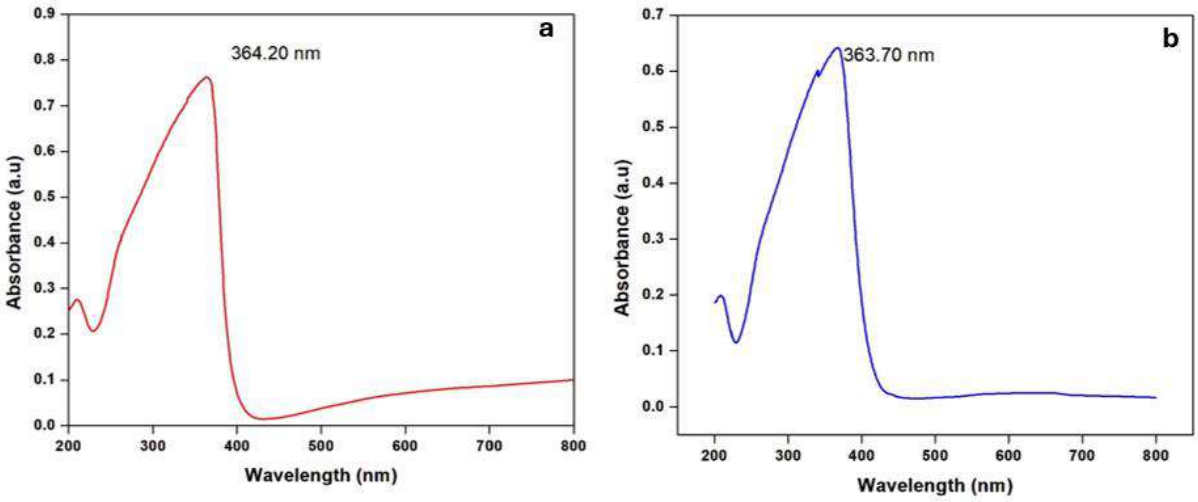


Fig 3. UV spectrum of a) ZnO nanoparticles b) ZnO nanoparticles prepared 1g of hexamine

4. Conclusion

In this study, ZnO nanoparticles were successfully synthesized using a simple chemical precipitation method. The influence of ethylene glycol and hexamethylenetetramine (HMT) on the structural and optical properties was systematically investigated. XRD analysis revealed that all samples exhibited the hexagonal wurtzite structure with high crystallinity. The crystallite size decreased with increasing HMT concentration, suggesting that HMT effectively controlled particle growth. Raman spectroscopy confirmed the structural purity and highlighted improved crystallinity with the addition of HMT. UV–Visible analysis showed a slight blue

shift in the absorption edge for HMT-modified samples, indicating reduced particle size and strong quantum confinement effects. Overall, the study demonstrates that the addition of ethylene glycol and HMT plays a vital role in tailoring the physicochemical characteristics of ZnO nanoparticles. The synthesized nanomaterials exhibit desirable optical and structural features, making them promising candidates for optoelectronic devices, photocatalysts, and sensing applications.

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Alpha and Beta radiations along Southern Coastal areas of Tamil Nadu

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ABSTRACT

The emission of radioactive substances into the environment is harmful to life due to the ionizing radiations. Even though the radioactive contamination of the environment is relatively small, it requires a great attention because of extreme degrading effects of ionizing radiation on living tissues. Soil is one of the major sources of radiation exposure to the population through the transfer of radionuclides into the environment. The issues related to the radioactively contaminated soils are being considered as a chemical contamination related to ionizing radiation. The adverse effects are directly related to the quantity of absorbed energy and the penetrating power of radiation. The study of natural radioactivity in marine and coastal environments is of significant importance for better understanding of the life of people around that area. The sampling sites were selected randomly to cover the coastal areas in Tirunelveli and Kanyakumari Districts. Ten samples were collected from each district. The radioactivity of the sand samples were measured using Geiger muller counter after recording their background radiations. The gross alpha activity of Kadiyapattanam (1.6150 Bq/g) and the gross beta activity of Enayamputhenthurai (2.1482 Bq/g) were higher than other samples in Kanyakumari District. Moreover in Tirunelveli district, the alpha (5.1087Bq/g) and the beta (14.214Bq/g) activities were found to be more in Kudankulam.

Keywords*: radioactivity, contamination, environment, radionuclides, penetrating*

1. Introduction

Natural radioactivity is widespread in the Earth's environment, and it exists in various geological formations such as earth crust, rocks, soils, plants, water, sand, sediments and air. It arises mainly due to the different amounts of radioactive nuclides in different sources. The concentrations of natural radioactive materials depend primarily on geological conditions and vary by soil level of different geographical regions [1]. Beach sands are composed mainly of quartz, feldspar, and other minerals resistant to wave abrasion. They are mineral deposits formed by the combination of weathering, fragmentation, and degradation [2]. Studies concerning the radiation hazards arising from the use of sand or soil showed that natural radiation is the largest contribution to external dose to the world population [3,4]. Ionizing radiations are a grave threat around the high background regions of the globe. The presence of monazite sand along the beaches among other factors has contributed to these dreaded radiations [5].

Radioactive contamination occurs when the emission of radioactive substances into the environment are in undesirable levels [6]. Rocks contain naturally occurring radionuclides such as ^{238}U, ^{232}Th and ^{40}K [7]. Such type of existence is harmful to life due to the emission of ionizing radiation and is potent enough to cause damage to tissues and DNA in genes. The south west coastal region of Kanyakumari district is witnessed as a naturally high background radiation area. The deposits of monazite on the coastal areas of Tamil Nadu are formed due to the weathering of rocks in Western Ghats [8]. Beach sand along the coastal regions of Kanyakumari district contains heavy minerals like ilmenite, rutile, zircon, monazite and sillimanite. The existence of ^{232}Th and ^{238}U are mainly due to the monazite bearing black sands. Almost all the rocks contain naturally occurring radionuclides such as ^{238}U, ^{232}Th and ^{40}K [8]. ^{226}Ra, an alpha emitter with a half life of 1600 years and ^{228}Ra, a beta emitter with a half life of 5.8 years are also existing along with these radionuclides [9]. Many residents along the coastal areas are proned to various diseases which are mainly caused by ionising radiations [10]. Hence it is imperative to calculate the back ground radiations and the radioactivity along these radiative spots. This study aims, to determine the gross alpha and the gross beta activities in the sand samples, to compare the radio activities of the samples from Kanyakumari and Tirunelveli Districts and to study the effects of radiation along the coastal areas.

2. Materials and Methods

Ten sampling sites were selected from Kanyakumari and Tirunelveli Districts and the beach sands were collected. Kootapuli, Panjal, Thomaiyarpuram, Perumanal, Uvari, Kooduthalai, Periyathalai, Kudankulam, Kuthenkully and Chettikulam were the sampling sites chosen from Tirunelveli District. Kanyakumari, Kadiyapattanam, Vaniyakudi, Muttom, Colachel, Simoncolony, Kovalam, Rajakamangalam, Ramanthurai and Enayamputhenthurai were the sampling sites selected from Kanyakumari district.

Sand samples collected from various beaches were brought to the laboratory. organic matter and pebbles if present were removed and the samples were initially sun dried by spreading them in a tray. Samples were later dried in an oven at 110^0c for complete removal of moisture for24hours. These samples were filled in plastic containers and the alpha and beta radiations were measured using a Geiger muller counter. A Geiger counter has two main parts, a chamber which is filled with gas and an information display. When the sample is kept inside the chamber, radiation enters the tube and when it collides with the gas, it pushes an electron away from the gaseous atom and creates an ion pair. The counter usually provide "counts per minute," or the number of ion pairs created for every 60 seconds. Before taking the alpha and beta count of the sample the background count was taken.

Radioactivity = (Net count /T x 100/E x 1/W)Bq/g

Net count=Sample count-Background count,

T - Time in seconds

W -Weight of the sample

E - Efficiency

3. Results and Discussion

The discharge of manmade radionuclides, along with the natural radioactive substances into the environment, contaminates the soil and this leads to ecological degradation [11,12]. Even though the radioactive contamination of the environment is relatively rare, it requires a greater attention because of the extreme degrading effects of ionizing radiation on living tissues. Emission of radioactive elements from certain industrial plants contaminates soil and accumulated in the vegetables and crops grown on that contaminated soil. Because of the alarming rates of radioactivity as per the previous studies and the existing diseases along the coastal areas, it is necessary to conduct a study in this area. The radioactivity levels of sand samples collected from the beach sands of Kanyakumari andTirunelveli Districts were measured and the results are tabulated and shown in Table:1.

Table:1 Alpha and Beta Radiations in Kanyakumari and Tirunelveli Districts

S. No	Samples from Tirunelveli District	Alpha Activity Bq/g	Beta Activity Bq/g	Samples from Kanyakumari District	Alpha activity Bq/g	Beta Activity Bq/g
1.	Kuthenkully	2.227	1.5753	Colachel	0.4427	0.4296
2.	Thomaiyarpuram	0.9135	3.2939	Vaniyakudi	0.1702	0.716
3.	Uvari	0.4703	3.7235	Kanyakumari	0.3916	0.5728
4.	Kudankulam	5.1087	14.214	Kadiyapattanam	1.615	0.716
5.	Kootapuli	2.113	0.8592	Enayam puthenthurai	0.7833	2.1482
6.	Periyathalai	1.0567	0.4296	Ramanthurai	0.227	0.5728
7.	Panjal	2.9135	1.7185	Simoncolony	0.1135	0.0431
8.	Perumanal	2.1135	1.0025	Muttom	0.1702	1.2889

9.	Kooduthalai	0.1702	1.2889	Kovalam	0.2838	0.4296
10.	Chettikulam	0.0567	2.005	Rajakkamangalam	0.4427	0.5728

3. 1 Alpha Activity in Tirunelveli District

The natural radioactive materials under certain conditions can create dangerous levels of radiation, and it is felt that the study of natural radioactivity in soil is necessary to assess health risks [13]. In this work, results have shown that the alpha activity of the samples in Tirunelveli District ranges from 0.0567 to 5.1087Bq/g and Kudankulam has the highest value of alpha activity than the other sampling sites. This is due to the availability of alpha emitting particles in the beach sand along with the radiation from the nuclear power plant. The results are highlighted in Fig-1.

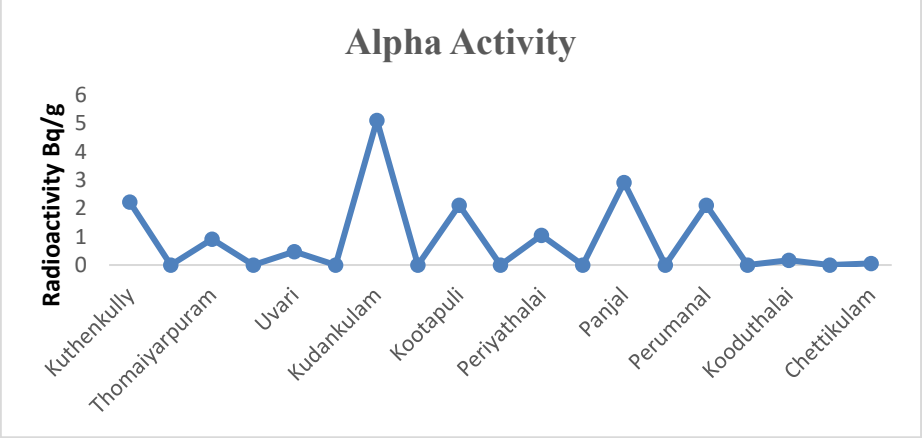


Figure:1 Alpha activity in Tirunelveli District

3. 2 Alpha activity in Kanyakumari District

The alpha activity in Kanyakumari District ranges from 0.1135 to 1.6150 Bq/g and Kadiapattanam has registered the highest activity than all the other nine sampling sites. Vaniyakudi and Muttom have similar value of alpha activity which is about 0.1702 Bq/g whereas, Colachel and Rajakkamangalam have similar alpha activity (0.4427 Bq/g). The lowest activity is observed in Simon colony. The results are shown in Fig-2. The exposure to even low level radiation may lead to somatic infirmities like cancer and genetic defects such as mutation and chromosome aberrations [14,15].

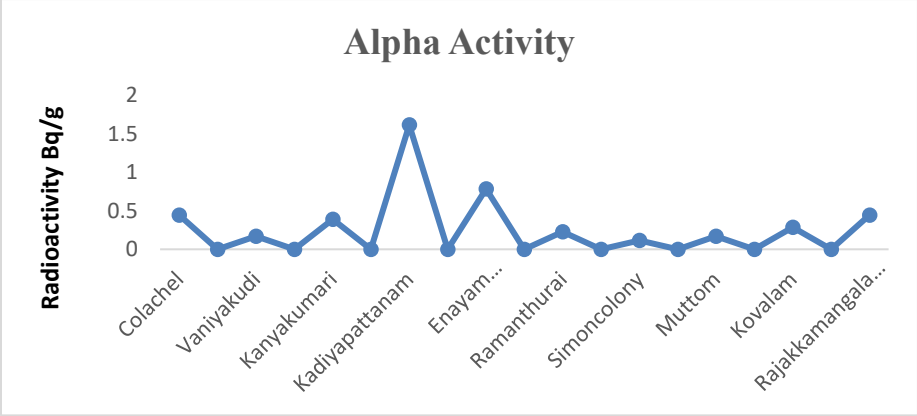


Figure:2 Alpha Radioactivity in Kanyakumari District

3. 3 Beta Activity in Tirunelveli District

It has been observed that the beta activity of Kudankulam is far higher (14.3214Bq/g) than all the other sampling sites in Tirunelveli district. The level of beta activity ranges from 0.4296 to14.214Bq/g. The abnormal high value of beta activity in the specified area is due to the presence of ^{40}K, which is a natural beta emitter [16,17,18] along with the radiation from the power plant. The results are shown in Fig.3.

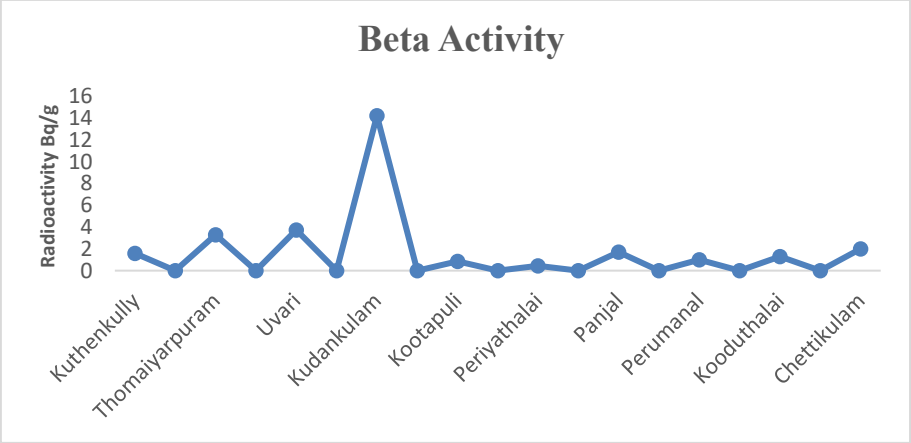


Figure:3 Beta activity in Tirunelveli District

3. 4 Beta Activity in Kanyakumari District

Kanyakumari District is a place of rich mineral wealth and natural resources. Inspite of its mineral wealth, it has its own radiation drawbacks in certain coastal areas. From the results, it is observed that the beta activity of Enayamputhenthurai is (2.1482 Bq/g) higher than all the other sampling sites in Kanyakumari district. Vaniyakudi and Kadiyapattanam have the similar value of beta activity which is about 0.7160 Bq/g. Kanyakumari, Rajakamangalam and Ramanthurai have similar beta activity of 0.5728 Bq/g. There is only minimum beta

activity(0.0431Bq/g) in the sample of Simoncolony, whereas, Colachel and Kovalam have registered a similar beta activity value of 0.4296Bq/g.

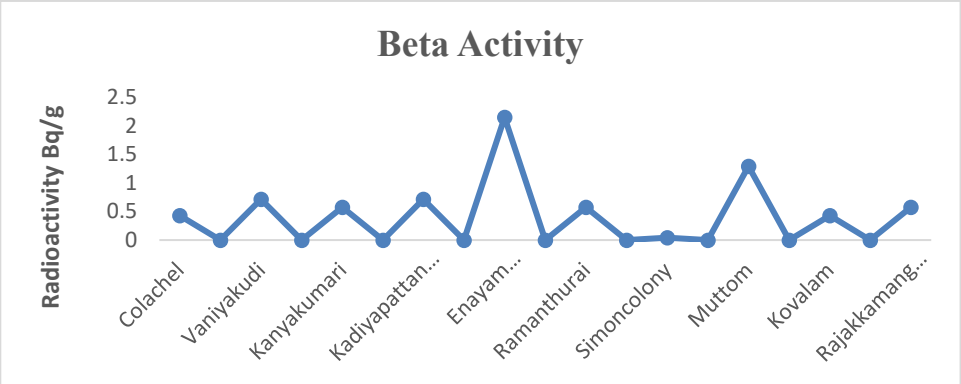


Figure:4 Beta activity in Tirunelveli District

4. Conclusion

The levels of radio activity due to alpha and beta radiations in sand samples collected from Kanyakumari and Tirunelveli district have been assessed. Kudankulam has a high degree of alpha and beta radiations which is due to the background as well as the industrial exposure in that area. In Kanyakumari District, Kadiapattanam has a high dose of alpha radiation and Enayamputhenthurai has a high dose of beta radiation. When we compare the radiation activities of Kanyakumari and Tirunelveli districts, Tirunelveli District has a high degree of alpha and beta radiations which is in an alarming rate. Moreover, in Kudankulam and Kadiapattanam, so many people are affected by chronic as well as dreadful diseases. Hence it is important to take precautionary measures to protect the future generation and environment from these harmful radiations.

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Structural and Chemical Differentiation in *Phyllanthus emblica* L. & *Phyllanthus acidus* L.

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ABSTRACT

This study compares the morphological, anatomical, and phytochemical characteristics of Phyllanthus emblica and Phyllanthus acidus to support accurate identification and pharmacognostic evaluation. Fresh leaves and fruits of both species were examined for major morphological traits, including growth habit, leaf structure, floral features, fruit form, and seed characteristics. Anatomical studies were conducted using hand-cut transverse sections of leaves, stained and observed under a compound microscope. Preliminary phytochemical screening of benzene leaf extract was carried out to detect major classes of secondary metabolites. The results indicate clear distinctions between the two species. Phyllanthus emblica has subsessile, closely arranged leaves, smooth spherical fruits, a thicker midrib, compact mesophyll, and denser supporting tissue. In contrast, Phyllanthus acidus shows alternate ovate-lanceolate leaves, ribbed acidic fruits, loosely arranged spongy parenchyma, and a higher number of stomata. Phytochemical analysis revealed the presence of alkaloids, phenols, tannins, saponins, quinones, and resins in both plants, with Phyllanthus emblica showing higher concentrations of several metabolites and uniquely containing coumarins. In conclusion, although both species share general features typical of the genus, they differ significantly in structural organization and chemical composition. These findings enhance species differentiation and highlight the stronger phytochemical and medicinal potential of Phyllanthus emblica.

Keywords: *Anatomy, Morphology, Phytochemical screening, Phyllanthus acidus, Phyllanthus emblica*

Introduction

The genus *Phyllanthus* (family Phyllanthaceae) comprises more than seven hundred species distributed across tropical and subtropical regions and is recognized for its extensive medicinal relevance [4 & 10]. Many species within this genus are commonly employed in traditional systems such as Ayurveda, Siddha, and folk medicine for the treatment of liver ailments, urinary disorders, diabetes, inflammation, and microbial infections [17]. Among these, *Phyllanthus emblica* (Indian gooseberry) and *Phyllanthus acidus* (star gooseberry) are of particular interest due to their nutritional richness and wide pharmacological applications.

Phyllanthus emblica is valued for its exceptionally high vitamin C content, phenolic compounds, and antioxidant potential, making it a widely used ingredient in herbal formulations [13]. In contrast, *Phyllanthus acidus*, though less studied, contains diverse phytoconstituents such as flavonoids, glycosides, and organic acids, which contribute to its antidiabetic, antimicrobial, and anti-inflammatory properties [22]. Despite their medicinal importance, the two species display notable differences in morphology and phytochemistry, which necessitates accurate identification to prevent substitution or adulteration in herbal preparations [16].

Morphological characters often serve as the primary basis for distinguishing closely related species. However, these features may vary with environmental conditions, making anatomical examination essential for reliable authentication [25]. Similarly, phytochemical screening provides further insight into the distribution of secondary metabolites that influence therapeutic properties and commercial value.

Although several isolated studies describe the properties of *Phyllanthus emblica* and *Phyllanthus acidus*, comprehensive comparative analyses integrating morphology, anatomy, and phytochemistry are limited. Such integrated evaluation is vital for establishing pharmacognostic standards, ensuring quality control, and supporting their safe and effective use in medicinal and nutraceutical industries.

Therefore, the objectives of the present study are:

1. To document and compare the morphological characteristics of *Phyllanthus emblica* and *Phyllanthus acidus*.
2. To examine the anatomical features of their leaves using transverse section analysis.
3. To evaluate their major phytochemical constituents through qualitative screening.

This systematic comparison enhances species identification and contributes to the scientific understanding of these important medicinal plants.

Materials and Methods

Plant Collection and Identification

Fresh and mature leaves and fruits of *Phyllanthus emblica* and *Phyllanthus acidus* were collected from Nagercoil and nearby regions during their respective flowering and fruiting seasons. Specimens were authenticated using standard taxonomic keys from the *Flora of the Madras Presidency*. Healthy, disease-free plant materials were selected, cleaned with distilled water, and processed immediately or stored for further analysis.

Morphological Study

Morphological characters including habit, bark texture, leaf structure, leaf arrangement, floral features, fruit morphology, taste, and seed characteristics were examined following standard botanical procedures. Measurements such as leaf length, fruit diameter, and tree height were recorded using a measuring tape and digital calipers. Fruit taste was assessed by a small sensory panel (3–5 individuals) to maintain consistency. Photographs were documented for comparative evaluation.

Anatomical Study

Anatomical analysis was conducted on fresh leaves and stems using the freehand sectioning method described by [11], with minor modifications. Thin transverse sections (1–2 cm) were cut using a sharp razor blade and transferred to distilled water to prevent dehydration. Selected thin sections were stained with 1% safranin for 2–3 minutes. Excess stain was removed using distilled water, and the sections were mounted in 50% glycerol. Slides were examined under a compound microscope at 10× and 40× magnifications. Photomicrographs were captured for documentation.

Extraction Procedure

Shade-dried leaves were powdered using an electric grinder. Twenty grams of powdered material from each species was macerated in 200 mL of methanol for 72 hours at room temperature with occasional shaking, following the cold extraction method described by [8]. The extract was filtered using Whatman No. 1 filter paper and the filtrate was concentrated at low temperature. Extracts were stored in amber-colored bottles until use.

Phytochemical Screening

Qualitative phytochemical tests were performed using established protocols to identify major classes of secondary metabolites, including alkaloids, phenols, tannins, saponins, quinones, coumarins, and resins. The following standard methods were used: [19, 12, 23 & 9]

- **Alkaloids:** Mayer's test
- **Phenols:** Ferric chloride test
- **Tannins:** Ferric chloride test
- **Saponins:** Foam test
- **Quinones:** Sulphuric acid test
- **Coumarins:** Sodium hydroxide–chloroform test
- **Resins:** Acetone-water test

Results and Discussion

Comparative Morphological Features of *Phyllanthus emblica* L. & *Phyllanthus acidus* L.

Morphological Character	*Phyllanthus emblica*	*Phyllanthus acidus*
Habit	Small to medium-sized deciduous tree, up to 8–18 m tall	Small tree, 2–9 m tall, densely branched
Bark	Greyish-brown, rough, exfoliating in irregular patches	Greyish, smooth, thin
Leaves	Simple, subsessile, light green, appearing like pinnate leaflets; 10–13 mm long	Alternate, ovate-lanceolate, smooth above and bluish-green beneath; 2–7 cm long
Leaf Arrangement	Closely s*et al*ong branchlets, giving a pinnate look	Arranged distichously, more widely spaced
Flowers	Greenish-yellow, unisexual, small, in axillary clusters	Pinkish to white, small, in dense clusters on leafless branches
Fruit	Nearly spherical, pale greenish-yellow, smooth, hard with 6 vertical furrows; 2–3 cm diameter	Oblate, pale yellow, juicy, with 6–8 ribs; 1–2 cm diameter
Fruit Taste	Sour, bitter, astringent with sweet aftertaste	Strongly sour and acidic
Seed	Single, trigonous, hard stone-like	4–6 seeds, embedded in ridges
Flowering & Fruiting Season	Flowers: March–April; Fruits: October–February.	Flowers: March–May; Fruits: June–September

The comparative morphological study of *Phyllanthus emblica* L. (Indian gooseberry) and *Phyllanthus acidus* L. (Star gooseberry) reveals significant variations in their external features, although both belong to the same genus *Phyllanthus* under the family *Phyllanthaceae*.

In terms of habit, *P. emblica* is a small to medium-sized deciduous tree reaching up to 18 m in height, while *P. acidus* is comparatively smaller, attaining a height of about 9 m and characterized by dense branching. This indicates adaptation to slightly different ecological conditions *P. emblica* being more robust and suited to varied climatic conditions [18], whereas *P. acidus* prefers tropical, moist environments.

The bark characteristics also differ markedly. *P. emblica* has greyish-brown, rough bark that exfoliates in irregular patches, signifying a mature, hardy tree. In contrast, *P. acidus* possesses smooth, thin, and greyish bark, which reflects its relatively tender and less woody nature.

A notable distinction is observed in their leaf morphology. The leaves of *P. emblica* are small, simple, subsessile, and closely set along slender branchlets, giving the appearance of pinnate leaflets. On the other hand, *P. acidus* bears larger, alternate, ovate-lanceolate leaves that are smooth above and bluish-green beneath, arranged distichously along the branches. This difference in leaf arrangement and texture influences their photosynthetic efficiency and aesthetic appearance.

The floral features show further divergence. *P. emblica* produces small, greenish-yellow unisexual flowers in axillary clusters, while *P. acidus* bears small pinkish-white flowers in dense clusters on leafless branches. This suggests differences in pollination strategies and visual attraction for pollinators [20].

Regarding fruit characteristics, both species yield edible fruits, but their morphology and taste vary. *P. emblica* fruits are nearly spherical, pale greenish-yellow, smooth, and hard with six vertical furrows, exhibiting a distinctive sour, bitter, and astringent taste with a sweet aftertaste. Conversely, *P. acidus* fruits are smaller, oblate, pale yellow, and juicy with 6–8 ribs, having a strong acidic flavor. These variations reflect differences in their phytochemical compositions and potential uses in traditional medicine and food industries.

The seeds also differ *P. emblica* contains a single, trigonous, hard stone-like seed, whereas *P. acidus* has 4–6 seeds embedded within ridges. This indicates distinct reproductive adaptations within the genus.

Finally, the flowering and fruiting periods show seasonal variation. *P. emblica* flowers during March–April and fruits between October–February, while *P. acidus* flowers from March–May and fruits between June–September. This temporal difference may reduce interspecific competition for pollinators and dispersal agents, allowing coexistence within similar habitats.

Overall, the comparative analysis highlights that although both species share certain generic characteristics of *Phyllanthus*, they exhibit distinct morphological differences in habit, leaf structure, fruit morphology, and reproductive cycles. These adaptations may have evolved in response to their ecological niches, pollination mechanisms, and dispersal strategies.

Anatomical Study of *Phyllanthus acidus* L. Leaf

1. Epidermis

- A single layer of cells present on the upper and lower surfaces (upper epidermis and lower epidermis).
- Covered with a cuticle to reduce water loss.
- Stomata may be present, usually more on the lower epidermis.

2. Mesophyll

Differentiated into:

- Palisade parenchyma: Located towards the upper epidermis; elongated cells rich in chloroplasts, responsible for photosynthesis.
- Spongy parenchyma: Present towards the lower epidermis; loosely arranged with air spaces to facilitate gaseous exchange.

3. Vascular Bundle

- Bundle is conjoint, collateral, and closed.
- Surrounded by a bundle sheath.
- Xylem: Oriented towards the upper (adaxial) side, conducting water and minerals.
- Phloem: Oriented towards the lower (abaxial) side, conducting food materials.
- Vascular bundles are well developed in the midrib compared to lamina.

4. Ground Tissue

- Located around the vascular bundle.
- Consists of parenchymatous cells providing mechanical support.
- May also contain collenchyma beneath the epidermis, giving additional strength.

5. Key Identification Features

- Clear differentiation of mesophyll into palisade and spongy parenchyma (characteristic of dicot leaves).
- Vascular bundle is large and prominent in the midrib region.
- Xylem is placed towards the upper side, phloem towards the lower side.

General Description

The image shows a dicot leaf transverse section at the midrib.

- A prominent vascular bundle with xylem (inner, pink-stained thick cells) and phloem (outer, smaller cells) is seen.
- Surrounding the bundle, parenchymatous ground tissue is visible.
- Epidermal layers form the outer boundary.

- The midrib is thicker compared to the lamina portions.

Anatomical Description of *Phyllanthus emblica* L. Leaf.

1. Epidermis

- Upper and lower epidermis clearly visible as a continuous outer layer.
- Both covered by cuticle.
- Stomata may be present (though not clearly visible in this image).

2. Mesophyll

- Palisade parenchyma: Present beneath the upper epidermis; elongated cells rich in chloroplasts (not distinctly visible due to midrib thickness but typical of dicot leaves).
- Spongy parenchyma: Present below palisade tissue; loosely arranged with intercellular spaces for gaseous exchange.

3. Vascular Bundle

- A prominent oval-shaped vascular bundle is visible at the center of the midrib.
- Surrounded by parenchymatous bundle sheath.
- Xylem (stained darker, larger thick-walled cells) oriented towards the adaxial (upper) side.
- Phloem (smaller cells) oriented towards the abaxial (lower) side.
- The bundle is conjoint, collateral, and closed.

4. Ground Tissue

- Region around vascular bundle filled with parenchyma.
- Provides mechanical support.
- Collenchyma may be present just below the epidermis in the ridges of the midrib.

5. Key Identification Features

- Midrib appears thicker compared to lamina.
- Prominent vascular bundle in the center.
- Clear adaxial-abaxial polarity (xylem above, phloem below).
- Surrounding ground tissue seen as lightly stained region.
- The section is stained pink:
- Xylem appears as dark-stained cells.
- Phloem appears as smaller, lighter-stained cells.

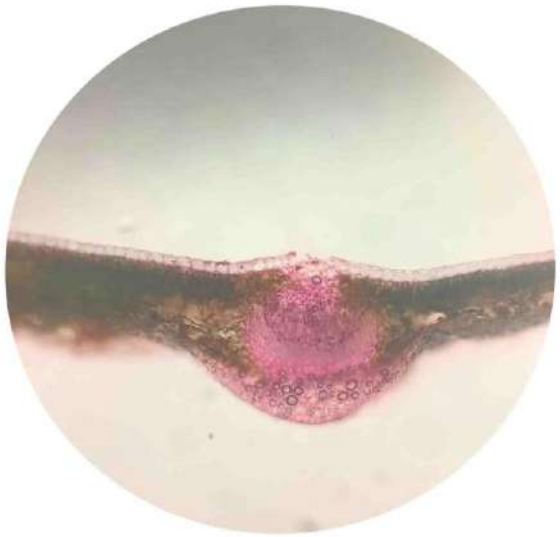
General Description

The microscopic image shows a transverse section of dicot leaf midrib. A large central vascular bundle is visible, surrounded by parenchymatous ground tissue. The epidermis forms

a protective covering on both upper and lower sides. The vascular bundle shows xylem facing upwards and phloem downwards. The midrib is distinctly thicker than the lamina portion.

Comparative Anatomical Study of *Phyllanthus emblica* L. and *Phyllanthus acidus* L. (Leaf)

A comparative examination of the transverse section (T.S.) of the leaves of *Phyllanthus emblica* and *Phyllanthus acidus* reveals typical dicot leaf characteristics in both species, yet distinct differences in structural organization and tissue differentiation are evident.



Anatomy of *Phyllanthus acidus* L.



Anatomy of *Phyllanthus emblica* L.

Anatomical Character	*Phyllanthus emblica* L.	*Phyllanthus acidus* L.
Epidermis	Upper and lower epidermis distinct; both covered by a cuticle. Stomata may be present, mainly on the lower surface.	Single-layered upper and lower epidermis; cuticular covering present; stomata abundant on the lower epidermis.
Mesophyll	Differentiated into palisade and spongy parenchyma; palisade cells compact and rich in chloroplasts.	Well differentiated into palisade and spongy parenchyma; spongy parenchyma loosely arranged with wide air spaces.
Vascular Bundle	Prominent oval-shaped vascular bundle at midrib; conjoint, collateral, closed type. Xylem directed upward (adaxial), phloem downward (abaxial).	Conjoint, collateral, closed vascular bundle surrounded by bundle sheath. Xylem oriented adaxially, phloem abaxially; well developed at midrib.
Ground Tissue	Parenchymatous ground tissue surrounds the vascular bundle; collenchyma may occur beneath the epidermis in the midrib region.	Parenchymatous ground tissue surrounds the bundle; collenchyma cells present below the epidermis, giving strength.
Key Features	Midrib thick and prominent; xylem darkly stained and phloem lighter; typical dicot structure with clear polarity.	Midrib thicker than lamina; distinct differentiation of mesophyll and well-defined vascular bundle; dicot leaf characteristics.

The anatomical analysis of *Phyllanthus emblica* and *Phyllanthus acidus* leaves confirms that both exhibit a typical dicotyledonous leaf structure, characterized by a dorsiventral arrangement with a well-defined upper and lower epidermis, differentiated mesophyll, and conjoint collateral vascular bundles. Despite these common features, notable variations exist in tissue organization and development.

The epidermal structure in both species is composed of a single layer of compactly arranged cells covered with a cuticle, which helps in reducing transpiration. However, *P. acidus* shows relatively more stomata on the lower epidermis, indicating an adaptation to enhance

gaseous exchange under dense canopy conditions, whereas *P. emblica* maintains a balanced distribution to reduce water loss in drier habitats [5].

In both species, the mesophyll tissue is clearly differentiated into palisade and spongy parenchyma, which is a diagnostic feature of dicot leaves. *P. emblica* exhibits tightly packed palisade cells rich in chloroplasts, implying higher photosynthetic efficiency. In contrast, *P. acidus* shows more loosely arranged spongy parenchyma with large intercellular spaces, facilitating better gas exchange and transpiration control [24].

The vascular bundle in both species is conjoint, collateral, and closed, surrounded by a bundle sheath that provides protection and support. However, *P. emblica* shows a more prominent and oval-shaped vascular bundle with well-differentiated xylem and phloem, indicating efficient transport of water, minerals, and nutrients. *P. acidus*, though similar in arrangement, possesses a comparatively smaller vascular bundle but with a well-developed bundle sheath and clear polarity (xylem upper, phloem lower).

The ground tissue in both leaves mainly consists of parenchymatous cells, offering mechanical support and storage functions. Collenchyma is present beneath the epidermis in both species, particularly in the midrib region, adding flexibility and tensile strength to the leaf. The ground tissue in *P. emblica* appears denser, correlating with its thicker leaf and greater mechanical stability.

Overall, both *Phyllanthus emblica* and *Phyllanthus acidus* exhibit the typical dicot leaf anatomy; however, *P. emblica* possesses a thicker midrib, denser ground tissue, and more compact mesophyll arrangement, whereas *P. acidus* shows more stomata and a loosely arranged spongy mesophyll. These differences may reflect their ecological adaptations *P. emblica* to semi-arid, sun-exposed conditions and *P. acidus* to relatively moist, shaded environments.

Comparative Phytochemical Analysis of *Phyllanthus emblica* L. & *Phyllanthus acidus* L.

Sl. No	Phytochemical components	Benzene Leaf Extract	
		***Phyllanthus emblica* L.**	***Phyllanthus acidus* L.**
1	Alkaloids	++++	++++
2	Phenols	+++	+++
3	Quinones	+	+
4	Tannins	+++	+

5	Saponins	++	+	
6	Coumarin		+	-
7	Resins		++++	+++
Absent (-); Very Low (+); Low (++); Moderate (+++); High (++++)				

The qualitative phytochemical analysis of the benzene leaf extracts of *Phyllanthus emblica* and *Phyllanthus acidus* revealed the presence of several bioactive compounds such as alkaloids, phenols, quinones, tannins, saponins, coumarins, and resins. The intensity of these constituents varied between the two species.

In *Phyllanthus emblica*, alkaloids and resins were found in high concentration (++++), followed by moderate amounts of phenols and tannins (+++), and low levels of saponins (++). Quinones and coumarins were present in very low quantities (+).

In *Phyllanthus acidus*, alkaloids and resins were also highly expressed (++++ and +++ respectively), while phenols were present in moderate concentration (+++). Tannins, saponins, and quinones were detected in very low to low amounts (+), and coumarins were completely absent.

These observations indicate that both species possess a rich diversity of secondary metabolites, though their relative abundance differs between the two.

The comparative phytochemical screening demonstrates that both *Phyllanthus emblica* and *Phyllanthus acidus* contain significant levels of active compounds, suggesting their potential medicinal value. However, the quantitative differences in specific phytoconstituents reflect their varied therapeutic properties and applications [15].

The high concentration of alkaloids in both species indicates strong pharmacological potential, as alkaloids are known for their antimicrobial, analgesic, and anti-inflammatory properties. This supports the traditional use of *Phyllanthus* species in treating infections and pain-related ailments [1, 2 & 14].

Phenols were moderately present in both extracts, suggesting strong antioxidant activity. Phenolic compounds are important natural antioxidants that scavenge free radicals, thereby contributing to the plants' hepatoprotective and anti-aging properties [21 & 7].

Tannins were more abundant in *P. emblica* than in *P. acidus*. The higher tannin content in *P. emblica* may account for its well-known astringent and antimicrobial effects and its use in traditional medicine for wound healing and digestive disorders.

Saponins were detected in low levels in *P. emblica* and in very low levels in *P. acidus*. Since saponins have expectorant and immune-boosting activities, *P. emblica* may possess relatively stronger activity in these aspects.

Coumarins were present only in *P. emblica*, indicating a unique phytochemical component absent in *P. acidus*. Coumarins are known for their anticoagulant and antioxidant roles, which may enhance the medicinal value of *P. emblica* [6].

Both species showed the presence of resins, which were high in *P. emblica* and moderate in *P. acidus*. Resins contribute to the plant's antimicrobial and protective functions, forming a defensive barrier against pathogens [3].

Overall, the results reveal that *Phyllanthus emblica* possesses a broader and more intense spectrum of phytochemical constituents compared to *Phyllanthus acidus*. This may explain its wider therapeutic use in traditional systems of medicine such as Ayurveda.

Conclusion

This study highlights clear morphological, anatomical, and phytochemical differences between *Phyllanthus emblica* and *Phyllanthus acidus*, confirming their distinct identity within the same genus. *Phyllanthus emblica* showed more compact tissue structure and a richer profile of secondary metabolites, while *Phyllanthus acidus* presented simpler anatomy and lower phytochemical levels. By integrating multiple analytical approaches, this work provides reliable identification markers and supports accurate pharmacognostic evaluation. The findings contribute useful scientific insights for herbal quality control and the future medicinal use of both species.

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Ethno spices used by Kani tribes of Kanyakumari Wildlife Sanctuary, Tamilnadu, India

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ABSTRACT

Spices are those delightful plants that make meals more enjoyable by enhancing their aroma, flavor, and color. The present study was carried out among the Kani – endemic tribe residing in and around foothills of Kanyakumari Wildlife Sanctuary, Tamilnadu, India. The data was collected by preparing structured questionnaire. A total of 15 spice plants were used as medicine by the tribes. The plants belonging to Zingiberaceae, Piperaceae, and Lauraceae were mostly used as spices. Herbs were mostly used as medicinal spice followed by tree and climber. Rhizome is the most frequently used plant part as spice for medicine preparation. Kani tribes still depend on medicinal herbs for meeting their primary healthcare needs.

Keywords: *Spice, Kani tribe, Kanyakumari Wildlife Sanctuary*

1. Introduction

Herbs are the seed-producing annual, biennial or perennial plant that does not develop persistent woody tissue but dies after one growing season. Spices are the any of the various fragrant plant products used to season or add taste to foods. Spices and herbs are defined as plant derived substances that add aroma.fFragrance and appetizing quality to food. Spices derived from rhizome, stem, roots, leaves, bark, flowers, fruits and seeds. Herbs are non-wood plants [1]. Spices are plant parts, which include fruits, Kernels, leaf, rhizome and bark. This ethnobotanical study was an attempt at collecting basic but valuable information on these aspects, which can lead to novel drugs in the future as a curative solution for health problems.

2. Materials and methods

2.1. Demography and Location

As per the 2001 census, scheduled tribes account for approximately 1% of Tamil Nadu's total population (651,321 individuals). There are a total of 36 tribal communities, with 6 classified as primitive tribes. The Kani, identified as a primitive tribe, inhabit the Kanyakumari and Tirunelveli districts of Tamil Nadu as well as parts of Kerala in the Western Ghats. According to the 1981 census, Kanyakumari district contained 48 Kani settlements, covering an area of 1250.05 hectares of forest land designated for 927 families. Between 1980 and 1985,

the government constructed roads to these settlements. Currently, the population of these tribes is estimated to be around 3,900 to 5,000.

The Kanyakumari Wildlife Sanctuary in Kerala along with Kalakkad Mundanthurai Tiger Reserve and Neyyar Wildlife Sanctuary are the southernmost tip of the Western Ghats and are home to the Kanis. Natural vegetation in this part of the world ranges from Southern Thorn Forests, Dry Deciduous and Moist Deciduous Forest, Semi Evergreen Forest to Evergreen Sholas with Grassy Downs. Due to its tremendous biological potential, Kanyakumari Wildlife Sanctuary was established in 2002.

2.2. Kani Tribe- The Kanikkars

Kanikkars, a forest-dwelling endemic tribe in the Southern Western Ghats, live in the Kanyakumari Wildlife Sanctuary, Kalakkad Mundanthurai Tiger Reserve, and Neyyar Wildlife Sanctuary. They are part of the Southern Tribal Zone in India. In Tamil, the term Kani signifies a unit of land. When the suffix Karan is added, the resultant term Kanikkaran is formed, which translates to ‘the proprietor of the land across various generations’. The word Kani or Kaanikkar also refers to someone who inherits land. Another interpretation of the word 'Kani' suggests that Kaan signifies forests, indicating that Kani are individuals associated with the forest, as Kaan translates to forest.

Ethnomedicinal data collection

To investigate the medicinal uses of spice plants among the Kani tribes, an ethnobotanical survey was carried out in the tribal areas of Pechiparai and Keeriparai Forest Ranges, located at the southern end of the Western Ghats. The Kani tribe resides along the forest edges of Kanyakumari and Tirunelveli districts in the southern Western Ghats of Tamil Nadu, India, as well as in the adjacent forests of Kerala. The survey was carried out using semi-structured open-ended interviews that followed established ethnobotanical techniques [2,3]. Semi-structured interviews allow for comprehensive insights and unplanned comments from participants. The information gathered encompassed the local name, the plant parts utilized, the preparation methods for each remedy, how they are used, and the specific ailments each plant addresses. The interviews were conducted in Tamil. Information gathered from direct interviews was immediately recorded in field notebooks as preliminary data.

2.3. Language

They speak a unique dialect, a mixed version of Tamil and Malayalam known as 'Malaibashai,' the language of the hills.

2.4. Food habits

The Kanis continue to enhance their diet by foraging for roots and tubers in the forest. Their tuber consumption includes varieties such as *Manihot esculenta, Dioscorea oppositifolia, and Ceropegia spiralis*, among others. They primarily rely on wild edible plants for their nutrition. Both wild and cultivated tubers serve as their main source of food. They refrain from consuming beef. The tribe also eats seeds from *Artocarpus heterophyllus*, fruits from *Ochlandra travancorica*, fruits from *Baccaurea courtallensis*, the endosperm of *Mangifera indica*, cotyledons from *Entada rheedii*, and seeds of *Cycas circinalis* that have been cooked through steaming.

2.5. Medicinal Plant Knowledge

The Kanis possess extensive knowledge of medicinal plants for their primary healthcare needs. They utilize herbal remedies to address ailments such as coughs, colds, fevers, and snake bites. The tribes' rich understanding of these plants stems from centuries of beliefs and observations. This knowledge has been passed down through generations.

2.7. Plant collection and Identification

Plant specimens were gathered by walking through the forest. Some of the plants were recognized on-site. Photographs were captured during the collection. While gathering, the taxa were categorized based on their growth forms: herb, shrub, tree, liana, and climber. Specimens were collected for the creation of voucher specimens. These voucher specimens were stored at the Department of Botany and Research Centre at Scott Christian College, Nagercoil. The plant specimens were identified with assistance from local and regional floras [4,5]. To ensure accurate spelling, update outdated synonyms, and maintain consistent nomenclature, all plant names were verified using [6].

3. Results and Discussion

3.1. Habit of medicinal plants

Herbs are primarily used by Kanis to prepare medicines. Nine of the fifteen ethnomedicinal spice plants were herbs, followed by three trees and three climbers. All cultures have utilized herbs as medicine since ancient times [7–9]. The herbs' immediate availability and ease of collection are additional factors in their favor [10]. [11] suggested that trees are typically subordinated to herbs and shrubs in the higher altitude zone. The fact that Kani tribal settlements are located in high-altitude areas may account for the higher percentage of herbs used as medicine. All cultures have utilized herbs as medicine since the beginning of time. Due to the abundance of herbs in the areas surrounding tribal settlements, this custom is still

observed. Deep, impenetrable tropical forests are home to kanis. However, they clear the forests.

Table 3.1. Ethno spices used by the Kani tribes

Sl. No	Binomial name	Kani / local name	Family	Parts used	Habit	Mode of preparation	Ethnomedicinal preparation	Therapeutic action/ disease it cures	Application
	Allium sativum L.	Poondu	Amaryllidaceae	Bulb	Herb	Paste	Bulb made into paste with honey administrated orally to get relief from abdominal pain during pregnancy.	Gynecological disease	Oral
	Alpinia galanga (l.) Willd.	Perarathai	Zingiberaceae	Rhizome	Herb	Decoction	Decoction of rhizome along with ginger rhizome , pepper and jaggery taken orally for three times for two days cure cough and cold. 2. Boil ten leaves with water (50 ml) . Consume 10 ml of the water cures and indigestion and gas trouble 3. Rhizome paste applied on the skin to cure scabies.	Cough and cold/ gastro intestinal/skin disease	Topical
	Alpinia calcarata (haw.) Roscoe	Chittrathai	Zingiberaceae	Rhizome	Herb	Decoction	Equal quantities of rhizome and Ocimum leaves are boiled with water to prepare decoction. About 20 ml of this decoction is consumed three times for seven days cures	Respiratory disease	Oral/Topical

							bronchitis and fever.		
	Boswellia serrata roxb. Ex colebr.	Kunthrigam	Burseraceae	Bark	Tree	Resin	Dried resin from bark use for treating joint pain arthritis	Skeleto muscular disease	Topical
	Cinnamomum verum J.Presl.	Karuva pattai	Lauraceae	Bark	Tree	Decoction	Boil 20 grams of bark in water. To treat bronchitis, the decoction (5 ml) is taken orally for seven days. 2. Boiled bark in coconut oil. Rheumatic pain is relieved by applying this oil topically for 21 days.	Respiratory disease / skeleto muscular disease	Oral
	Eryngium foetidum L.	Rasa chedi	Apiaceae	Leaf	Herb	Paste	Leaves made into paste is applied topically over skin reduces itching	Dermatological disease	Oral
	Ferula asafoetida Linn	Perumkayam	Apiaceae	Stem-Gum resin	Tree	Paste	Gum resin used to treat gastritis and acts as appetizer.	Gastro-intestinal disease	Oral
	Hyptis suaveolens (L.) Poit	Natha puchadi	Lamiaceae	Leaf	Herb	Juice	1. Burns are treated topically with leaf extract. 2. Hand-squeezed leaf juice is combined with breast milk and applied to the afflicted eyes twice a day to treat an eye infection.	Dermatological diseases/eye infection	Topical.
	Leucas aspera (Willd.) Link	Thumbai	Lamiaceae	Leaf and root	Herb	Decoction	1. To get rid of intestinal worms, drink 20 milliliters of leaf	Gastro intestinal disease/head ache	Paste

							decoction. 2. A fine paste made from ground leaves and roots. When applied topically to the forehead, this paste (5 gm) relieves headaches.		
	Peperomia pellucida (L.) Kunth	Thirumeni	Piperceae	Leaf	Herb	Paste	Leaves made into paste and applied topically over cut wounds.	: Dermatological disease	Oral
	Piper mullesua buch.-ham. Ex d. Don	Kattu nalamilaghu	Piperceae	Fruit	Climber	Decoction	Fruit decoction (25 ml) is taken orally drunk twice a day for three days cures cough and cold..	Respiratory disease	Topical
	Piper nigrum L.	Nalla milaghu	Piperceae	Fruit	Climber	Decoction	1. An oral curry made with equal parts piper seeds, mustard, dried ginger, fenugreek, garlic, and turmeric powder and a small amount of water can heal uterine delivery wounds. 2. A decoction made with a small amount of jaggery, water, and dried ginger that is taken once at night to treat fever, colds, and coughs.	Gynecological disease/ Respiratory disease	Oral/Topical
	Zingiber officinale roscoe	Inchi	Zingiberaceae	Rhizome	Herb	Juice	1. Drinking rhizome juice after meals relieves gas and	Gastro-intestinal/ circulatory disease	Topical

							indigestion. 2. The haeme count is increased when rhizome extract (10 ml) and honey (5 ml) are taken orally for a month.		
	Zingiber zerumbet (l.) Roscoe ex sm.	Chenthikil angu	Zingiberaceae	Rhizome	Herb	Paste	Rhizome paste is applied over body prevents honey bee sting	Honey bee sting	Oral
	Zingiber montanum (K.D. Koenig) Link.	Kattu Inchi	Zingiberaceae	Rhizome	Herb	Paste	Rhizome (10 gm) made into paste taken orally cures gas trouble.	Gastro-intestinal	Oral

3.2. Plant parts used for medicine preparation

Kanis prepare medicines using every part of the plant. The most utilized plant part is the rhizome, which is followed by the leaves, fruit, and bark. The rhizome is where the plant typically stores its proteins, starch, and other nutrients. Rhizomes act as a defense mechanism, enabling plants to endure harsher weather conditions like intense cold and wildfires. They are the plant's perennation organs [12]. The rhizome's active ingredients are used in food additives, spices, cosmetics, preservatives, and the pharmaceutical industry. Leafy spices were also widely used by the tribes. It is simple to gather leaves from the forest [13]. Compared to other plant parts, leaves are easily obtained in large quantities, which may explain their high usage.

3.3. Mode of preparation

Different forms of medicine are prepared by Kani tribes. They are divided into five groups. Paste (5 taxa) was the most widely used preparation method, followed by decoction (5 taxa), raw (1 taxa), juice (2 taxa), oil (1 taxa), and resin (1 taxa). When making medications, water is frequently utilized as the solvent. Making a paste is a very simple way to make a medication. A single plant species is used in the majority of medicinal preparations, though occasionally several species are combined. Depending on the kind of illness and severity of conditions, different preparation and application techniques are used. When making herbal medicines, Kani tribes commonly use adjuvants such as cane sugar, palm sugar, coconut milk, honey, cow milk, and breast milk.

3.4. Medicinal validation of spice plants

Bulbs of *Allium sativum* is with allicin a lipid soluble sulfur compound, which can be easily damaged by cooking and has the ability to cure allergic reactions and gastrointestinal disorders [16]. Phytochemical screening shows that the rhizome of *Alpinia* is rich in flavonoids, volatile oil, terpenes and it has been used as a remedy for gastro intestinal diseases, acts as inti-inflammatory agent [17]. *Cinnamomum verum* bark contains alkaloids, terpenes, volatile oils and cinnamaldehyde. Bark extracts showed good ameliorative effects in induced collagen induced arthritic mice [18]. Boswellic acid is the active ingredient of *Boswellia serrata* , clinical studies proved that it possess anti-inflammatory, anti-arthritic property [19]. *Erygium foetidium* contain volatile compounds which suppress viral diseases and infections also it is proved to possess anti-inflammatory property [20] *Ferula asafetida* produces gum resinous material which is rich in ferulic acid helps in curing gastritis [21]. *Hyptis suaveolens* has identified as medicinal plant due to the presence of phenols, saponin, terpenes and sterols, wound healing property is due to free radical scavenging activity and the effect of antioxidant enzymes in granuloma tissue [22]. *Leucas aspera* are rich in various phytochemicals such as triterpenoid, sterols, ursolic acid, diterpenes, nicotine [23] this could be the reason for its analgesic effect. Pellucidin a secondary metabolite isolated from *Peperomia pellucida* [24] is responsible for reducing pain in cut wounds. *Piper* species contains piperine which poses antihistamine activity and bronchodilator activity. Clinical studies proved that Zingiber species increased the gastrointestinal motility [25]

5. Conclusion

Endemic tribe residing in the foothills of Western Ghats use spices to treat various ailments. The tribal people have acquired the knowledge about the medicinal plant from their ancestors which transferred from generation to generation. Due to deforestation, certain valuable plants were under the stage of extinction. Such medicinal plants should be conserved and regenerated. Medicinal plants used by the tribe must be subjected for pharmacological investigation for the discovery of novel drugs.

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From traditional healers to modern science: A review of the medicinal potential of *Solanum trilobatum* L.

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ABSTRACT

Solanum trilobatum L. is a well-known medicinal plant widely employed in traditional healthcare practices, particularly in South India, for the management of respiratory and inflammatory ailments. Commonly known as "Thuthuvalai", this thorny climber occupies an important position in Siddha and Ayurvedic systems of medicine. The present review integrates traditional ethnomedicinal knowledge with contemporary pharmacological evidence, offering a concise overview of the therapeutic applications, phytochemical constituents, and medicinal potential of S. trilobatum. Ethnomedicinal documentation indicates that the leaves, flowers, and fruits of S. trilobatum have been traditionally used in the treatment of bronchial asthma, chronic cough, sore throat, tuberculosis, and fever. The plant is also regarded as a rejuvenating agent that supports respiratory function and enhances immune defense. In traditional practices, it is administered as herbal decoctions, powdered formulations, or incorporated into food preparations for both preventive and therapeutic purposes. Phytochemical studies have revealed the presence of several bioactive compounds in S. trilobatum, including solasodine, solanine, flavonoids, alkaloids, glycosides, and saponins. These compounds are reported to exhibit diverse pharmacological activities such as antioxidant, anti-inflammatory, antimicrobial, antitumor, hepatoprotective, and immunomodulatory effects. Evidence from in vitro and in vivo studies supports its potential role in the management of respiratory disorders, infections, and certain chronic diseases. Although the plant shows considerable therapeutic promise, clinical investigations remain limited. This review emphasizes the need for further pharmacokinetic, toxicological, and clinical studies to establish its safety and efficacy. Conservation of this ethnomedicinal species is also essential due to its increasing medicinal demand and ecological value. Overall, Solanum trilobatum highlights the relevance of traditional medicinal knowledge in guiding modern pharmacological research and plant-based drug development.

Keywords: *Solanum trilobatum L., Traditional uses, Pharmacological Properties.*

Introduction

Medicinal plants have been used in Homeopathy, Ayurveda, Allopathy, and traditional medicine since ancient times. They continue to play a vital role in both traditional and modern systems of healthcare. Their relevance has increased due to side effects of synthetic drugs, rising antibiotic resistance, and high costs. In rural areas, dependence on traditional medicine remains high due to limited access to modern healthcare. In fact, 80% of the population in developing countries still relies on natural remedies [1]. In India, over 75% of people live in rural regions close to natural resources, fostering a rich tradition of plant-based healing [2].

The therapeutic effects of medicinal plants stem from complex chemical substances known as secondary metabolites [3]. These plants are economically important as they serve as raw materials for traditional pharmaceuticals [4]. Their chemical constituents can produce specific physiological effects in the human body. Ethnopharmacological research is considered effective in discovering novel anti-infective agents [5]. Understanding plant chemistry aids not only in drug discovery but also in identifying new sources of economic compounds such as tannins, gums, and oils. Moreover, it helps validate the efficacy of folklore remedies [6].

Botanical description

Solanum trilobatum is a slender prickly scrambling shrub, prickles curved, broad-based, yellowish and numerous along the stems, otherwise almost glabrous. Leaves rounded-ovate in outline, obtusely 3-5-lobed, 2-7 cm long, 1-4 cm wide, glabrous or slightly stellate, with a few prickles along the petiole and midrib. Inflorescences extra-axillary, peduncle short, 3-9-flowered; pedicels 1-2 cm long, widely divergent. Calyx 3 mm long, with narrow teeth, sparsely stellate. Corolla 12-16 mm long, deeply lobed, stellate-pubescent outside, purple, reflexed; stamens protruding, anthers 7 mm long, yellow. Fruits globose, scarlet. Seeds compressed, 3 mm dm.

Traditional Therapeutic Relevance of *Solanum Trilobatum* L.

Solanum trilobatum L. holds a prominent position in traditional South Indian medicinal systems, particularly Siddha and Ayurveda. Known locally as "Thuthuvalai" in Tamil, the plant is extensively used for its potent therapeutic properties. The roots, stems, and leaves of the plant are traditionally used in the management of a wide range of respiratory disorders, such as acute and chronic bronchitis, asthma, sinusitis, tonsillitis, common cold, persistent cough, tuberculosis, and other pulmonary infections [7-10]. The leaves are mainly used in treating dyspepsia, spermatorrhoea, tuberculosis, ear problems, and bacterial infections. The plant's mucolytic and bronchodilatory effects are well-recognized in folk medicine. The therapeutic effects of the plant are attributed to the presence of bioactive

constituents, including solasodine, flavonoids, and glycoalkaloids, which are known to exhibit anti-inflammatory, antioxidant, and antimicrobial properties [11].

In Siddha medicine, *Solanum trilobatum* is classified as a "Siddha kayakalpa" herb used for rejuvenation and immunity enhancement. The leaf juice is also traditionally applied topically for treating ulcers, skin eruptions, and insect bites. The presence of steroidal alkaloids further validates its therapeutic role in promoting respiratory and dermatological health [12].

Modern Pharmacological Perspectives of *Solanum Trilobatum* L.

Modern pharmacological investigations have validated several of the plant's traditional uses. *Solanum trilobatum* exhibits a diverse range of bioactivities including antibacterial, antifungal [13,14] anticancer [15-20] antioxidant [21] antidiabetic [22] hepatoprotective [23] Chemoprotective [24] antinociceptive [25] antihyperlipidemic [26] anti-inflammatory [27-29] and mosquitocidal activity [30, 31]. These activities are mainly due to its abundant phytochemical profile comprising steroidal alkaloids (such as solasodine), glycosides, flavonoids, and phenolic compounds [32, 33].

Antimicrobial Activities

Solanum trilobatum L., a plant extensively employed in traditional medicinal practices of South India, has attracted increasing scientific attention for its antimicrobial potential in recent years. Experimental studies have revealed that extracts obtained from different plant parts, especially the leaves and stems, possess notable antibacterial activity against a wide range of human pathogenic microorganisms. In particular, methanol and ethanol-based extracts have been reported to effectively suppress the growth of both Gram-positive and Gram-negative bacteria, including *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Klebsiella pneumoniae* [34, 35].

The antibacterial potential is largely attributed to bioactive compounds such as alkaloids, flavonoids, phenolic acids, and glycosides that compromise the structural integrity of bacterial cell walls or interfere with key enzymatic functions [32]. The presence of steroidal alkaloids like solasodine may also contribute to membrane permeability alterations in microbial cells. In addition to antibacterial effects, *S. trilobatum* also exhibits noteworthy antifungal activity. Ethanolic extracts have shown strong inhibition of antifungal activity against pathogenic fungi such as *Candida albicans*, *Aspergillus niger*, and *Trichophyton rubrum*, fungal species commonly linked to respiratory and skin infections [33]. These findings highlight the plant's broad-spectrum antimicrobial potential which provides scientific justification for its traditional use in treating infections.

Anticancer Activities

Solanum trilobatum L., a medicinal species widely recognized in Indian traditional healthcare practices, has recently attracted considerable research interest for its prospective anticancer activity. Experimental investigations using both cell culture models and animal systems have reported notable cytotoxic effects against a range of human cancer cell lines. These antineoplastic actions are largely associated with bioactive constituents such as steroidal alkaloids, glycosides, and phenolic compounds, which are known to induce apoptosis and suppress abnormal cell proliferation *[36].*

Methanolic and ethanolic extracts of *S. trilobatum* have shown significant cytotoxicity against HeLa (cervical cancer), MCF-7 (breast cancer), and A549 (lung cancer) cell lines. The mechanism of action involves induction of apoptosis through mitochondrial membrane disruption, DNA fragmentation, and cell cycle arrest [24]. Moreover, the antioxidant constituents of the plant contribute to the reduction of oxidative stress, thereby aiding in the prevention of cancer onset and progression [32].

Moreover, phytochemical analyses have revealed the presence of bioactive constituents, including solasodine and flavonoids, which are suggested to influence intracellular signaling cascades involved in tumor development. These compounds may contribute to the suppression of oncogene expression while promoting the activation of tumor suppressor pathways [33]. Collectively, these findings underscore the promise of *S. trilobatum* as a valuable candidate for the development of novel plant-derived anticancer agents.

Antioxidant Activities

In recent years, *Solanum trilobatum* L., a medicinal plant traditionally used in South Indian systems of medicine, has gained attention in modern pharmacology for its notable antioxidant properties. The strong antioxidant activity of the plant is primarily associated with its diverse phytochemical makeup, notably flavonoids, phenolic compounds, alkaloids, and glycosides. [32].

The antioxidant capacity of *S. trilobatum* has been evaluated using multiple in vitro methods, including DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging, ABTS, nitric oxide scavenging, and ferric reducing antioxidant power (FRAP) assays. Findings from these assessments indicate that aqueous and ethanolic extracts derived from the leaves and stems exhibit pronounced free-radical neutralizing activity, showing efficacy comparable to that of standard antioxidants such as ascorbic acid [35]. This activity is primarily attributed to the ability of plant-derived compounds to donate electrons or hydrogen atoms to reactive radicals, thereby stabilizing them and limiting oxidative damage. Oxidative stress plays a critical role in

the development of various chronic conditions, including cancer, cardiovascular disorders, neurodegenerative diseases, and the aging process [36].

In vivo investigations further validate the antioxidant potential of *Solanum trilobatum*. Studies using animal models have demonstrated that administration of its extracts significantly reduces lipid peroxidation while elevating the levels of key endogenous antioxidant enzymes, including superoxide dismutase (SOD), glutathione peroxidase (GPx) and catalase (CAT), in liver and kidney tissues [37]. These results indicate that the plant not only mitigates oxidative damage but also strengthens the body's intrinsic antioxidant defense mechanisms. The remarkable antioxidant properties of *S. trilobatum* highlight its therapeutic promise for managing and preventing conditions associated with oxidative stress, corroborating its traditional use as a revitalizing and health-promoting medicinal herb.

Antidiabetic Activities

Solanum trilobatum L., non-woody plant commonly utilized in traditional Indian medicine. Its antidiabetic potential has recently been explored using contemporary pharmacological approaches. The increasing global prevalence of diabetes mellitus, particularly type 2 diabetes, has prompted the scientific community to explore plant-based remedies with hypoglycemic potential. Among such candidates, *S. trilobatum* has gained attention as a potential natural therapeutic agent.

Phytochemical analyses of *S. trilobatum* have revealed the presence of biologically active compounds such as alkaloids, flavonoids, glycosides, and saponins, recognized for their role in modulating glucose metabolism and enhancing insulin sensitivity [32]. These constituents play a significant role in modulating carbohydrate-digesting enzymes and improving peripheral glucose utilization. In diabetic animal models, research has demonstrated the effects of ethanolic and aqueous *S. trilobatum extracts* significantly reduce fasting blood glucose levels. In streptozotocin-induced diabetic rats, administration of the extract led to a marked improvement in blood glucose, glycosylated hemoglobin (HbA1c), and serum insulin levels [37]. This suggests a dual mechanism involving both insulin mimetic action and pancreatic β-cell regeneration.

Moreover, the extract was found to inhibit key carbohydrate-metabolizing enzymes such as α-amylase and α-glucosidase, thereby reducing postprandial hyperglycemia [38]. This enzyme inhibition delays glucose absorption in the intestine and offers a mechanism similar to clinically used antidiabetic drugs like acarbose. Furthermore, the antioxidant constituents of *S. trilobatum* help mitigate the oxidative stress commonly observed in diabetes. By decreasing lipid peroxidation and boosting the activity of endogenous antioxidant enzymes such as

superoxide dismutase (SOD) and catalase (CAT), the plant extract supports pancreatic function and may help prevent diabetes-related complications [33].

Hepatoprotective Activities

The liver, being the central organ in detoxification and metabolic regulation, is highly susceptible to damage from toxins, drugs, infections, and oxidative stress. Modern pharmacological research has identified *Solanum trilobatum* L. has emerged as a promising natural agent with hepatoprotective properties, supporting its traditional use in managing liver disorders.

Phytochemical analyses of *S. trilobatum* have identified steroidal alkaloids, flavonoids, saponins, and phenolic compounds, which collectively contribute to its hepatoprotective effects via antioxidant and membrane-stabilizing actions [32]. These bioactive constituents play a key role in neutralizing free radicals and safeguarding hepatocytes against oxidative damage.

Experimental studies have confirmed the hepatoprotective effects of *S. trilobatum* in animal models of chemically induced liver injury. For instance, Wistar rats with paracetamol-induced hepatotoxicity showed marked improvement following treatment with ethanolic extracts of *S. trilobatum*. Biochemical markers such as serum glutamate oxaloacetate transaminase (SGOT), serum glutamate pyruvate transaminase (SGPT), alkaline phosphatase (ALP), and bilirubin levels were markedly reduced, indicating liver function normalization [37].

Histopathological evaluations of liver tissues further supported the biochemical findings, showing reduced necrosis, inflammation, and fatty changes in extract-treated animals compared to untreated controls. The hepatoprotective effect is thought to arise from the upregulation of endogenous antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx), which together help reduce oxidative stress and cellular injury [35]. Moreover, *S. trilobatum* extracts have demonstrated protective activity against carbon tetrachloride (CCl_4)-induced liver fibrosis by inhibiting lipid peroxidation and restoring normal hepatic architecture [33]. These findings highlight the plant's potential not only in acute hepatotoxic conditions but also in chronic liver disorders. The cumulative evidence suggests that *Solanum trilobatum* offers significant hepatoprotective benefits and may serve as a safe, plant-based adjunct or alternative in liver therapy.

Antinociceptive Activities

Pain management continues to be a major focus in pharmacological research because of the complexity of antinociceptive pathways and the limitations of conventional analgesics, which frequently cause adverse effects. Consequently, medicinal plants such as *Solanum*

trilobatum L., traditionally used for alleviating pain, have garnered significant attention in contemporary biomedical investigation. *Solanum trilobatum* contains diverse phytochemicals, including steroidal alkaloids, flavonoids, and saponins, many of which possess anti-inflammatory and analgesic properties. These compounds are believed to influence both central and peripheral mechanisms of pain modulation [32].

Experimental studies have shown that *S. trilobatum* extracts exhibit notable antinociceptive effects in various rodent models. In one investigation, ethanolic leaf extracts significantly decreased pain responses in both the acetic acid-induced writhing assay, representing peripheral pain, and the hot-plate test, a model of central nociception, suggesting a dual mechanism of action[35]. The antinociceptive effect is thought to involve inhibition of pro-inflammatory mediators such as prostaglandins and cytokines, along with modulation of opioid receptors, although the exact mechanisms require further elucidation [33]. The presence of antioxidant compounds in the extract also may modulate pain by alleviating oxidative stress, a key factor in inflammatory antinociception.

In addition to reducing acute nociceptive responses, *S. trilobatum* has also shown efficacy in chronic pain models, such as formalin-induced paw licking and tail immersion tests, suggesting that it may have long-term benefits in neuropathic and inflammatory pain conditions [34]. These findings underscore the plant's potential as a natural analgesic, offering a scientific basis for its traditional application in treating painful inflammatory disorders and suggesting further research into its active constituents and mechanisms.

Antihyperlipidemic Activities

Hyperlipidemia, a major risk factor for cardiovascular diseases, is marked by increased levels of serum lipids such as total cholesterol, triglycerides, low-density lipoprotein (LDL), and very low-density lipoprotein (VLDL). Contemporary pharmacological studies on *Solanum trilobatum* L., a medicinal plant long valued in Indian traditional medicine, have demonstrated promising antihyperlipidemic activity, supporting its traditional role in promoting systemic health.

Phytochemical screening of *S. trilobatum* has been shown to contain biologically active compounds such as steroidal alkaloids, flavonoids, glycosides, saponins, and polyphenols all of which are well-recognized for lipid-lowering and antioxidant effects [32]. These compounds likely contribute to the modulation of lipid metabolism and prevention of oxidative modification of lipoproteins. In experimental models of diet-induced hyperlipidemia, oral administration of ethanolic leaf extract of *S. trilobatum* markedly lowered serum levels of total cholesterol, triglycerides, LDL, and VLDL, while simultaneously increasing high-density

lipoprotein (HDL) levels [24]. These effects were comparable to standard antihyperlipidemic drugs such as atorvastatin, indicating the plant's therapeutic relevance.

The proposed mechanism involves inhibition of HMG-CoA reductase, the key enzyme in cholesterol biosynthesis, and enhancement of bile acid excretion, leading to reduced lipid accumulation [33]. Furthermore, the plant's antioxidant compounds help prevent lipid peroxidation, a key factor in the progression of atherosclerosis and other cardiovascular complications [35]. Histopathological examination of liver tissues from treated animals revealed reduced hepatic fat deposition and improved liver architecture, suggesting a protective effect on lipid-induced hepatic damage. This hepatoprotective and lipid-modulating dual action positions *Solanum trilobatum* as a viable natural alternative in the management of dyslipidemia and related metabolic disorders. Given its multifaceted mechanism of action, low toxicity, and accessibility, *S. trilobatum* holds promise for development into functional foods or nutraceuticals targeting lipid disorders and cardiovascular health.

Anti-inflammatory Activities

Inflammation is a complex physiological response to injury, infection, or stress and is central to the pathophysiology of various chronic conditions, including arthritis, cardiovascular disease, and metabolic syndrome. While non-steroidal anti-inflammatory drugs (NSAIDs) remain the mainstay of therapy, their long-term use is associated with gastrointestinal and renal side effects. In this context, plant-based alternatives such as *Solanum trilobatum* L. have drawn considerable interest in modern pharmacological research due to their promising anti-inflammatory properties.

Traditionally used in Siddha and Ayurvedic medicine to treat respiratory and inflammatory conditions, *S. trilobatum* is rich in bioactive compounds such as steroidal alkaloids (e.g., solasodine), flavonoids, saponins, and phenolic acids, which are known to modulate inflammatory pathways [32]. These bioactive constituents play a role in reducing of inflammatory mediators and oxidative stress, both of which are critical mediators of chronic inflammation.

In experimental studies, ethanolic and aqueous extracts of *S. trilobatum* have shown significant inhibition of inflammation in animal models. In carrageenan-induced paw edema and cotton pellet granuloma models in rats, treatment with *S. trilobatum* extract resulted in a notable reduction in edema and granuloma weight, comparable to standard drugs like indomethacin [35]. The anti-inflammatory effects of *Solanum trilobatum* appear to be mediated through the downregulation of pro-inflammatory cytokines, including tumor necrosis factor-alpha (TNF-α) and interleukin-6 (IL-6), along with the inhibition of cyclooxygenase (COX)

and lipoxygenase (LOX) pathways [34]. In addition, the plant's antioxidant activity supports the reduction of inflammation-induced oxidative damage, as reactive oxygen species (ROS) are known to exacerbate inflammatory responses [36]. Histopathological examinations of inflamed tissues further validate these protective effects, demonstrating decreased leukocyte infiltration, tissue necrosis, and vascular congestion in treated groups. Collectively, these findings highlight *S. trilobatum* as a promising therapeutic agent for managing both acute and chronic inflammatory conditions with minimal side effects.

Mosquitocidal Activities

Mosquito-borne diseases, including dengue, malaria, chikungunya, and zika virus, remain major public health concerns globally, especially in tropical and subtropical areas. The increasing resistance of mosquitoes to conventional synthetic insecticides and concerns about environmental toxicity has prompted the exploration of plant-based alternatives. Among them, *Solanum trilobatum* L., a well-known medicinal plant in Indian traditional medicine, has demonstrated notable mosquitocidal properties under modern scientific scrutiny.

Phytochemical studies indicate that *S. trilobatum* is rich in bioactive compounds including steroidal alkaloids (e.g., solasodine), flavonoids, phenolics, and saponins, many of which possess insecticidal and larvicidal properties [32]. These secondary metabolites are believed to interfere with the nervous system and metabolic pathways of mosquito larvae and adults, leading to mortality.

In laboratory studies, extracts of *S. trilobatum*—especially ethanolic and chloroform fractions have shown potent larvicidal activity against major mosquito vectors such as *Aedes aegypti*, *Anopheles stephensi*, and *Culex quinquefasciatus*. For instance, Manimegalai and Senthilkumar [39] reported that methanol extracts of *S. trilobatum* leaves induced significant larval mortality in *Aedes aegypti*, with LC_{50} and LC_{90} values of 86.43 ppm and 172.15 ppm, respectively. The mosquitocidal efficacy is often dose-dependent and increases with exposure duration. Besides larvicidal activity, the plant has also demonstrated ovicidal and pupicidal effect have been 39.000 observed, indicating the plant's potential to disrupt multiple stages of the mosquito life cycle [40]. These bioactive extracts have also exhibited low toxicity toward non-target organisms, positioning *Solanum trilobatum* as a promising candidate for environmentally friendly vector control strategies. Furthermore, its potential incorporation into biopesticide formulations provides a sustainable alternative to conventional chemical-based mosquito management. With the increasing demand for natural and biodegradable insect control agents, *S. trilobatum* emerges as a valuable botanical resource for developing novel mosquitocidal agents that are both effective and ecologically safe.

Immunomodulatory Activities

The immune system plays a central role in maintaining physiological balance and defending against infections, inflammatory disorders, autoimmune conditions, and cancer. With the rising interest in plant-derived immunomodulators as safer alternatives to synthetic drugs, *Solanum trilobatum* L., a widely used medicinal plant in South Indian traditional systems, has gained recognition in modern pharmacological research for its potential to modulate immune responses.

Phytochemical studies of *S. trilobatum* have revealed a wealth of bioactive constituents, including steroidal alkaloids (notably solasodine), flavonoids, phenolic compounds, and glycosides. These constituents are known for their ability to influence immune cell activity, cytokine expression, and antioxidant defense mechanisms [32]. Experimental studies in animal models have demonstrated that *S. trilobatum* possesses significant immunostimulatory activity. Oral administration of its extracts enhanced both innate and adaptive immune responses in mice, as evidenced by increased phagocytic activity, stronger humoral antibody responses, and elevated lymphocyte proliferation, indicating broad-spectrum immune activation [38]. Additionally, the extract stimulated the production of key cytokines, including interleukin-2 (IL-2) and interferon-gamma (IFN-γ), which are essential for T-cell mediated immunity. This immunomodulatory effect is further supported by the plant's antioxidant properties, which help protect immune cells from oxidative stress and maintain their functional integrity [35].

Beyond its immunostimulatory effects, preliminary studies suggest a possible immunoregulatory effect, wherein the extract modulates overactive immune responses and reduces inflammation-associated immune imbalances [34]. This dual action—stimulating defense mechanisms while controlling immune over activity makes *Solanum trilobatum* a promising immunomodulator for conditions such as infections, immunodeficiency, and chronic inflammatory diseases. Given its safety profile and efficacy demonstrated in preclinical models, *S. trilobatum* holds strong potential for development into herbal immunotherapeutics and nutraceuticals that support immune health.

Cytotoxicity

The cytotoxic potential of different fractions of *Solanum trilobatum* exhibited that 50µg of petroleum ether extract exposed the comprehensive cell lyse in both L929 and Vero cells [13] and also the ethanolic extract of the plant has slightly toxic confirmed by examined different activities in test animals [41].

Oviposition activity

The extracts obtained from acetone, chloroform and petroleum ether from the *Solanum trilobatum* shows the oviposition activity against the vector *Culex quinquefaciatus* Among this petroleum ether shows the maximum effectiveness against the parasite ovicidal activity [[42]. Its leaf extract possesses the oviposition and skin repellent activity against *A. stephensi* and they further confirmed the absence of any discomfort or hypersensitivity to the users [43].

Conclusion

Solanum trilobatum L., revered in traditional South Indian medicine, exemplifies the rich therapeutic legacy embedded in ethnobotanical knowledge. This review underscores its multifaceted medicinal potential, especially in treating respiratory and inflammatory conditions, as supported by both traditional practices and emerging pharmacological evidence. The presence of diverse bioactive compounds lends scientific credibility to its traditional uses, yet comprehensive clinical validation remains a pressing need. Merging historical ethnobotanical knowledge with modern scientific approaches not only affirms its therapeutic promise but also calls for sustainable conservation efforts. Ultimately, *S. trilobatum* serves as a vital link between age-old healing systems and the evolving landscape of evidence-based medicine.

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Traditional Uses to Therapeutic Potential: An Ethnobotanical Review of *Sesamum indicum L.*

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ABSTRACT

Sesamum indicum L., commonly known as sesame, recognized as one of the earliest cultivated oilseed crops in human history, valued for its high nutritional content, oil yield, and diverse medicinal properties. With a rich history spanning thousands of years, sesame occupies an important role in traditional medical systems across Asia, Africa, and the Middle East. This review seeks to present a thorough ethnobotanical account of S. indicum, tracing its traditional uses and linking them with contemporary pharmacological findings to explore its full therapeutic potential. Traditional healing traditions including Traditional Chinese Medicine, Ayurveda, Unani, and African ethnomedicine have long utilized sesame seeds, oil, leaves, and roots for a wide range of health conditions. These include treatments for skin disorders, respiratory issues, digestive ailments, reproductive health, and musculoskeletal pain. Particularly, Sesame oil has been extensively employed as a vehicle in medicinal formulations due to its warming, nourishing, and penetrative properties. Ethnobotanical surveys also highlight its use in rituals, wound healing, and infant care in various indigenous cultures. Modern pharmacological research supports many of these traditional claims, revealing a diverse array of bioactive compounds in sesame, including lignans (sesamin, sesamol, sesamolin), tocopherols, phytosterols, and unsaturated fatty acids. These constituents contribute to its antioxidant, anti-inflammatory, antidiabetic, antihypertensive, anticancer, and neuroprotective activities. Additionally, studies on sesame's hepatoprotective and cardioprotective properties have further substantiated its application in the management of chronic lifestyle-related diseases. This review synthesizes data from ethnobotanical literature, phytochemical studies, and pharmacological investigations to present an integrated understanding of S. indicum's medicinal value. It also emphasizes the importance of preserving traditional knowledge while promoting scientific validation through clinical research. Given its wide availability, cultural acceptance, and therapeutic versatility, S. indicum holds promise as a natural health-promoting agent in both traditional and modern medicinal contexts. In conclusion, the ethnobotanical and therapeutic profile of Sesamum indicum underscores its potential in the development of plant-based pharmaceuticals and nutraceuticals, warranting further interdisciplinary research and conservation efforts.

Keywords: *Sesamum indicum L., Traditional Uses, Therapeutic Potential*

Introduction

Sesame (*Sesamum indicum* L.), a member of the Pedaliaceae family, is among the oldest oilseed crops known to have been cultivated and consumed by humans. Its origins trace back to ancient times, with initial domestication believed to have occurred in regions of present-day Pakistan. Over the centuries, sesame cultivation expanded across Asia, particularly to countries like India, China, and Malaysia. Historical records indicate that sesame has been used in Chinese culture for more than 5,000 years [1]. Today, major producers include India, Sudan, Myanmar, China, and Tanzania. Notably, recent years have witnessed a significant rise in sesame production across Africa, with Tanzania emerging as the world's leading producer, surpassing India [2].

The widespread cultivation and popularity of sesame are attributed to its distinctive aroma, rich flavor, and diverse applications in food and traditional practices. Sesame seeds are commonly processed into oil, ground into paste, or used as garnishes in various culinary preparations. Beyond their culinary appeal, sesame seeds are valued for their high nutritional content and recognized pharmacological properties. Additionally, increasing attention is being given to the agronomic and technical aspects of sesame cultivation to enhance productivity and quality [3].

Botanical Description

Sesame (*Sesamum indicum* L.), belonging to the Pedaliaceae family, is an important oilseed crop cultivated in various forms based on seed coat color—primarily white, black, and yellow varieties. Among these, white and black sesame are the most commonly cultivated types. Black sesame is recognized for its vigorous and resilient growth, drought tolerance, and resistance to lodging, whereas white sesame is valued for its superior oil content and quality, making it the most extensively cultivated variant. Botanically, Sesame is an upright, annual herbaceous plant that typically grows to a height of about 60–150 cm. Its stem may be hollow or filled with white pith, and its leaves measure approximately 3–10 cm in length and 2.5–4 cm in width, vary from ovate to rectangular with a slightly hairy surface, appearing singly or in small groups at the axils. The calyx lobes are lanceolate, 5–8 mm long, and densely covered with fine hairs. The corolla is tubular in shape, with a length of approximately 2.5–3 cm and a diameter of 1–1.5 cm, is predominantly white with occasional purplish-red or yellow hues. Flowers possess four enclosed stamens and a superior, four-chambered ovary with a hairy exterior. Blooming typically occurs from late summer to early autumn. Fruit is a capsule with a rectangular shape, it measures approximately 2–3 cm in length and 6–12 mm in diameter.

marked by longitudinal ribs and a hairy surface. Depending on pigmentation, seeds are classified as either white or black sesame [4].

Nutritional Components

Sesame seeds are highly nutrient-rich, providing substantial amounts of protein (about 21.9%), fat (around 61.7%), dietary fiber, essential minerals such as calcium and iron, and vitamins including the B-complex group and vitamin E. Sesame oil is notable for its high proportion of unsaturated fatty acids (up to 80%), especially oleic and linoleic acids, which contribute significantly to cardiovascular and immune health. The seed proteins are nutritionally complete, supplying all essential amino acids, with globulins constituting the predominant fraction. In addition, sesame meal remains a valuable protein source, containing nearly 50% protein. The seeds contain 12 unsaturated fatty acids and are dubbed the "Queen of Oil" due to their 45–57% oil content. Vitamins like γ-tocopherol, dominant in black sesame, offer potent antioxidant properties. Carbohydrates such as glucose, raffinose, and sesamose are also present. Sesame is a good source of minerals including potassium, magnesium, and zinc. However, antinutrients like oxalic and phytic acids can hinder mineral absorption, though cooking and enzymatic treatments can mitigate these effects and little amounts of tannins [5,6].

Traditional Uses

Food

Sesame is extensively incorporated into traditional food systems, especially across Asia, owing to its versatility, distinctive flavor, and rich nutritional profile. In Chinese cuisine, sesame is commonly transformed into oil, paste, sweets, cakes, and sesame-filled dumplings, serving as an important ingredient in both domestic and commercial cooking. Among these products, sesame oil is the most widely used. It contains high levels of essential fatty acids such as linoleic and oleic acids, along with gamma-tocopherol (vitamin E), lignans, and phytosterols. Cold-pressed sesame oil maintains high nutritional quality and is favored for its aroma and cost-effectiveness compared to olive oil [7-9].

Modern extraction methods—including CO_2 supercritical, enzymatic, and microwave-assisted techniques—enhance oil yield and preserve bioactives. Sesame oil exhibits anti-inflammatory and skin-repair properties, making it useful beyond nutrition. The by-product, sesame meal, is high in protein, fiber, and antioxidants, and supports gut health as a prebiotic [10].

Processed sesame foods have expanded through compounding with grains, beans, fruits, and vegetables, creating functional beverages and bakery items [11]. Sesame protein isolate, used as a binder or thickener, enhances the nutritional profile of baked goods. Mixing

Chia or kiwi oil with sesame oil helps optimize the omega-3 to omega-6 ratio and enhances antioxidant stability [12]. Sesame-based fats, including margarine and ghee alternatives, offer trans-fat-free options for health-conscious consumers. Sesame lignans contribute to cardiovascular, liver, and metabolic health, positioning sesame as a valuable ingredient in functional foods [13].

Feeds

Sesame meal containing more than 45% crude protein along with essential amino acids, serves as a valuable plant-based feed. Fermentation decreases its antinutritional factors, allowing it to partially replace soybean meal in the diets of broilers and lactating ewes, thereby enhancing growth performance, milk production, and feed efficiency [14,15].

Fertilizer

Sesame meal is a nutrient-dense organic fertilizer, providing essential elements such as nitrogen (N), phosphorus (P), and potassium (K). Its use enhances fruit quality and soil health while benefiting crops like tobacco, watermelon, and strawberries through improved microbial activity and nutrient content [16].

Fuels

Sesame residues are now explored for biofuel, offering a renewable alternative to fossil fuels. Biodiesel from sesame oil, produced via transesterification, achieves up to 92% yield and shows similar efficiency to mineral diesel in engine performance [17,18].

Cosmetics

Sesame oil, approved by the U.S. FDA for cosmetics, is used in lipsticks, moisturizers, and ointments. Components like myristic acid and flower-derived fragrances support its role in natural skincare and cosmetic formulations [19].

Insecticide

Sesamin has fungicidal and insecticidal properties and enhances pyrethroid insecticides. It's used against lice and in termite-repellent wood treatments, offering a sustainable pest control solution in agriculture and households [20].

Other Uses

Sesame oil fumes are used in ink and copy paper production, while sesame is also utilized in making lubricating soaps. Defatted sesame powder improves emulsion stability in food and cosmetic products, enhancing texture and shelf life [21].

Traditional Chinese Medicine

According to *Shennong Ben Cao Jing*, sesame seeds are traditionally employed to address “deficiencies in the middle, nourish the five internal organs, enhance vitality, promote

muscle growth, and replenish the marrow." In the framework of Chinese medicine, black sesame is believed to tonify the liver and kidneys while moisturizing the bowels, acting as a gentle laxative. It has been used to manage conditions such as hemorrhoids, dysentery, constipation, cough, amenorrhea, dysmenorrhea, ulcers, and hair loss. Additionally, sesame seeds serve as a topical ointment, lactation enhancer, diuretic, tonic, and pain reliever. In Traditional Chinese Medicine (TCM), sesame oil is valued as an effective carrier, aiding the absorption of medicinal compounds through the skin [22].

Pharmacological Benefits of Sesame

Sesame oil and seeds offer notable health benefits, particularly supporting the kidneys, spleen, liver and digestive system. Rich in healthy fats, sesame oil aids in internal organ nourishment and intestinal lubrication. It promotes healing of minor burns, acts as a UV protector, and serves as a carrier oil in pharmaceuticals. Used in massage, it provides analgesic effects, easing pain from conditions like chemotherapy-induced phlebitis and limb trauma. These properties make sesame a valuable resource in therapeutic and medicinal applications [23, 24].

Antioxidant Effect

In everyday cooking, incorporating antioxidants into oils is crucial to slow down their oxidation. Refined sesame oil naturally possesses antioxidant properties, which help extend its shelf life in the food industry. This is largely due to the high-temperature roasting step involved in its refinement. During roasting, the Maillard reaction between reducing sugars and free amino acids not only enhances the flavor of sesame oil but also boosts its antioxidant activity. Additionally, the sesamin and sesaminol content of sesame oil is altered by roasting. At elevated temperatures, sesamolin undergoes thermal decomposition, converting into sesamol. Unroasted sesame oil contains relatively low levels of sesamol, but roasting significantly increases its concentration. Since sesamol exhibits strong antioxidant activity in the body, roasted sesame oil demonstrates greater resistance to rancidity [26]. Furthermore, antioxidant components from sesame seeds can be used to fortify other oils; for example, adding extracts from the outer skin of sesame seeds to sunflower oil improves its oxidative stability [26].

Sesamin, a key compound in sesame, exhibits strong antioxidant properties by scavenging free radicals and mitigating oxidative stress. It enhances antioxidant enzymes like SOD and CAT and protects cells from H_2O_2-induced damage. Studies show sesamin can regulate the SIRT1-SIRT3-FoxO3a pathway, reducing apoptosis and promoting cell survival. It also helps prevent cardiac remodeling by lowering ROS levels. These results highlight its potential role as a therapeutic antioxidant agent [27, 28, 29].

Cholesterol Control and Lipid Balance

Sesamin has been shown to exert notable lipid-lowering effects by influencing key pathways in fatty acid and cholesterol metabolism. It decreases levels of harmful lipids such as LDL, VLDL, and triglycerides while increasing protective HDL levels. Research indicates that sesamin downregulates genes involved in cholesterol absorption (e.g., NPC1L1, ACAT2) and synthesis (e.g., HMG-CoA reductase), while upregulating CYP7A1 to enhance cholesterol catabolism. Additionally, it promotes cholesterol efflux by increasing the expression of transporters like ABCA1 and ABCG1 through regulatory pathways including PPARγ1, LXRα, and MAPK. These actions make sesamin a promising natural agent for managing dyslipidemia and supporting cardiovascular health [30,31].

Anti-Inflammatory activity

Sesamin exhibits strong anti-inflammatory activity by suppressing pro-inflammatory cytokines like IL-6 and IL-1 in synovial fibroblast cells. It inhibits TNF-α-induced inflammation, which is linked to rheumatoid arthritis. Sesamin metabolites, particularly catechol conjugates such as SC1, exhibit enhanced anti-inflammatory activity by suppressing interferon-beta and iNOS expression in macrophage-like cells. These findings highlight sesamin's therapeutic potential in managing inflammatory conditions [32,33].

Hypoglycemic Activity

Type 2 diabetes is an increasingly prevalent global health concern marked by impaired metabolic regulation. Research indicates that white sesame oil can help reduce blood glucose levels and mitigate diabetes-related complications. In studies with diabetic rats, a diet containing 12% sesame oil led to a significant decrease in fasting blood glucose over 60 days compared to controls. Similarly, an 8-week clinical trial in diabetic patients demonstrated that sesame oil, administered alone or alongside glibenclamide, significantly lowered fasting and postprandial glucose, HbA1c, LDL, and triglyceride levels, while raising HDL levels. These findings highlight sesame oil's potential in managing diabetes and improving lipid profiles [34].

Cardiovascular Protective Effects

Hypertension is a major contributor to cardiovascular diseases, projected to affect over 1.5 billion people by 2025. Sesame seeds, abundant in polyunsaturated fatty acids, lignans, phytosterols, and vitamin E, contribute to blood pressure regulation and cardiovascular health. Research indicates that sesamin supplementation can lower blood pressure, reduce oxidative stress, and protect against cardiac damage in hypertensive and diabetic models. Clinical studies

have also demonstrated improvements in systolic blood pressure, body mass index (BMI), and overall heart function. Additionally, sesamin modulates biomarkers like MDA, TAC, and TGF-β1, indicating its potential in reducing cardiovascular risk and improving overall heart health [35, 36].

Anti-Tumor Effect

Sesamin exhibits strong anticancer properties through mechanisms includes anti-proliferation, apoptosis induction, and can also inhibits metastasis and angiogenesis. It acts via key pathways including STAT3, PI3K/AKT, ERK1/2, and p53. Studies also show that sesamin blocks the Wnt/β-catenin signaling pathway, especially in colon cancer. These actions contribute to slowing tumor growth and progression, highlighting sesamin's potential as a natural anti-cancer agent [37].

Bone Health

Sesamin has shown potential in inhibiting human osteoclast differentiation and function, crucial for bone resorption. It reduces markers like TRAP, DC-STAMP, and CathK, limiting osteoclastogenesis without affecting NFATc1 expression. This suggests its role in reducing bone degradation and promoting skeletal health [38].

Hearing Protection

Sesamin and sesame oil demonstrate protective effects against hearing loss by promoting auditory hair cell regeneration and upregulating genes associated with hearing, such as Tecta. Studies in zebrafish and mouse models have shown enhanced kinocilia growth and lowered hearing thresholds, underscoring their potential as therapeutic agents for auditory disorders.

Safety

With increasing interest in functional foods and supplements, assessing the safety of sesame and sesamin is essential. Drug-sesamin interaction studies in rats showed no significant effect on diclofenac metabolism. Acute toxicity tests of sesame oil and ethanolic extracts in mice and rats revealed no mortality or adverse effects, even at high doses. No behavioral or physiological abnormalities were detected, confirming that sesame is safe for human consumption at standard dosages [40].

Conclusion

Sesame is among the earliest cultivated oil crops, valued for its rich nutritional profile and medicinal properties. Beyond oil production, it is widely processed into products like sesame paste, milk, and confections. Over 180 phytochemicals such as lignans, polyphenols, and essential fatty acids—have been identified in sesame, many with proven health benefits

including antioxidant, anti-inflammatory, anti-cancer, and cardiovascular protective effects. Despite this, gaps remain in research related to sesame's genetic improvement, pharmacokinetics, and bioavailability. Expanded studies with robust methodologies are necessary for clearer clinical validation. Given its drought tolerance and suitability for intercropping, sesame holds promise for economic uplift in arid regions, especially with advances in agricultural technology.

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Impact of Seaweed Liquid Fertilizers and NPK on the Growth and Productivity of *Lycopersicum esculentum* L.

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ABSTRACT

Modern agricultural practices have relied extensively on chemical fertilizers, which have played a major role in enhancing food production. However, their prolonged and excessive use can adversely affect soil health by disrupting beneficial soil microorganisms and causing toxicity. In this context, seaweed-based fertilizers present an eco-friendly and sustainable alternative, as they improve soil moisture retention and support long-term agricultural sustainability. The present study aimed to develop and evaluate different consortia of seaweed liquid fertilizers (SLFs) for enhancing crop productivity. Seaweeds such as Ulva lactuca and Gracilaria verrucosa were collected from the rocky shores of Muttom (8.1262° N, 77.3196° E) in the Gulf of Mannar along the southeastern coast of Tamil Nadu. The effects of liquid seaweed extracts on the growth, yield, and pigment content of Solanum lycopersicum were assessed. The results demonstrated that lower concentrations of SLFs were more effective in promoting plant growth. Comparative analyses among SLF-treated plants, those receiving NPK fertilizers, and untreated controls (water) revealed that SLF applications significantly enhanced growth parameters, including shoot length, root length, and leaf area, compared to the control. Furthermore, yield attributes indicated that treatments with Ulva intestinalis and Gracilaria tenuistipitata markedly increased plant height, number of leaves, branches, pods, grains, as well as fresh and dry biomass relative to untreated plants. Among all treatments, SLF derived from Gracilaria tenuistipitata exhibited the most pronounced positive effects on plant growth and yield.

Keywords: *Seaweed, Liquid Fertilizer, Ulva intestinalis and Gracillaria tenuistipitata*

Introduction

Agriculture today faces a convergence of escalating crises, among which ensuring adequate food production for a rapidly expanding population remains one of the most pressing. In India, the Green Revolution marked a turning point by significantly increasing agricultural productivity; however, it also led to a sharp rise in the use of chemical fertilisers. Since 1981–82, fertiliser consumption has grown substantially, often resulting in excessive and indiscriminate application in crop production systems. In parallel, marine macroalgae, commonly known as seaweeds, are classified by botanists into three principal phyla based on

their pigment composition and stored food reserves: green algae (Chlorophyta), brown algae (Phaeophyta), and red algae (Rhodophyta) [1].

Seaweed extracts, available in liquid or water-soluble powder formulations, represent the most widely utilized seaweed-based products in horticultural crop production [2]. These extracts are commonly applied as foliar sprays across a broad range of crops, including vegetables, ornamentals, and fruit trees such as potato, tomato, plum, cherry, almond, and mango. Foliar application is generally most effective when performed in the morning hours, as stomatal opening facilitates better absorption, and the efficacy of the extracts also varies with the developmental stage of the plant [3,4,5]. Plant responses to seaweed liquid formulations differ depending on both the crop species and the seaweed source. Reported benefits include enhanced yield, increased fresh and dry biomass, improved shoot and root development, higher seed yield and seed weight, increased fruit weight, improved seed germination, enhanced mineral uptake, greater resistance to pests, insects, and diseases, improved tolerance to frost stress, extended shelf life of fruits, and stimulation of early flowering [6].

Over the years, a wide range of seaweed species have been explored and applied as seaweed liquid fertilizers (SLFs) in tomato cultivation to improve crop protection, yield, and fruit quality [7,8,9,10,11,12,13,14]. Despite these extensive studies, the red seaweed species *Gracilaria tenuistipitata* has not yet been investigated or utilized as a source of SLF for tomato cultivation. Accordingly, the Solanaceae crop *Solanum lycopersicum* L. was selected for the present study, and the red seaweed *Gracilaria tenuistipitata* was chosen to evaluate its potential influence on tomato growth and productivity. Foliar application of seaweed liquid fertilizers (SLFs) has been widely reported to enhance plant growth, grain development, and yield in a variety of agricultural and horticultural crops, including vegetables, trees, and palms. In this context, evaluating the efficacy of seaweed-based extracts is essential for advancing sustainable crop production practices and ensuring long-term food security. Therefore, the objective of the present investigation was to assess the effects of foliar application of SLFs derived from *Gracilaria tenuistipitata* and *Ulva intestinalis* on the growth and yield performance of tomato (*Solanum lycopersicum* L.).

Materials and methods

Collection of Seaweeds

The seaweed species *Gracilaria tenuistipitata* (family Gracilariaceae) and *Ulva intestinalis* (family Ulvaceae) were collected from the Muttom coastal region of the Gulf of Mannar, located on the southeastern coast of Tamil Nadu, India (8.1262° N, 77.3196° E). Sampling was carried out in both intertidal and subtidal zones at depths ranging from 0.5 to 1.0 m during low

tide periods. Collections were made at three-month intervals from July to October 2024. The collected seaweed samples were identified using standard taxonomic keys provided by [15,16]. The systematic classification of the seaweeds followed the schemes proposed by [17,18].

Development of dry seaweed powder

The collected seaweed samples were thoroughly cleaned with seawater to remove extraneous materials such as epiphytes, adhering debris, sand particles, pebbles, and shells. The samples were subsequently washed with tap water followed by distilled water to ensure complete removal of surface impurities. The entire thalli were shade-dried at room temperature and then finely ground to obtain a powder of 40-mesh particle size. The powdered samples were stored under refrigerated conditions for further analysis.

Preparation of Seaweed Liquid Fertilizers (SLFs)

The seaweeds were handpicked during low tide periods from depths of 0.5 to 1.0 m and initially washed with filtered seawater to remove adhering sand particles, epiphytes, and other unwanted impurities. The samples were then transported to the laboratory and washed thoroughly with tap water three to four times to eliminate excess salts. The cleaned seaweeds were shade-dried for one week at ambient temperatures (27–30 °C), followed by oven drying at 60 °C for 48 h [19]. The oven-dried material was subsequently ground into a fine powder using a mixer grinder (Preethi Eco-chef) and stored in airtight containers for future use. For extraction, 500 g of the powdered seaweed was mixed with 5,000 mL of distilled water and heated at 60 °C for 45 min in a stoppered conical flask. After cooling, the mixture was filtered through four layers of muslin cloth. Seaweed extracts were prepared separately from *Ulva intestinalis* (green seaweed) and *Gracilaria tenuistipitata* (red seaweed).

Selection of crop plants

The experimental crop plant selected for this study belongs to the family Solanaceae. Certified seeds of *Lycopersicum esculentum* were obtained from the Regional Pulses ICAR-KVK, Thirupathisaram. Seeds exhibiting uniform size, shape, color, and weight were carefully selected for the experiment. The selected seeds were stored in a metal container until further use [20].

Experimental Study

The experimental study was conducted at Nenjanthi Colony. The field was cleared of weeds and irrigated regularly. Seeds of *Lycopersicum esculentum* were sown in plots measuring 4 m × 3 m, with two seeds placed along the sides of ridges at 30 cm spacing. For each treatment, ten plants per row were selected. Treatments were applied using seaweed liquid fertilizer (SLF), NPK fertilizer, and normal water. The first foliar spray was administered to 15-day-old

seedlings, followed by three additional sprays at 15-day intervals, up to 60 days. Control plants received only water as foliar spray.Growth parameters, including seed germination, shoot length, and leaf area, were recorded and tabulated on the 15th, 30th, 45th, and 60th day. Biochemical parameters, such as chlorophyll content, were determined following [20]. The entire experiment was conducted in triplicate.

Estimation of chlorophyll 'a' and 'b'

The estimation of chlorophyll was done by the method of [20].

Yield Parameter

The yield parameters such as fresh weight, dry weight, plant height, number of leaves per plant, number of pods per plant, number of grains per pod and number of branches of SLF treated and control of *Lycopersicum esculantum* were recorded at 60th day.

Results

Collection of seaweed



Gracilaria tenuistipitata



Ulva intestinalis

Seaweed liquid fertilizer (SLF)





Crop Plant *Lycopersicum esculentum L.*





Phytochemical screening

The preliminary phytochemical analysis of the seaweed fertilizers used in the present study has been studied and reported in the table1. The phytochemical screening of *U.intestinalis* SLFs and distilled water extract revealed the presence of alkaloid, flavanoid phenolic compound ,tannins ,triterpenoids.

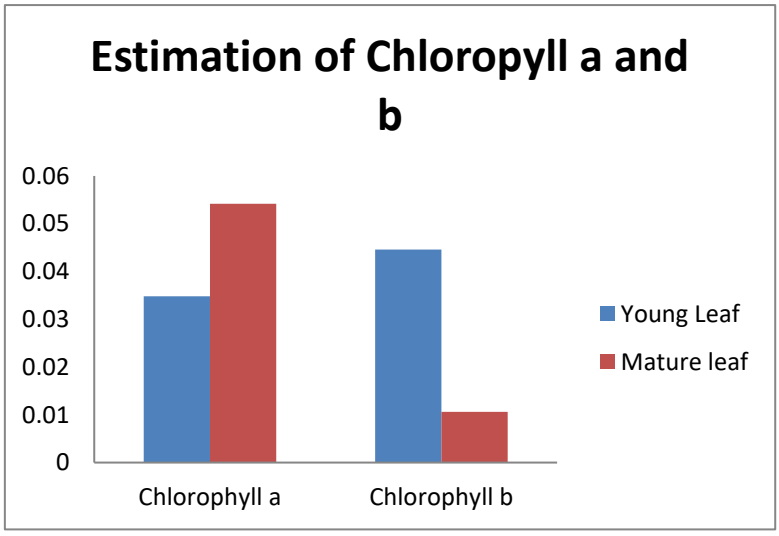
Table 1: Phytochemical analysis of the seaweed fertilizers

phytochemical Analysis	Test	*U.intestinalis SLFs+Dis. water*	*U.intestinalis* SLFs+ Methanol	*G.tenuistipitata* SLFs+Dis.water	*G.tenuistipitata SLFs+Methanol*
Alkaloid test	Mayer's reagent	-	+	+	+
Alkaloid test	Picric Acid test	-	+	+	+
Alkaloid test	Iodine soln. Test	-	+	+	+
Flavonoid test	Conc.	+	+	+	+
Phenolic compound test	Potassium dichromate test	-	+	+	+
Phenolic compound test	Feric chloride 10%	-	-	+	+
Phenolic compound test	Feric chloride 5%	+	-	+	+
Tannins	Lead acetate test	+	-	+	+

Phenolic compound test	Iodine Test (Dil.Iodine)	+.	+	+	+
Tannins	Bremer's test	+	-	+	+
Flavonoid	Alkaline Reagent test	+	-	+	+
Tannin	10% of NaOH test	-	+	+	+
Triterpenoids test	Slkowski's test	-	+	-	+
Triterpenoids test	Foam test	-	-	+	-
Triterpenoids test	Coumarins test	-	-	+	-
Triterpenoids test	Kellarkillani test	+	+	-	-
Triterpenoids test	Quinones test	+	-	+	-

Ulva intestinalis SLFs and distilled water extract revealed the presence of flavonoids ,phenolic compound and tannins. *Ulva intestinalis* SLFs and methanol extract revealed the presence of flavonoids, alkaloids, phenolic compound tannins and triterpinoides. *Gracilaria tenuistipitata* SLFs and distilled water extract revealed the presence of flavonoids alkaloids phenolic compound and tannins. *Gracilaria tenuistipitata* SLFs methanol extract revealed the presence of flavonoids, alkaloids, phenolic compound and tannins.

Fig: 2 Estimation of chlorophyll a and b



The treatment of SLFs during experimental period on chlorophyll ‘a’ was presented in table. The chlorophyll ‘a’ content was registered 0.0348 mg/g in the treatment of young leaves which was statistically at par with mature leaves 0.0542 mg/g. The treatment of SLFs during experimental period on chlorophyll ‘a’ was presented in fig 2. The chlorophyll ‘b’ content was registered 0.0446 mg/g in the treatment of young leaves which was statistically at par with mature leaves 0.0106 mg/g [21].

Yield parameters

Table 2: Effect of *Ulva intestinalis* SLFs, NPK and yield attributing characters of L*ycopersicum esculentum*

Parameters	**Control**	**SLFs**	**NPK**
Height of plant	80cm	120cm	100cm
Number of leaves	100	150	120
Number of fruits	15	25	20
Number of flowers	20	30	25
Number of branches	50	80	60

Table 3: Effect of *Gracilaria tenuistipitata SLFs,NPK,and yield attributing characters of lycopersicum esculentum*

Parameters	**Control**	***SLFs***	**NPK**
Hight of plant	***90cm***	***140cm***	***120cm***
Number of leaves	110	160	***130***
Number of fruits	20	30	***25***
Number of flowers	25	40	***35***
Number of branches	70	100	***80***

Conclusion

The observations on yield attributes discovered and *Ulva intestinalis* and *Gracilaria tenuistipitata* is SLF, NPK and control enhanced the plant height number of leaves, number of pods, number of grains, number of branches, fresh weight and dry weight than untreated plants. Plants treated with SLF of *Gracilaria tenuistipitata* shown enhanced effect when compared to others.

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Therapeutic Potential of *Ulva Lactuca* Ulvans as Natural Anticoagulants

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ABSTRACT

The present study investigates the isolation, characterization, and anticoagulant potential of ulvans, sulfated heteropolysaccharides, extracted from the green macroalga Ulva lactuca. Two extraction methods, cold and hot, were employed, followed by purification using column chromatography and identification via Thin Layer Chromatography (TLC). The anticoagulant efficiency was assessed using the Activated Partial Thromboplastin Time (APTT) assay. Results indicate that Ulva lactuca is a viable source of ulvans with significant anticoagulant activity. The cold extraction method yielded a higher purity polysaccharide with stronger anticoagulant effects, while the hot extraction method resulted in a higher yield but slightly reduced purity and activity. These findings suggest the potential of Ulva lactuca-derived ulvans as natural anticoagulant agents, warranting further investigation into their therapeutic applications.

Keywords: *Seaweeds, Anticoagulant, Ulva, APTT assay*

1. Introduction

Ulva species, commonly known as sea lettuce, are ecologically significant green algae and a source of bioactive compounds. Ulvans, sulfated heteropolysaccharides from *Ulva* cell walls, possess diverse therapeutic properties, including antioxidant, antiviral, anti-inflammatory, immunomodulatory, and anticoagulant effects [1, 2]. Their anticoagulant activity, similar to heparin, involves inhibiting the intrinsic coagulation pathway and prolonging APTT. Ulvans are biodegradable, renewable, and potentially safer than synthetic anticoagulants [2]. Previous research has explored ulvan extraction, purification, and biological activities, noting that extraction methods influence yield and bioactivity [3, 4]. This study aimed to isolate ulvans from *Ulva lactuca*, purify them, and evaluate their *in vitro* anticoagulant potential, comparing cold and hot extraction methods.

2. Materials and Methods

2.1. Collection and Identification of *Ulva* Species

Ulva species were collected from the coastal region of Muttom, Kanyakumari District. Manual collection from the intertidal zone was followed by identification using standard marine algae manuals and expert consultation, confirming the species as *Ulva lactuca* L.

2.2. Sample Preparation

Ulva lactuca samples were washed with fresh and distilled water, air-dried at room temperature (3-5 days), and then ground into a fine powder. The powder was sieved for uniformity and stored in airtight containers.

2.3. Extraction of Polysaccharides

- **Cold Extraction:** Dried *Ulva* powder (1:20 w/v in distilled water) was incubated with 1 gm cellulase (room temperature, 24-48 hours). The filtrate was precipitated with ethanol/acetone, incubated at 4°C, centrifuged (4,000-6,000 rpm, 20-30 minutes), dissolved in distilled water, dialyzed (24-48 hours), and freeze-dried.
- **Hot Extraction:** Dried *Ulva* powder (1:20 w/v in distilled water) was heated (80-90°C, 2-3 hours) with optional 1 gm cellulase addition. Post-cooling and filtration, polysaccharides were precipitated, incubated, centrifuged, dissolved, dialyzed, and freeze-dried as in cold extraction.

2.4. Separation and Identification of Components

- **Column Chromatography:** Powdered *Ulva* extract (ethanol/methanol) was concentrated and loaded onto a silica gel column. Components were eluted with a solvent mixture, and fractions were collected. Elution was monitored by UV detection or color changes.
- **Thin Layer Chromatography (TLC):** *Ulva* extract (ethanol/methanol/chloroform: methanol) was spotted on activated silica gel TLC plates. Development with hexane: ethyl acetate allowed visualization under UV light. Rf values were calculated and compared with standards for identification.

2.5. Activated Partial Thromboplastin Time (APTT) Test

Ulva extract was mixed with normal human plasma, followed by kaolin, phospholipid, and calcium chloride. Clotting time was measured and compared to a control and Heparin. Prolonged clotting time indicated anticoagulant properties.

3. Results and Discussion

3.1. Identification of *Ulva lactuca*

Marine algal samples were identified as *Ulva lactuca* L. (Family: Ulvaceae, Division: Chlorophyta). Key diagnostic features included a bright green, thin, membranous thallus (10–

20 cm length, 5–10 cm width), sheet-like, translucent, bilayered structure with an irregularly ruffled margin, and parenchymatous organization of two cell layers with cup-shaped chloroplasts [5].

3.2. Polysaccharide Extraction Yield and Purity

Extraction Method	Yield (mg/gm)	Purity Observations	Anticoagulant Activity
Cold Extraction	0.2	Higher purity, light color, preserved heat-sensitive compounds	Stronger
Hot Extraction	1.0	Higher yield, darker color, partial degradation of heat-sensitive components, slightly lower purity	Slightly reduced

Cold extraction yielded 0.2 mg/gm of high-purity polysaccharide with strong anticoagulant activity, consistent with better preservation of sulfate groups and molecular integrity [3, 6]. Hot extraction yielded 1.0 mg/gm but with reduced anticoagulant efficiency due to potential partial desulfation and degradation at elevated temperatures [4, 7].

3.3. Separation and Identification of Components

Column chromatography effectively fractionated ulvans based on size and charge, separating polar (e.g., alginic acid, fucoidan) and less polar (e.g., pigments, fatty acids) compounds. This enhanced ulvan purity by removing contaminants [8, 9]. TLC confirmed specific compounds within fractions.

3.4. Anticoagulant Activity (APTT Assay)

Ulvans from *Ulva lactuca* demonstrated significant anticoagulant activity, prolonging clotting time in the APTT assay. This effect was comparable to Heparin, suggesting a similar mechanism involving the intrinsic coagulation pathway [1, 2, 10].

4. Conclusion

This study successfully isolated and characterized ulvans from *Ulva lactuca*, confirming their significant anticoagulant potential. Cold extraction yielded higher purity ulvans with stronger anticoagulant activity, despite a lower yield. These findings support *Ulva lactuca*-derived ulvans as natural anticoagulants, offering a renewable and potentially safer alternative. Further research is needed to optimize extraction, conduct detailed structural characterization, and perform *in vivo* studies.

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Antimicrobial activity of *Odonus niger* skin extracts on clinical and fish pathogenic bacteria

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ABSTRACT

Fish skin is a great source of bioactive substances, which are involved in the innate defence mechanisms and can be used as natural antimicrobial agents. The antimicrobial potential of O. niger skin extract prepared from solvents petroleum ether, ethyl acetate, ethanol and methanol were assessed. Antibacterial activities were determined against clinical bacterial strains (Escherichia coli, Staphylococcus aureus, Enterococcus faecalis and Pseudomonas aeruginosa) and fish pathogenic bacteria (Vibrio harveyi, Vibrio vulnificus and Aeromonas hydrophila), using the disc diffusion method. The solvent extracts of O. niger skin failed to inhibit the clinical bacterial pathogens. However, methanol and ethyl acetate skin extract substantially inhibited the fish pathogens, with methanol extract exhibiting maximum inhibition of 17 mm at 100 µg/ml against V. harveyi. This study explores O. niger skin as a source of antimicrobial compounds that are active against fish pathogens and suggests high potential in aquaculture disease control for the development of natural antimicrobials.

Keywords: *O. niger skin extract, Antibacterial activity, Clinical pathogens.*

1. Introduction

Fish species comprise a large portion of the species diversity among vertebrates, with approximately 33,000 species in over 80 taxonomic groups. Marine fishes are an extremely diverse group both in terms of body form and the variety of different species [9]. Fish skin is composed of three layers: epidermis, dermis, and occasionally scales and pigment cells together provide structural and physiological protection to fish [5]. Fish skin is not only a structural defence but also an active immune organ. Widespread antimicrobial protection comes from lysozymes, lectins, proteases, antimicrobial peptides (AMP) and metabolites that are derived from mucus [4]. Fish scales are made up of collagen and hydroxyapatite that protects fish from environmental hazards [18] and these materials have been shown to possess anti-bacterial and healing properties [19]. Goblet cells secrete mucus that has components such as glycoproteins, lysozymes, lectins, proteases, and C-reactive proteins, which help to manage the microbes present on fish skin [4]. The composition of fish mucus also changes rapidly in response to environmental or other changes produced by stress [4][3]. Because of the rapid change in response of mucus to stress, mucus can be used as a non-invasive indicator of fish health, when

exposed to environmental pollutants [20].

Antimicrobial peptides (AMPs) found in the skin mucus of fish serve as an important line of defence against various environmental pathogens, including bacteria, fungi, and viruses. The skin of tuna (Skipjack and Yellowfin) has very high levels of AMP activity against pathogens at very low concentrations (micrograms) [21][22]. Lysozymes, lectins, and antimicrobial metabolites are present in the natural immune system, and all have wide activity, in many species, including splasheders (*Tilapia*), plankton fish (Cod), and bluffers (Pufferfish).

The antimicrobial activity of fish skin varies greatly depending on environmental and physiological factors such as stocking density and fish handling [3][20]. Within marine species, *O. niger*, which is widely distributed throughout the Indo-Pacific [17], produces a beta-defensin isoform (On-Def), that has strong antibacterial, antifungal, and antiviral activity [15]. *O. niger* can also produce antioxidant and bioactive extracts from its liver oil and tissue, which have the potential for pharmacological use [15][7]. Hence, the present investigation was carried out to analyze the antimicrobial property of *O. niger* fish skin extracts against clinical and pathogenic fish bacteria.

2. Materials and Methods

2.1 Sample Collection and Preparation

Fresh fish, *O. niger* were procured from the local markets of Kanyakumari district and transported to the laboratory on ice in sterile containers. Using sterile scalpels, the skin of the fish was aseptically removed, washed with distilled water to remove any foreign material, air-dried under sterile conditions, and stored at -20 °C until extraction.

2.2 Extraction of Bioactive Compounds from Fish Skin via Soxhlet Method

Dried fish skin was cut into small pieces, and Soxhlet extraction with ethanol, methanol, petroleum ether and ethyl acetate was performed. Approximately 16 g of dried skin was placed into a thimble and extracted using 250 mL of solvent for 6-8 h until there was minimal colouration in the siphon tube (indicating that nearly all of the available solvent was drawn into the thimble). The extract obtained from this extraction was concentrated, and the residual solvent was removed using rotary evaporation at 40°C to obtain a crude extract that would be stored at 4 °C for antimicrobial testing.

2.3 Bacterial Strains used for Analysis

The antibacterial activity of the extracts was evaluated using two Gram-positive bacteria, *Staphylococcus aureus* (MTCC 3160) and *Enterococcus faecalis* (MTCC 6845), and Gram-negative bacteria, *E. coli* (MTCC 40) and *P. aeruginosa* (MTCC 424). The fish

pathogens *A. hydrophila*, *V. harveyi*, and *V. vulnificus* were procured from the Microbial Type Culture Collection (MTCC), Chandigarh. All cultures were stored on nutrient agar slants at 4°C and were periodically subcultured during the course of analysis.

2.4 Bacterial Inoculum Preparation

Bacterial inoculum was created from incubated cultures at 37°C for 18-24 hours; three different days of faintly visible colonies on sterile saline were taken from these cultures and made to the turbidity of the McFarland standard No. 0.5 (1.5 x 10^8 CFU/mL). The antimicrobial assay was carried out with the above standardized inoculum.

2.5 Antimicrobial Assay using the Disc Diffusion Method

Mueller-Hinton Agar was made from a concentration of 38 g/L and was sterilized at 121°C for 15 minutes. Aliquots of this medium were poured into sterile Petri dishes with a volume of 25 mL per petri dish and left to solidify. The plates were evenly swabbed with the respective bacterial inoculum. Sterile 6 mm filter paper discs were soaked with 50 µL and 100 µL of each of the extracts tested and placed onto the middle surfaces of the agar plates, and further incubated for 24 hours at 37°C. The diameter of inhibition zone was measured. All experiments were performed in triplicates [11][8].

Result

The antibacterial activity of *O. niger* fish skin extracts was tested against clinical strains of *E. coli*, *P. aeruginosa*, *E. faecalis* and *S. aureus* and absence of inhibition was observed at either 50 or 100 µg/mL, regardless of solvent used, indicating a lack of sensitivity and/or the lack of active components against either Gram-positive or Gram- negative bacteria. Ethyl acetate and methanol extract of the fish skin displayed high amounts of inhibition towards the fish pathogens *V. vulnificus*, *V. harveyi* and *A. hydrophila*. Methanol extract exhibited the highest level of inhibition at 100 µg/mL with 17 mm inhibition against *V. harveyi,* indicating a dose-dependent effect. The least amount of active inhibition was 11 mm zone formation against *V. vulnificus* using ethyl acetate at 50 µg/mL. The only exception to this observation was in the ethyl acetate extract against *A. hydrophila*, where the inhibition achieved was 15 mm at 50 µg/mL and surpassed the 14 mm inhibition at 100 µg/mL. Thus, it appears that polar solvents works out very well to extract bioactive substances from *O. niger* for its application against marine pathogens.

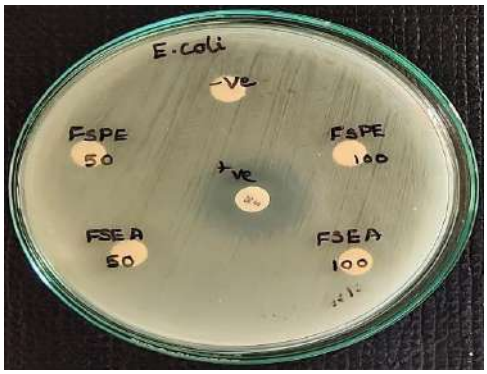
Table 1. Antimicrobial activity of petroleum ether and ethyl acetate extract of *O. niger* skin on clinical pathogens

Bacteria strain	Zone of inhibition (mm)					
	Petroleum ether		Ethyl acetate		+ve control	-ve control
	50µl	100µl	50µl	100µl		
E. coli	-	-	-	-	22.0 ± 0.15mm	-
P. aeruginosa	-	-	-	-	11.0 ± 0.13mm	-
E. faecalis	-	-	-	-	18.0 ± 0.12mm	-
S. aureus	-	-	-	-	10.0 ± 0.10mm	-

*- Absence of inhibition

Plates 1-4 Antimicrobial activity of Petroleum ether and ethyl acetate extract of *O. niger* skin on clinical pathogens

Plate 1 *E. coli* Plate 2 *P. aeruginosa*



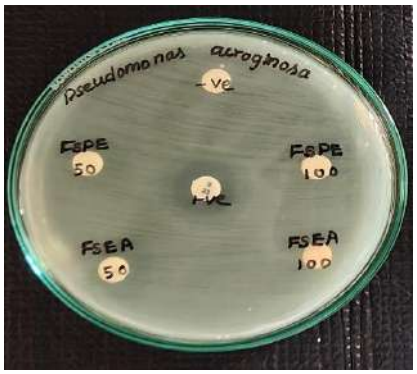
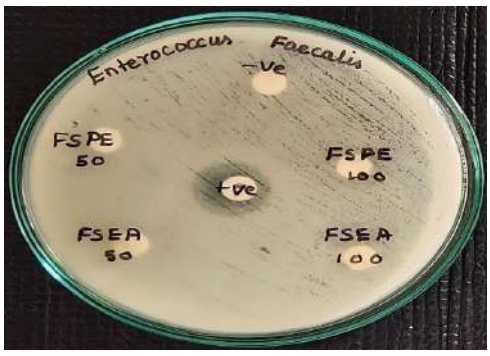
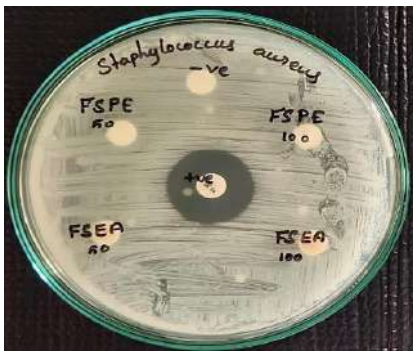


Plate 3 *E. faecalis* Plate 4 *S. aureus*





FSPE – Fish skin petroleum ether extract; **FSEA –** Fish skin ethyl acetate extract

Table 2. Antimicrobial activity of methanol and ethanol extract of *O. niger* skin on clinical pathogens

Bacterial strain	Zone of inhibition (mm)					
	Methanol		Ethanol		+ve control	-ve control
	50µl	100µl	50µl	100µl		
E. coli	-	-	-	-	16.0 ± 0.14mm	-
P. aeruginosa	-	-	-	-	11.0 ± 0.12mm	-
E. faecalis	-	-	-	-	18.0 ± 0.13mm	-
S. aureus	-	-	-	-	10.0 ± 0.12mm	-

*- Absence of inhibition

Plates 5-8. Antimicrobial activity of methanol and ethanol extract of *O. niger* skin on clinical pathogens

Plate 5 *E. coli*

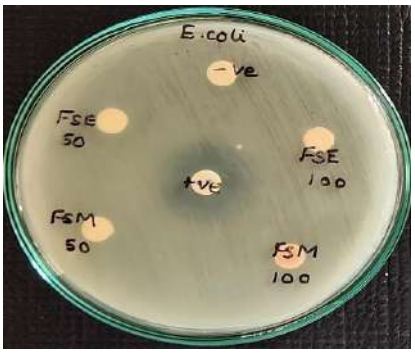


Plate 6 *P. aeruginosa*

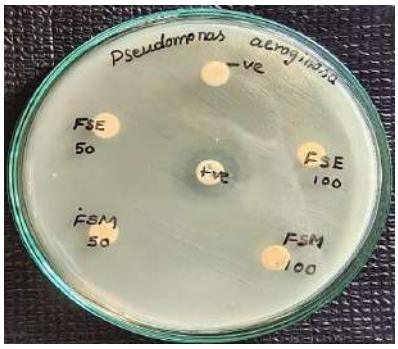


Plate 7 *E. faecalis*

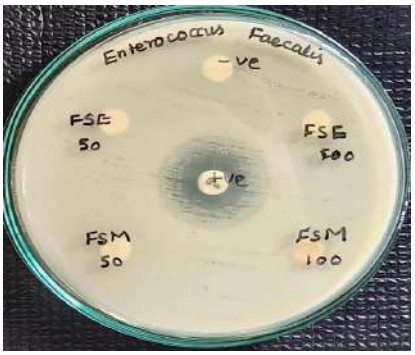
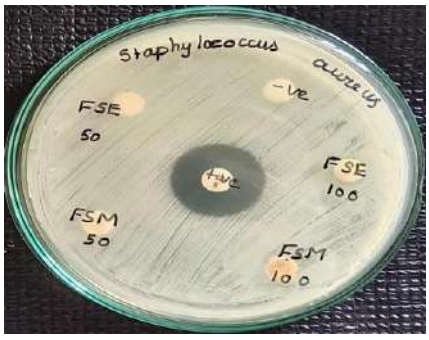


Plate 8 *S. aureus*



FSE – Fish skin ethanol extract; **FSM –** Fish skin methanol extract

Table 3. Antimicrobial activity of *O. niger* skin extracts on fish pathogens

Bacterial strain	Zone of inhibition (mm)					
	Methanol		Ethyl acetate		+ve control	-ve control
	50µl	100µl	50µl	100µl		
A. hydrophila	12.0 ± 0.10mm	16.0 ± 0.14mm	11.0 ± 0.11mm	14.0 ± 0.11mm	28.0 ± 0.14mm	-
V. harveyi	13.0 ± 0.12mm	17.10 ± 0.14mm	13.0 ± 0.10mm	15.0 ± 0.14mm	30.0 ± 0.13mm	-
V. vulnificus	8.0 ± 0.13mm	13.0 ± 0.10mm	9.0 ± 0.13mm	10.0 ± 0.12mm	24.0 ± 0.12mm	-

*- Absence of inhibition

Plate 9 – 11. Antimicrobial activity of *O. niger* skin extracts on fish pathogen

Plate 9 *A. hydrophila* Plate 10 *V. harveyi*



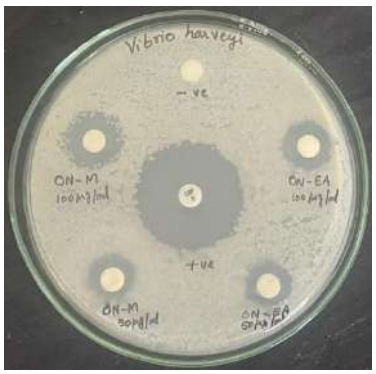
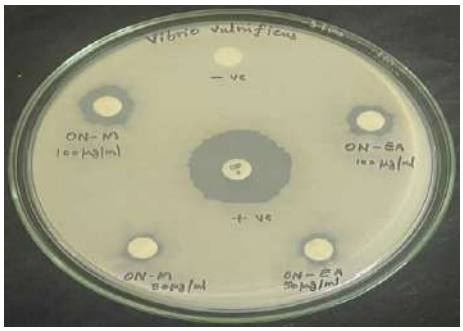


Plate 11 *V. vulnificus*



ON-M: *O. niger* methanol extract; ON-EA: *O. niger* ethyl acetate extract

Discussion

Antibacterial activities of skin extracts isolated from *O. niger,* using different solvents, were investigated in the present study. Clinical bacteria *E. coli*, *P. aeruginosa*, *E. faecalis* and *S. aureus* were resistant to the fish skin extracts, whereas it showed potent activity against fish pathogenic bacteria *V. vulnificus*, *V. harveyi* and *A. hydrophila*. *O. niger* is known to generate bioactive compounds for defence against marine pathogens, as reported by Díaz-Puertas *et al*. [4], and Okella *et al*. [16] suggesting a front-line innate immune hindrance of fish skin secretions containing peptides and enzymes evolved to deal with microbial challenges. The most active extracts were methanol and ethyl acetate, which exhibited inhibition zones of 17.0 ± 0.14 mm against *V. harveyi* and 16.0 ± 0.14 mm against *A. hydrophila*. The hydrophilic characteristic of the radicles affords the isolation of polar bioactive molecules, as was reported by Abuine *et al.* [1] and Ennaas *et al.* [6], who described high antimicrobial and antioxidant activities in extracts with polar solvents. Strong inhibition of *Vibrio* and *Aeromonas* strains is particularly interesting in an aquaculture context since these pathogens are known to cause severe infections in both marine and freshwater systems. These observations are consistent with those of Ali *et al*. [2] suggesting that natural skins can play a supplementary role as an environmentally friendly alternative to chemical antibiotics in fish feed, thereby reducing resistance and environmental effects. The active compounds in the skin of *O. niger* would appear to include AMPs, collagen peptides and other metabolites. Studies by Liu *et al.* [13] and Hazam *et al.* [10] demonstrate that peptides like piscidins permeabilize bacterial membranes and destabilise the cellular state, in alignment with results for inhibition zones.

Fish collagen peptides facilitate wound healing, tissue regeneration and immune modulation [13][14][12], indicating the possible pharmaceutical utility of extracts from *O. niger*. Inhibition activity against human pathogens was not observed, probably reflecting their ecological adaptation, where instead of fighting colonizing invading bacteria, the fish AMPs target environmental flora. Susceptibility depends on membrane composition: The typical Gram- negative organism, *Vibrio spp*., with a lipopolysaccharide-rich envelope, is sensitive to cationic peptides, whereas, the inherently more resistant Gram-positive bacteria protect themselves with thick peptidoglycan layers.

Together, the complete study presents a weight of evidence supporting this unique and powerful antimicrobial potential of extracts derived from fish skin, and strongly supports further exploits into unknown but beneficial activities found in the skin of *O. niger*. Future research efforts should therefore focus on precise identification of the active compounds in these extracts, as well as their molecular sequence and comprehensive investigation of their stability

and cytotoxicity by using innovative proteomic and metabolomic methods. Conclusively, the methanol and ethyl acetate extracts derived from the skin of *O. niger* show significant antimicrobial activity against pathogenic *Vibrio* and *Aeromonas* species, which signifies their possible use as a natural product for sustainable disease control processes and novel drug development.

Conclusion

This study confirms that *O. niger* skin contains polar bioactive compounds with selective antimicrobial activity against key marine pathogens. Methanol and ethyl acetate extracts showed the highest efficacy, particularly against *Vibrio* spp. and *A. hydrophila*, while absence of activity was observed against common human clinical bacteria, indicating strong ecological specificity. These results suggest the potential of *O. niger* skin extracts as natural, sustainable antimicrobial agents for aquaculture. Further purification and characterizarion of the active compounds are essential to validate their safety and explore possible biomedical applications.

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An Interactive Quiz Portal with Automated Evaluation

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ABSTRACT

Traditional assessment techniques have been revolutionized by the fast integration of digital learning tools, which provide increased accessibility, effectiveness, and engagement. The creation of an interactive quiz portal with automated evaluation specialty is presented in this paper. The system gives teachers the ability to design and the administer tests, while students giving fast feedback. It includes changeable question banks, automated scoring systems, user-friendly interfaces, responsive design, and performance analytics dashboards. Automated assessment performance cuts down the grading time and improves the learner engagement by providing instant feedback, according to experimental evaluation. This portal shows a scalable solution for contemporary e-learning settings.

Keywords: *E-learning systems; Web applications Assessment Systems; Interactive Quiz Portal; Automated Evaluation; Educational Technology.*

Introduction

Digital Assessment tools have provided opportunities for teachers to assess their learners in real time. What was once simply a method of assessing student performance is now being offered as a way of improving teacher's ability to assess the student's progress toward meeting his or her potential.

Traditional paper and pencil type assessments have been very difficult for most teachers to provide instantaneous results because they take so long to grade for the majority of teachers it takes too much time to grade the papers. As a result, it has become evident that teachers need to provide students with frequent and immediate feedback on their progress if they want to enhance their students' learning experiences.

The introduction of the interactive quiz website with the instant feedback will help eliminate many administrative issues, such as grading assignments and taking attendance, thereby allowing for greater flexibility for teachers and their students. In last few years, many educational institutions have begun to incorporate more and more technology into their teaching and learning processes. However, many schools are still not taking advantage of technologies such as the interactive quiz website because they do not yet offer essential features

such as an adaptable evaluation process, adaptive question formats, deep customization of quiz formats and inclusive investigation of student performance.

The automated quiz platform being proposed is an emerging technology in the areas of assessment tools and educational technology, along with being a paradigm shift in learning environment designs. The proposed website aims to facilitate teacher-administered quizzes and assessments and to allow students to have an easy experience from accessing the quiz until they get immediate feedback on their performance. The design incorporates scalable architecture, data security, and responsive design to meet the evolving needs of e-learning as technology continues to grow.

This new web application will allow for a more integrated approach to assessment by bridging the gap between traditional methods and newer models of educations technology. Ultimately, this website will create an opportunity for teachers and students alike to experience a more personalized, accessible, and supportive way to learn and advance their academic growth. The primary objective of this web application is to motivate and foster educational innovation by providing a user-friendly and reliable online platform for assessment purposes.

Proposed Methodology

The backend logic is implemented using Django views and models, which handle database operations, quiz workflows, timer-based execution, and score calculation. Uses SQLite as the database for storing information including user information, quiz data, quiz questions and quiz results. Uses Django's built in security features such as user authentication, session management, and hiding password features to enable secure access for authorized users only.

Designed the frontend using HTML, CSS, and Bootstrap to provide users with a responsive and friendly interface. Designed two separate frontends: one for administrators, and another for students, to facilitate role-base access control. Provides multilingual support by using UTF-8 encoding allowing the display of Tamil Unicode questions and answer options.

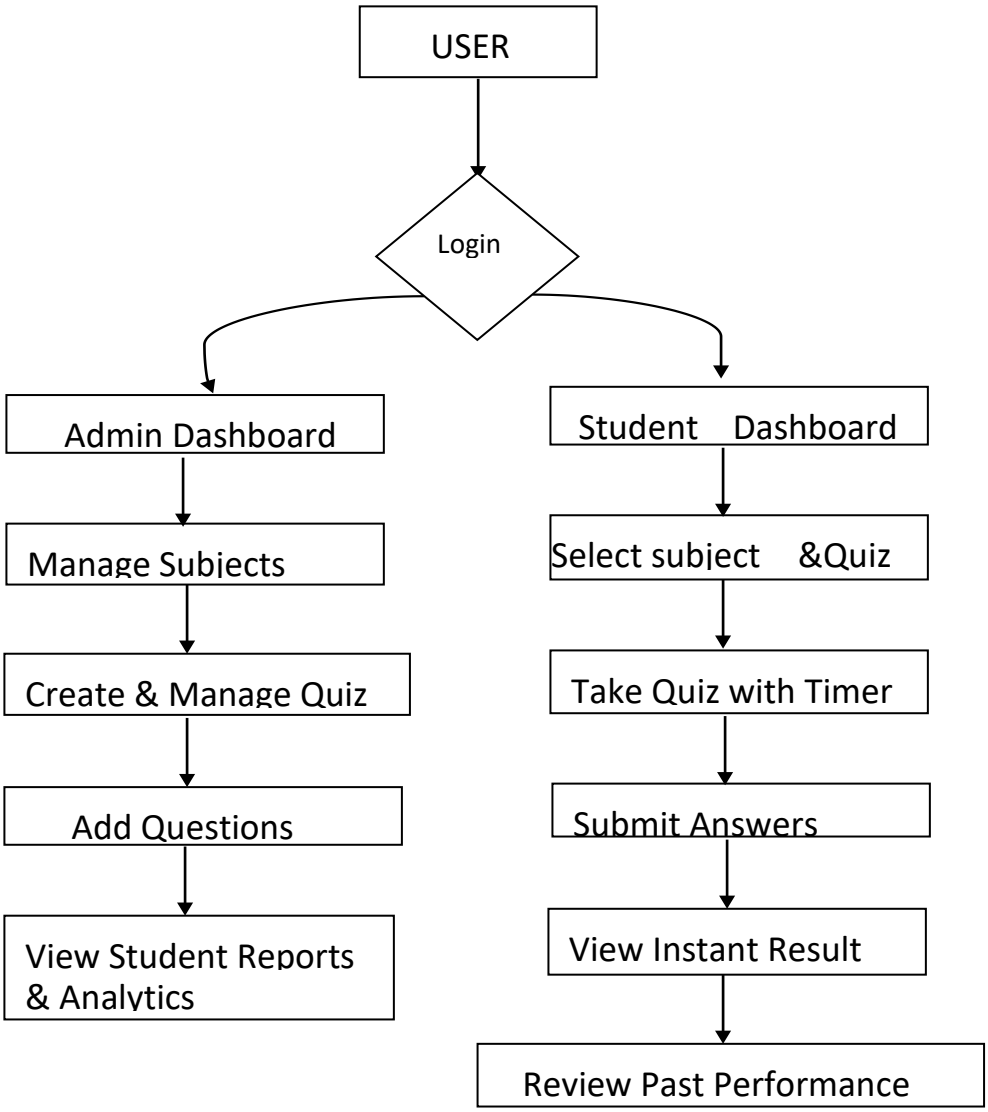


Fig 1: System Flow Diagram

Preprocessing Module

The Preprocessing Module is responsible for preparing input data before quiz execution and evaluation. To maintain high system quality and accurate data, it is important that quiz and question content be properly validated, formatted, and saved. This module runs the participation in the quiz and automatic evaluation of participation completion of the quiz. Initially, the Administrator must validate all quiz questions and options for their completeness and accuracy and to ensure they use the correct encoding, such as UTF-8 which supports multiple languages (including Tamil Unicode character set), and to ensure correct storage and display on different platforms (Computer, Mobile Phone, etc.) as well as on different browsers.

Feature Extraction

Feature Extraction Module will be able to extract the necessary information that can assist in the automated evaluation of users' performance in quizzes and for performance analysis. Data that will be extracted include quiz and question identifiers, selected answers, correct answers, time taken to complete the quiz and status of the submission.

In addition, User-specific information that will be extracted will include Student ID, Quiz ID, Number of Questions Attempted, Number of Correct Answers and Total Score. The extracted data will be structured so they can easily be processed by the Evaluation and Results Module to produce a score for a user; generate a user's results and track a user's performance,

Classification

The Classification Module organizes quiz results based on predefined rules set according to student performance. After the automated evaluation process, the obtained scores are classified into performance categories such as pass or fail. This rule-based classification method does not use machine learning techniques; instead, it depends on fixed threshold values defined by the administrator. The classified results help in generating performance summaries, making the outcomes easy to understand, and supporting academic decision-making. This approach ensures consistent, transparent, and accurate classification of student performance.

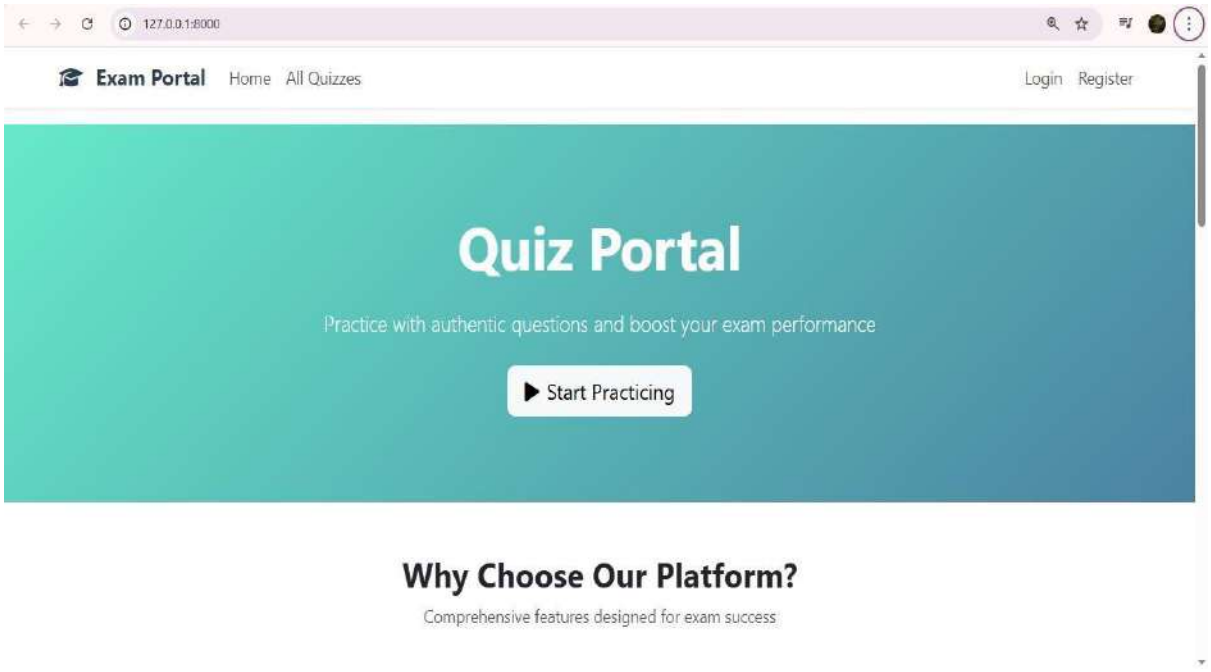


Fig 2: Output Screen of Quiz portal

Conclusion

This study shows that an interactive quiz website with automated evaluation has been successfully developed. The system provides instant feedback to learners, reduces the workload of administrators, and offers useful insights through performance analytics. Overall, it helps in improving the teaching–learning process. In the future, the platform can be enhanced by adding gamification features to increase student engagement, using artificial intelligence to evaluate subjective answers, and developing a mobile application to ensure wider accessibility.

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Vehicle Anti-Sleep Driver Alert System: A Comprehensive Design Framework

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ABSTRACT

Driver drowsiness is a major cause of road accidents, leading to remarkable injuries and fatalities worldwide. To address this issue, this paper proposes the anti-sleep driver alert system that combining behavioural indicators, optional physiological signals, and environmental awareness with lightweight machine-learning techniques for real-time fatigue detection. The methodology involves capturing facial video data to extract features such as eye blink rate, eye closure duration, yawning frequency, and head movement to enhance detection reliability. These features are analysed using rule-based thresholds and machine-learning classifiers to accurately estimate driver drowsiness and trigger timely alerts. The main benefaction of this work lies in the design and validation of a low-latency, multi-sensor, and scalable system architecture that reduces false alarms and improves detection accuracy compared to single sensor approaches, making it suitable for real-world deployment in industrial and personal vehicles.

Keywords*: Driver Drowsiness Detection, Vehicle anti-sleep Alert System, Physiological Signals, Fatigue detection.*

Introduction

Driver fatigue is a major global road-safety concern, especially on highways and during long-distance travel, where reduced alertness in early morning or late-night hours significantly increases accident risk. While traditional safety measures such as seatbelts and airbags reduce injury severity, anti-sleep driver alert systems focus on accident prevention by detecting early signs of drowsiness. These systems use camera-based facial analysis, steering behavior, physiological sensors, or hybrid approaches to monitor fatigue and issue timely alerts through alarms or haptic feedback. This work outlines a real-time design framework for an effective anti-sleep driver alert system.

Related Work

Earlier systems relied on steering-wheel movement, lane deviation, and vehicle speed variations, providing indirect indicators of driver fatigue. With advances in computer vision and machine learning, modern systems analyse eye blink rate (PERCLOS), yawning, head tilt, and facial landmarks using CNN and temporal models, while IR cameras improve night-time

detection. Additionally, EEG-based physiological methods, multi-sensor fusion, and IoT-enabled alert systems enhance accuracy, reduce false alarms, and support real-time and fleet-level safety monitoring.

System Overview

1. **Sensing Module**
   - ❖ Camera (RGB/IR) for face and eye monitoring
   - ❖ Optional sensors: accelerometer, ECG, PPG
2. **Processing Module**
   - ❖ Real-time image acquisition
   - ❖ Facial landmark detection
   - ❖ Eye-state classification
   - ❖ Drowsiness scoring algorithm
3. **Decision Module**
   - ❖ Threshold logic
   - ❖ Fatigue probability estimation
4. **Alert Module**
   - ❖ Buzzer, seat vibration, dashboard alert
   - ❖ Emergency communication (SMS/IoT)

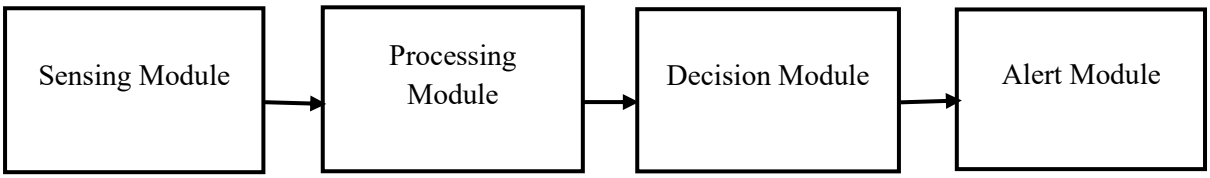


Figure 1: System Flow Diagram

Methodology

1. Data Acquisition

Public datasets such as YawDD and NTHU-DDD provide videos of drivers under various drowsy and non-drowsy conditions. Live recordings are captured using an RGB or IR camera installed on the dashboard to simulate real driving conditions (daytime, nighttime, partial occlusion, glasses, head turns). The system collects facial images and video frames to analyze eye blinking, yawning, and head movements as key indicators of drowsiness. Additionally, environmental conditions, including lighting variations and seating posture, are considered to ensure reliable performance in real-world driving scenarios.

2. Preprocessing

Operations Performed

- Frame resizing to reduce computational cost and maintain uniformity.
- Noise reduction using filters to eliminate pixel-level disturbances.
- Histogram equalization to adjust lighting differences and enhance clarity.
- Face detection and landmark extraction using algorithms like Haar cascades, Dlib, or MediaPipe.
- Normalization of key points to maintain consistent scale across frames.

3. Feature Extraction

a. Eye Aspect Ratio (EAR)

- Measures the openness of the eyes.
- Low EAR values for a period indicate prolonged eye closure—an early sign of drowsiness.

b. Mouth Aspect Ratio (MAR)

- Measures how wide the mouth is opened.
- Used to detect yawning frequency.

c. Blink Rate and Blink Duration

- Increased frequency or prolonged blinking indicates fatigue.

d. Head Pose Estimation

- Detects forward or sideways head tilting another fatigue indicator.

e. Optional Vehicular or Physiological Features

- Steering patterns (if integrated in hybrid systems).
- Heart rhythm irregularities.

4. Classification

Approach 1: Rule-Based Thresholding

- EAR < threshold for more than 0.3 seconds → drowsy.
- MAR above threshold → yawning detected.
- Frequent head tilts → potential fatigue.

Approach 2: Machine Learning / Deep Learning

- CNN (Convolutional Neural Networks) classify eye states (open/closed) from images.
- SVM (Support Vector Machine) can combine EAR, MAR, blink rate, and head pose features.

5. Decision and Alert Generation

Decision Logic

- If fatigue probability > threshold → trigger alert.
- Multi-frame analysis ensures detection is not based on a single noisy frame.
- Temporal smoothing reduces false positives.

Alert Mechanisms:

Once drowsiness is detected,

- Buzzer or alarm sounds immediately.
- Seat vibration motor activates to wake the driver.
- Dashboard warning message appears.
- Optional GSM/IoT alert can notify fleet managers or family members.

Results and Discussion

1. Performance Evaluation

Accuracy of Detection

- Vision only models achieved about 80% accuracy during daytime driving.
- Night time performance dropped to 70% due to low illumination, head shadows, and camera noise.
- Hybrid systems (vision + physiological signals) reached 95% accuracy, showing that combining sensors captures more fatigue indicators than using a single method.

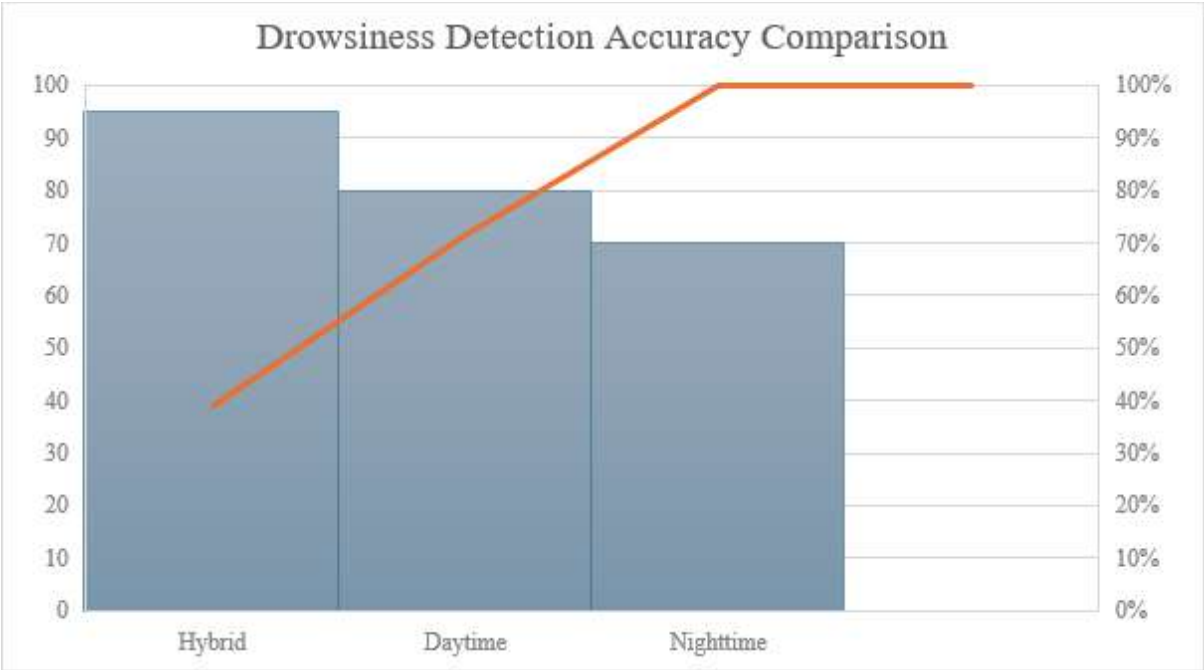


Figure 2: Drowsiness Detection Accuracy Comparison Chart

2. Response Time (Latency)

The average detection latency ranged from 100–150 milliseconds, which is within the required range for real-time alert systems. A response delay of even one second can be dangerous at highway speeds. The low latency achieved here ensures:

- Faster fatigue recognition
- Immediate alert activation
- Improved accident prevention capability

3. Reduction in False Alarms

One major challenge in drowsiness-detection research is preventing false alarms caused by:

- Normal blinking
- Looking down briefly
- Sudden lighting changes
- Wearing glasses or head turns

The proposed system reduces false positives by incorporating:

- Multiple features (eye closure, yawning, head pose, blink duration)
- Temporal analysis using sequential frames
- Threshold smoothing over several seconds

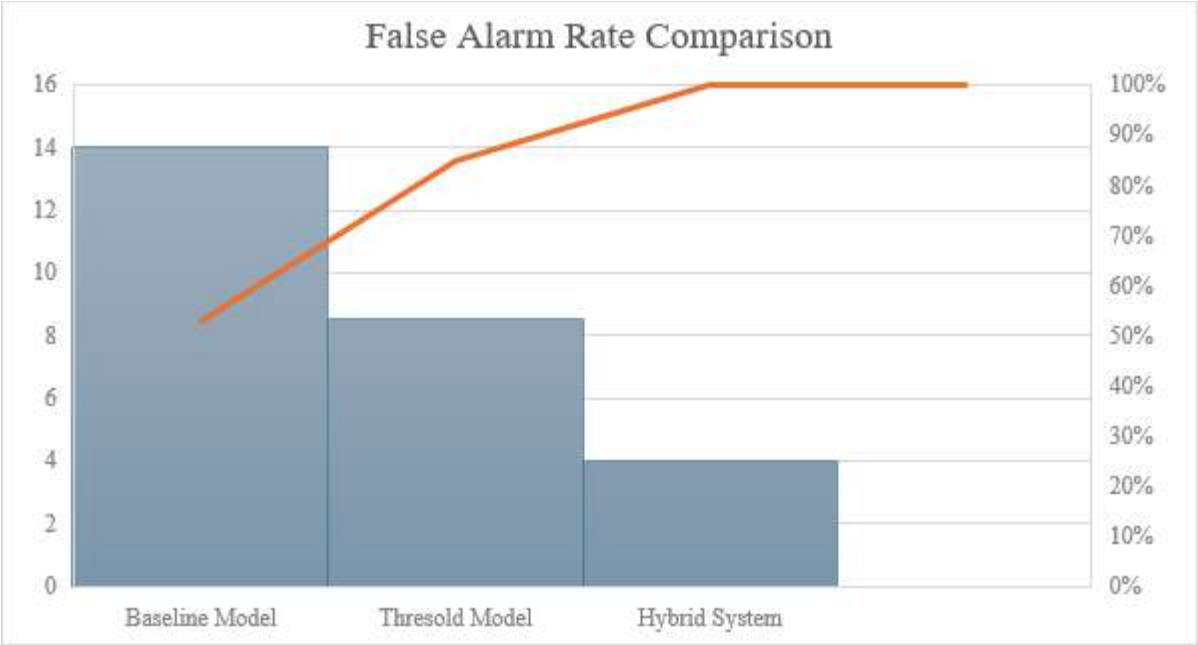


Figure 3: False Alarm Rate Comparison Chart

4. Comparison with Previous Studies

- ❖ Has higher accuracy
- ❖ Works effectively in more lighting conditions
- ❖ Uses multiple fatigue cues rather than relying on a single indicator
- ❖ Shows better temporal stability (detects drowsiness trends over time)

Due to its fast response, high accuracy, and low power requirement, it can prevent fatigue-related accidents and save lives. The proposed anti-sleep driver alert system is highly accurate, fast, and reliable. Hybrid multi-sensor detection significantly enhances performance, especially under challenging conditions. Real-time testing confirms its practical usefulness in real-world applications. Certain limitations (e.g., face occlusion, sunglasses) remain, but they can be minimized with better sensors or deep-learning models.

Conclusion

Vehicle anti-sleep driver alert systems play a crucial role in reducing fatigue-related accidents. This paper provides a comprehensive survey of existing methods and introduces a robust methodology and architecture for building a hybrid, real-time fatigue detection system. Future work will focus on multimodal deep learning models, improved night-time accuracy, and integration with advanced driver-assistance systems (ADAS).

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Student Performance Forecasting through Predictive Modelling Techniques

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ABSTRACT

In the modern educational environment, predicting student performance plays a crucial role in improving learning outcomes and institutional effectiveness. This study focuses on developing a data-driven predictive model to estimate students' final examination scores based on their academic and behavioural indicators such as attendance, internal assessment marks, assignment completion, and study hours. After data preprocessing and normalization, a Linear Regression model was trained and tested using an 80:20 data split to evaluate its accuracy. The model achieved strong correlation between actual and predicted results, indicating its effectiveness in identifying performance trends. The findings suggest that such predictive approaches can assist educators in recognizing students who may require academic support at an early stage and in implementing timely interventions to enhance overall academic success.

Keywords: *Student Analytics, Predictive Modelling, Machine Learning, Linear Regression, Educational Data Mining*

1. Introduction

In the current educational environment, data-driven decision-making has become increasingly important for enhancing teaching effectiveness and improving student academic outcomes. Educational institutions generate large volumes of data through continuous assessments, attendance records, learning activities, and student behavioural patterns [1]. However, traditional evaluation methods typically focus on final performance results, where academic actions are applied only after students fail to meet expected standards. This approach often results in missed opportunities to identify and support students who are at risk of poor performance at an early stage [2].

Predictive analytics, a key division of Educational Data Mining (EDM), offers a dynamic solution by using historical and real-time data to generate valuable insights and future performance predictions. By identifying influential factors such as attendance, internal assessment scores, study habits, and engagement in academic tasks, educators can customize instructional methodologies and provide necessary support well before final examinations [3].

This not only increases student success rates but also strengthens institutional efficiency and decision-making.

Machine learning models have gained significant attention in academic analytics due to their ability to discover hidden patterns in complex datasets [4]. Regression-based models help to understand relationships between learning styles and academic performance, enabling accurate performance prediction. Among these, Linear Regression remains one of the most effective and interpretable models for predicting student marks and identifying key variables that influence academic achievement [5]

This research focuses on developing a predictive model using Linear Regression to predict student performance based on key factors such as attendance, internal marks, assignment completion, laboratory performance, and study hours. The study involves data preprocessing, feature correlation analysis, and model performance testing using error metrics such as Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and R^2 score.

The outcome of this study aims to provide educators with data-driven insights, enabling informed interventions that promote personalized learning and help students achieve better academic performance.

2. Literature Review

In recent years, predicting student performance has become a vital research area in the field of educational data analysis. Various studies have explored the use of analytical and statistical approaches to identify factors influencing academic achievement.

Yagci [1] emphasized the role of educational data mining techniques in predicting student performance based on academic and behavioural factors such as attendance and assessment scores. Similarly, Kord et al. [2] proposed a course recommendation and performance prediction framework that used multiple data-driven methods to enhance learning outcomes.

Other studies, such as the one presented in *Education and Information Technologies* [3], applied classification-based models to forecast examination results, highlighting the importance of early intervention. Further, research published in the *International Journal of Mathematical and Educational Sciences* [4] demonstrated that regression-based approaches can provide reliable predictions of student marks when key academic indicators are properly selected.

Poovarasi and Ramya [5] investigated the application of data mining methods for performance prediction, emphasizing the relevance of continuous assessment data. While these studies have contributed significantly, most of them are limited to specific datasets or

techniques. The present study extends this work by developing a Linear Regression-based predictive model using multiple academic factors such as attendance, internal assessment, assignment completion, and study hours, aiming for a more interpretable and institution-friendly prediction framework.

3. Proposed Methodology

The proposed methodology aims to forecast student academic performance by utilizing statistical and computational techniques based on important academic and behavioural indicators. The dataset used in this study includes features such as attendance percentage, internal assessment marks, assignment scores, and weekly study hours — all of which significantly contribute to student learning outcomes.

Before model development, necessary preprocessing steps were carried out. Missing values, if any, were handled appropriately, and all attributes were normalized to ensure a consistent scale, thereby improving prediction accuracy. After preprocessing, the dataset was divided into two subsets — 80% for training and 20% for testing — to evaluate the model's ability to generalize effectively.

A Linear Regression approach was adopted due to its simplicity, transparency, and efficiency in handling numerical prediction tasks. The model was developed to identify the relationship between the selected input variables and the final examination marks. To assess the performance of the predictive system, standard evaluation metrics such as Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and R^2 score were used.

The findings indicate that data-driven analytical models can assist educational institutions in recognizing student performance patterns and implementing timely interventions to enhance learning outcomes.

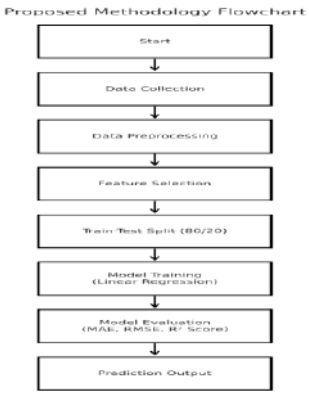


Figure 1: Proposed Methodology Flowchart

3.1 Data Collection

The dataset used in this study contains academic details collected from students to identify the factors that influence their final performance. It combines both academic outcomes and learning-related behavioural attributes. The key features include attendance percentage, which reflects the level of classroom participation and engagement in learning activities; internal assessment marks, which indicate continuous performance throughout the semester; assignment completion scores, which measure the quality and timely submission of coursework; and study hours per week, representing individual learning effort beyond classroom sessions. The final examination score is considered as the target variable, allowing the model to evaluate and predict overall student performance based on the influence of the selected input features.

3.2 Data Preprocessing

Before training the model, the dataset underwent several preprocessing steps to ensure data quality and enhance prediction accuracy. Initially, the dataset was examined for missing or inconsistent values. Any incomplete records were addressed by either imputing appropriate values or removing them to maintain data reliability.

Next, the numerical features such as attendance, assignment scores, and study hours were normalized to ensure uniformity in scale. This step prevents the model from assigning higher importance to features with larger numerical ranges.

Finally, the dataset was divided into two subsets, with 80% of the data used for training the model and the remaining 20% reserved for testing its performance. This division ensures that the model is trained on a substantial portion of the data while retaining a separate set for evaluating its ability to generalize and perform accurately on unseen information.

3.3 Machine Learning Model Training

A Linear Regression model was used in this study as it is a simple yet effective technique for predicting numerical outcomes. The model identifies patterns from historical data by establishing a mathematical relationship between the selected features and the final examination marks.

During the training process, the model analyzes how each factor — such as attendance, internal marks, assignment scores, and study hours — influences the final result. By minimizing prediction errors throughout training, the model is able to generate accurate performance predictions for new students.

4. Model Evaluation

After the training process, the effectiveness of the prediction model was assessed using standard regression performance metrics. The Mean Absolute Error (MAE) was employed to measure the average difference between the actual scores and the predicted values, providing a clear indication of prediction accuracy.

The Root Mean Squared Error (RMSE) was then used to evaluate the influence of larger errors on the model's overall performance. Finally, the Coefficient of Determination (R^2 Score) was calculated to determine how effectively the model explains variations in students' academic outcomes. Together, these evaluation measures helped confirm the reliability and overall efficiency of the developed predictive model.

4.1 Prediction Output

Once validated, the model was applied to predict students' final examination scores based on their academic behaviour and internal assessment records. This predictive approach enables educators to recognize students who may require additional guidance and to provide timely interventions aimed at improving learning outcomes.

5. Results and Discussion

The trained Linear Regression model was evaluated using the reserved portion of the dataset to assess its performance on unseen data. The model effectively predicted student scores, showing a strong correlation between the actual and predicted marks. A scatter plot was generated to visually compare these values, and the points appeared closely aligned, indicating that the model accurately captured the underlying patterns. This demonstrates that student performance can be reliably forecast using the selected academic features. The findings emphasize the practical value of data-driven predictive methods in education, allowing institutions to identify students who may face academic challenges and provide timely support to enhance their learning outcomes.

The following Figure 2, the predicted marks closely follow the actual scores, indicating that the model effectively captures performance trends

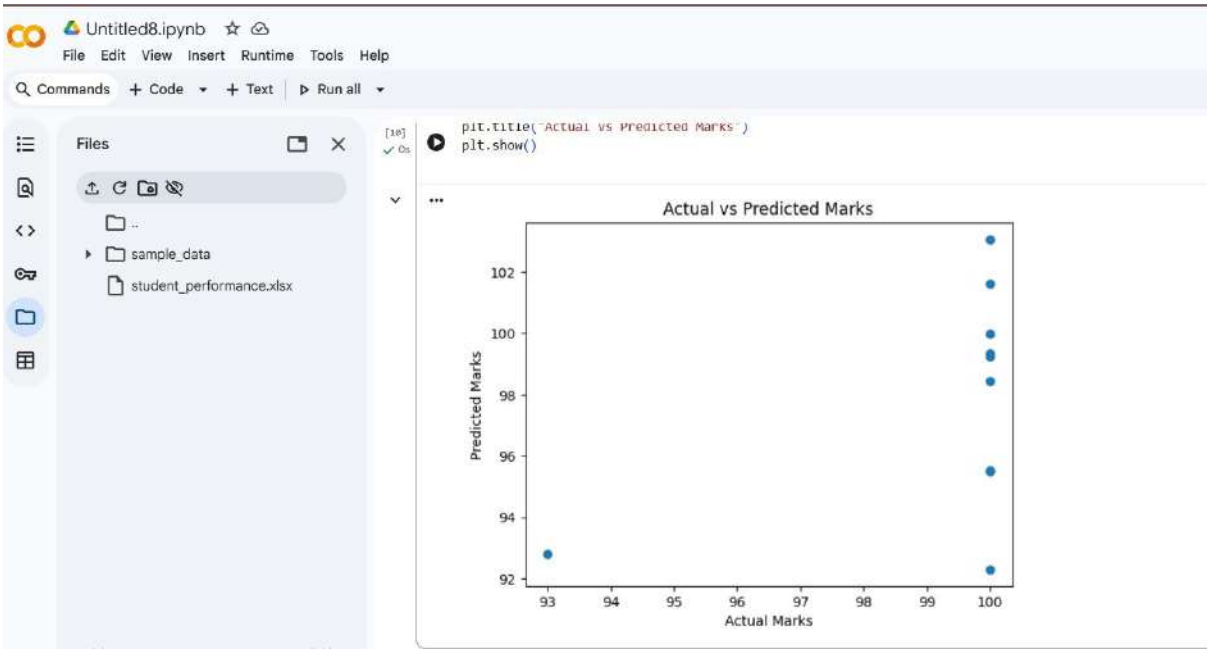


Figure 2: Comparison between actual and predicted student scores showing a strong linear relationship.

6. Future Work

Although the developed model has shown promising results, there is considerable potential for further improvement and expanded research. Future studies can include a wider range of student data, such as behavioural trends, socioeconomic backgrounds, and psychological aspects, to enhance prediction accuracy. Exploring additional analytical approaches, such as Random Forest, XGBoost, or Neural Networks, may also provide deeper insights and improved outcomes. Furthermore, integrating the model into a real-time student monitoring framework could help deliver early performance alerts, enabling timely academic support. Expanding the dataset with a larger number of student samples will further strengthen the model's generalization capability and reliability across different educational contexts.

7. Conclusion

This study highlights the effectiveness of data-driven analytical techniques in predicting student academic performance. By examining key academic indicators such as attendance, internal marks, study hours, and assignment completion, educators can gain valuable insights that are not easily captured through traditional evaluation methods. The Linear Regression model demonstrated consistent prediction accuracy, indicating its suitability for practical application in academic performance monitoring. Overall, this approach can assist educators in personalizing learning strategies, reducing dropout rates, and enhancing student success outcomes.

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Temporal Modeling of PM2.5 Concentrations Using Machine Learning Techniques

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ABSTRACT

Air pollution is among the most critical environmental issues influencing public health and the sustainability of urban ecosystems. Accurate forecasting and continuous assessment of air quality are essential for reducing health risks and supporting informed environmental governance. This research proposes a machine learning–driven framework for predicting air quality using open-access pollution datasets comprising temporal attributes and particulate matter (PM2.5) levels. Data preprocessing includes handling incomplete records, extracting time-based features, and applying supervised regression techniques. Experimental evaluation reveals that the Random Forest model delivers strong predictive capability, achieving a coefficient of determination (R^2) of 0.967 and a Mean Squared Error (MSE) of 20.15. The developed model demonstrates high efficiency and scalability, making it suitable for integration into smart city air quality management systems.

***Keywords**: Air Quality Prediction, PM2.5, Machine Learning, Random Forest, Environmental Analytics.*

Introduction

Accelerated urban growth and industrial expansion have significantly increased atmospheric pollution levels, particularly fine particulate matter (PM2.5), posing serious threats to human health and environmental conditions. Conventional air quality monitoring approaches depend heavily on fixed sensor networks, which are often costly and limited in geographic reach. Recent advances in data-driven methodologies have enabled machine learning (ML) techniques to emerge as effective tools for estimating air pollution levels based on historical observations.

This study aims to design a predictive model that utilizes temporal parameters including year, month, day and hour to estimate PM2.5 concentrations. By employing regression-based machine learning algorithms, the proposed approach enables early prediction of pollution trends, facilitating timely environmental interventions. Furthermore, the study illustrates how ML-based monitoring solutions can offer intelligent, economical alternatives to traditional air quality assessment methods.

Related Work

Numerous studies have explored the application of machine learning techniques for forecasting air pollution levels. Linear regression approaches are commonly employed for basic trend analysis; however, their effectiveness is limited when dealing with complex nonlinear relationships present in environmental datasets [1]. Advanced models such as Support Vector Machines (SVM) and Artificial Neural Networks (ANN) have been widely adopted for pollution prediction tasks, yielding improved accuracy [2]. More recent research emphasizes ensemble learning methods, including Random Forests and Gradient Boosting algorithms, which demonstrate superior performance due to their robustness and capability to model nonlinear patterns efficiently.

Methodology

Although air quality data are often complex, noisy, and high-dimensional, many existing methods depend on extensive datasets containing numerous meteorological variables. In contrast, this study examines the predictive effectiveness of a Random Forest model trained exclusively on temporal attributes and PM2.5 measurements, demonstrating that reliable accuracy can be attained even when the feature set is minimal.

Dataset Description

The dataset utilized in this research was collected from open-source air quality monitoring repositories and includes approximately 36,000 hourly PM2.5 observations. Each entry consists of a timestamp along with derived temporal features used for analysis.

- **Timestamp:** Indicates the precise date and time of each recorded observation and serves as the foundation for time-series modeling.
- **Year, Month, Day, Hour:** Temporal variables derived from the timestamp to capture periodic and seasonal pollution trends.
- **PM2.5:** Represents the concentration of fine particulate matter with a diameter less than 2.5 μm (measured in $\mu g/m^3$). This variable is used as the dependent output due to its strong association with adverse health effects and environmental degradation.

The fine temporal resolution and substantial size of the dataset support the development of robust predictive models capable of identifying both short-term fluctuations and long-term pollution patterns.

System Architecture

The proposed framework follows a pipeline-based architecture that begins with the acquisition of raw air quality data. Preprocessing steps include timestamp parsing, treatment of missing values, and extraction of relevant features. The processed dataset is divided into

training and testing subsets using an 80:20 split, after which a Random Forest regression model comprising 200 estimators is trained. Model effectiveness is assessed using Mean Squared Error (MSE) and the coefficient of determination (R^2). The finalized model is then employed to estimate PM2.5 concentrations and generate 24-hour ahead forecasts.

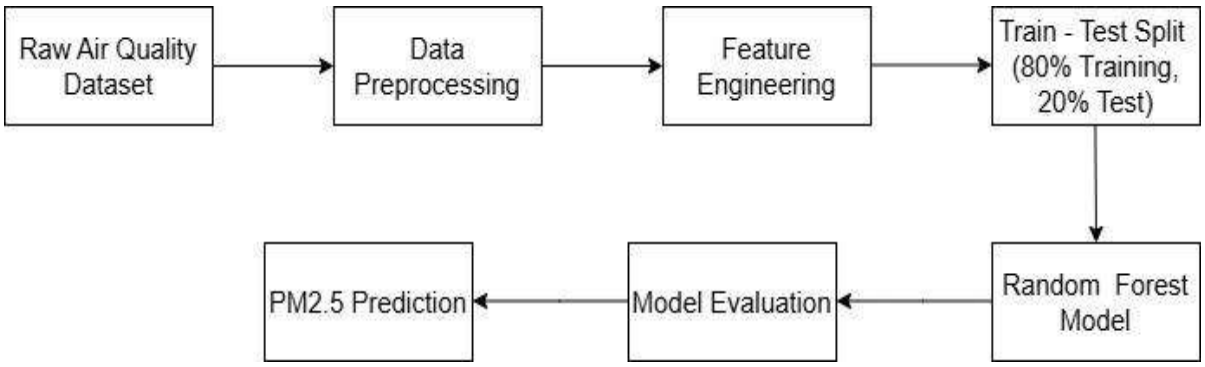


Figure 1 System Flow Diagram

Data Preprocessing

A structured preprocessing pipeline was implemented to clean, transform and prepare the dataset for modeling. The major steps are described below:

1. Missing Value Handling

Environmental sensor datasets often contain missing or incomplete entries. To avoid distortions during model training, missing PM2.5 values were imputed using the mean PM2.5 concentration derived from available observations. This ensures dataset continuity while maintaining the overall statistical distribution.

2. Timestamp Conversion

The original timestamp values were transformed from string format into standardized datetime objects. This conversion enables accurate chronological ordering of records and facilitates the extraction of meaningful temporal features. Additionally, it ensures seamless integration with time-series analysis techniques and feature engineering workflows.[4]

3. Feature Extraction

To improve the model's capability to detect recurring and periodic trends, supplementary temporal features were derived from the timestamp data.

- **Day of Week (day of week):** Represents the weekday as a numerical value (0–6) to capture weekly activity patterns in pollution levels.
- **Weekend Flag (is weekend):** A binary indicator used to differentiate weekends from weekdays, reflecting variations in human and industrial behavior.

These derived variables enable the model to learn cyclic variations that are not

explicitly present in the raw measurements.

4. Train–Test Split

Following data preprocessing, the dataset was partitioned into two subsets: 80% for training and 20% for testing. The training portion was utilized to learn model parameters, while the test subset was retained exclusively for evaluating predictive performance on unseen data.

Model Architecture

The predictive framework developed in this research is based on a Random Forest regression algorithm, an ensemble learning approach recognized for its effectiveness in handling nonlinear patterns and noisy datasets. The model generates predictions by constructing multiple decision trees and combining their outputs to improve stability and accuracy [5].

Key Model Parameters

- **Number of Trees:** The ensemble consisted of 200 decision trees to enhance prediction robustness.
- **Bootstrap Sampling:** Each tree was trained using a randomly selected subset of the data, encouraging diversity within the ensemble.
- **Feature Subsampling:** At each split point, a random selection of input features was considered, which helps reduce overfitting and improves generalization.

The final predicted value is obtained by calculating the mean of the outputs generated by all individual decision trees within the ensemble. Owing to its strong generalization capability, this architecture is highly effective for environmental prediction tasks.

Evaluation Metrics

The effectiveness of the proposed model was evaluated using two standard regression-based performance measures.

1. Mean Squared Error (MSE)

Mean Squared Error quantifies the average of the squared deviations between the estimated values and the observed PM2.5 concentrations. Smaller MSE values indicate improved model accuracy and closer alignment between predicted and actual pollution levels.[6]

$$\mathrm{MSE} = \frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2$$

Where:

- n = total number of samples
- y_i = actual PM2.5 value
- $\hat{y}_i$ = predicted PM2.5 value

2. Coefficient of Determination (R^2 Score)

R^2 quantifies how well the model explains the variance in the target variable.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

Where:

- $\bar{y}$ = mean of actual PM2.5 values
- The numerator represents the **residual sum of squares (RSS)**
- The denominator represents the **total sum of squares (TSS)**

An R^2 score close to 1.0 signifies strong explanatory power. An R^2 value near 0 indicates that the model performs no better than a baseline mean predictor. Using both metrics ensures balanced evaluation across prediction accuracy and variance explanation.

Forecast Generation

Once the training phase was completed, the Random Forest model was applied to estimate future PM2.5 concentration levels. The forecasting process followed a structured sequence:

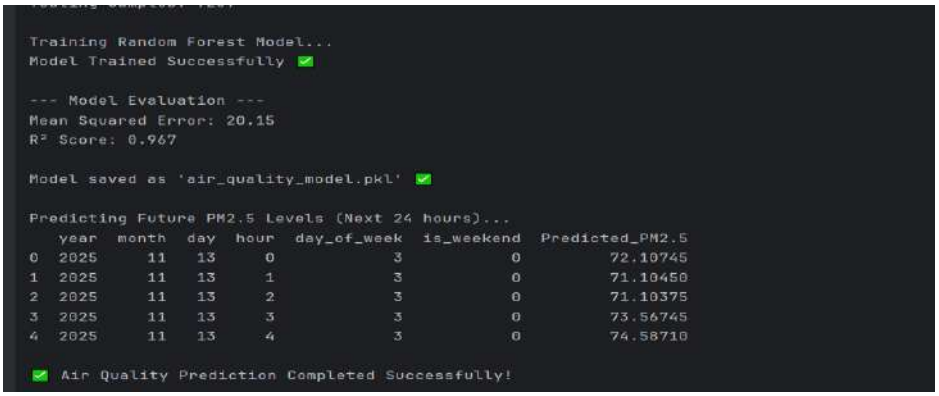
1. Feeding the preprocessed test data into the trained model to obtain hourly PM2.5 predictions.
2. Generating 24-hour ahead forecasts by extending the timestamp features and applying the model recursively.
3. Comparing predicted values with observed values (for available hours) to evaluate short-term forecast reliability.

The resulting forecasts provide actionable insights into short-term air quality trends, supporting environmental planning, early warnings, and public health advisories.

Results and Discussion

The performance of the trained Random Forest regression model was evaluated using the testing dataset. The model recorded a Mean Squared Error (MSE) value of 20.15 and achieved an R^2 score of 0.967, indicating that approximately 96.7% of the variability in PM2.5

concentrations was effectively captured. The combination of a high coefficient of determination and a low error metric confirms the model's ability to generate accurate predictions with minimal deviation from observed values.



```
Training Random Forest Model...
Model Trained Successfully ✅

--- Model Evaluation ---
Mean Squared Error: 20.15
R² Score: 0.967

Model saved as 'air_quality_model.pkl' ✅

Predicting Future PM2.5 Levels (Next 24 hours)...
   year  month  day  hour  day_of_week  is_weekend  Predicted_PM2.5
0  2025     11   13     0            3           0         72.10745
1  2025     11   13     1            3           0         71.10450
2  2025     11   13     2            3           0         71.10375
3  2025     11   13     3            3           0         73.56745
4  2025     11   13     4            3           0         74.58710

✅ Air Quality Prediction Completed Successfully!
```

Figure 2 Model Evaluation using Random Forest Model

The system effectively captures temporal variations in air quality. Notably, higher PM2.5 concentrations were observed during late-afternoon and early-evening hours, likely due to increased vehicular traffic, industrial activity, and lower atmospheric dispersion during these periods. The model successfully learns these periodic fluctuations even without the inclusion of additional meteorological parameters such as temperature, humidity, or wind speed.

The low error rate and high generalization accuracy highlight the robustness of the Random Forest architecture for short-term pollution forecasting. These outcomes validate that the model is capable of learning complex nonlinear dependencies embedded in time-series data and can reliably support applications such as air-quality monitoring, public health alerts, and urban pollution management.[5]

These results demonstrate that the model accurately predicts PM2.5 levels with minimal deviation, while

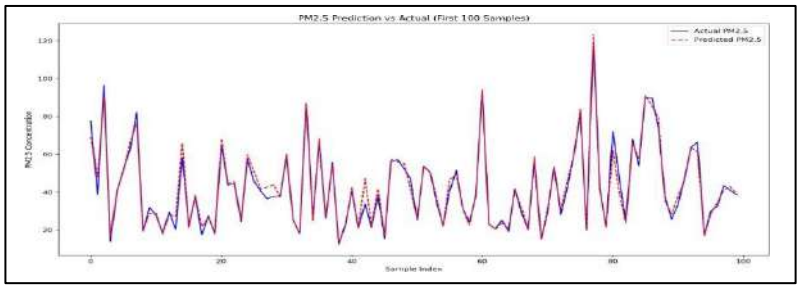


Figure 3 Comparison between actual and predicted PM2.5 values for test samples

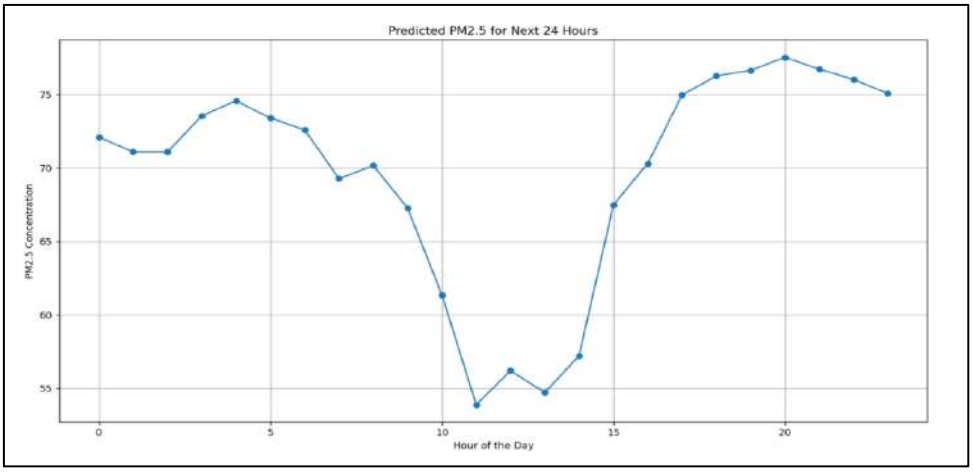


Figure 4 The forecast for the next 24 hours.

Figure 3 presents a comparison of actual versus predicted PM2.5 values for the test samples. The close alignment of the two curves indicates that the model accurately follows the underlying temporal trends. **Figure 4** illustrates the generated 24-hour forecast, showing the model's capability to extend learned patterns into future time steps with stable predictive behavior.

The proposed system effectively captures time-dependent fluctuations in air pollution levels, with elevated PM2.5 concentrations typically occurring during late afternoon periods, likely influenced by increased vehicular movement and industrial operations.[6] The low prediction error indicates that the Random Forest algorithm successfully learns temporal dependencies even in the absence of additional meteorological variables.

Conclusion

This study highlights the effectiveness of machine learning techniques for air quality prediction when relying solely on temporal information. The Random Forest regression model demonstrated strong forecasting capability for PM2.5 concentrations using time-based features, achieving an R^2 value of 0.967. The proposed approach can function as a core analytical component for smart city infrastructures, environmental monitoring platforms, and pollution control support systems.

Future work may involve incorporating atmospheric parameters such as temperature, humidity, and wind characteristics, as well as exploring advanced deep learning models—including LSTM architectures—to improve long-term forecasting accuracy. Moreover, deploying the model through an interactive web-based platform (e.g., Streamlit) could enhance accessibility for policymakers and the general public.

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A Review on Integrated Bioinformatics and Machine Learning in the Discovery of Biomarkers for Ischemic Stroke

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ABSTRACT

Ischemic Stroke is the leading cause of death and long-term disability globally due to the complexity of genetic, molecular, environmental, and clinical interactions in the body. With the use of next-generation sequencing technology, multi-omics technology, and through computational approaches, all of the things that contributed to an individual's ischemic stroke are assessable and studied systematically and can help researchers create new biomarkers. The combination of Bioinformatics and Machine Learning strategies provides researchers with an avenue to integrate large amounts of heterogeneous data and derive new Molecular Signatures, predictive and diagnostic models. This review provides a current overview of what has been done to date using both Bioinformatics Tools and Machine Learning Techniques for ischemic stroke research. In addition to studies discussing the various types of data that can be used in stroke, transcriptomic, and genomic data analysis, as predicted by using Network-Based/Pathway Approaches, New AI techniques are also being developed to discover new biomarkers and better understand the disease. Key Challenges Associated with the Discovery of New Biomarkers for Ischemic Stroke, Ethical Issues, and Future Directions in the Area of Translational and Precision Medicine for Ischemic Stroke are also discussed in this review.

Keywords: *Ischemic stroke, bioinformatics, genome analysis, transcriptomics, machine learning, biomarkers, systems biology, computational neuroscience*

1. Introduction

Ischemic stroke occurs when blood fails to adequately supply the brain with enough oxygen-rich blood. If the blood does not return to the brain (as in the case of an artery/vein blockage), damage to nerve cells occurs, resulting in loss of function. There have been significant advances in the acute management of stroke, but it continues to be a significant health problem on a global scale [1]. Traditional factors associated with the risk of stroke, such as hypertension, diabetes, smoking, and age, do not explain the variation among individuals regarding susceptibility to stroke, the differences between patients suffering from stroke, and how they respond after having a stroke. Recent evidence shows that genetic and molecular factors play a key role in the initiation, progression, and recovery from ischemic stroke [2].

Growth of omic technologies, such as genomics, transcriptomics, epigenomics, proteomics, and metabolomics, has generated a plethora of large databases that identify

molecular alterations associated with ischemic injury. Omics technologies encompass a broad range of high-throughput approaches, including genomics, transcriptomics, proteomics, metabolomics, and epigenomics, that enable the comprehensive characterization of biological systems at multiple molecular levels. These technologies generate large-scale datasets capturing variations in genes, RNA transcripts, proteins, metabolites, and regulatory mechanisms, thereby providing deeper insights into disease mechanisms, molecular heterogeneity, and biological pathways. Advances in next-generation sequencing, mass spectrometry, and microarray platforms have significantly enhanced the resolution, accuracy, and efficiency of omics data acquisition. When integrated with computational and machine learning approaches, omics technologies facilitate biomarker discovery, disease classification, risk prediction, and personalized medicine by uncovering complex molecular patterns that are not detectable using traditional experimental or statistical methods [3].

The size and complexity of these datasets require sophisticated computational analytical methods to analyze and interpret. Bioinformatics provides the user with tools for processing, integrating, and analyzing biological datasets. Machine Learning (ML) provides tools for identifying patterns, selecting relevant features, and modeling to predict outcomes. Together, bioinformatics and ML are the basis for modern computational neuroscience and for future precision stroke research [4, 5].

This review discusses the evolving literature regarding bioinformatics and ML approaches for ischemic stroke and provides a perspective on the computer science aspects of biomarker discovery. Rather than focus on any specific study, we emphasize methodologies, analysis pipelines, and innovations that impact this rapidly evolving field.

2. Fundamentals of Bioinformatics in Research on Ischemic Stroke

2.1 Sources of Data and Public Repositories

By allowing the reuse of data and cross-cohort analysis, databases available to everyone have accelerated stroke research. Gene expression and genomic datasets are obtained from databases, including Gene Expression Omnibus (GEO) and Array Express. The information generated from genome-wide association studies has progressively contributed to the identification of loci associated with stroke by utilizing summary statistics and population-based genome data [6]. Clinical metadata, imaging data, and experimental animal models supplement the molecular datasets and produce an integrated analysis across many biological levels. The availability of such resources has led to a shift in stroke research from hypothesis-driven research to data-driven discoveries.

The Major Bioinformatics Data Types and their Applications in Ischemic Stroke are listed in Table 1. Advanced computational frameworks now enable the fusion of heterogeneous data types to uncover complex disease mechanisms that may not be evident from single-layer analyses. Such integrative approaches facilitate the identification of robust biomarkers, improve disease stratification, and enhance the predictive modeling of clinical outcomes. Moreover, multi-scale data integration supports translational research by bridging experimental findings with real-world patient data, ultimately contributing to more precise and personalized therapeutic strategies [7].

Table 1. Major Bioinformatics Data Types and Their Applications in Ischemic Stroke

Data Type	Source/ Repository	Analytical Methods	Biological Insights
Genomic data (GWAS, variants)	Genome-Wide Association Studies (GWAS) Catalog, GEO, population cohorts	Variant calling, association testing, Polygenic Risk Score (PRS)	Genetic susceptibility, vascular, and coagulation pathways
Transcriptomic data (microarray, RNA-seq)	GEO, ArrayExpress	Differential expression, Gene Ontology (GO) and pathway enrichment	Inflammation, immune response, apoptosis, neuronal repair
Epigenomic data	Public methylation datasets	Differential methylation analysis	Gene regulation and stroke risk modulation
Proteomic data	Mass spectrometry datasets	Protein interaction and pathway analysis	Post-translational regulation and signaling cascades
Clinical metadata	Hospital records, cohort studies	Statistical modeling, ML-based prediction	Disease stratification and outcome prediction
Imaging data	MRI, CT datasets	Radiomics, multimodal fusion	Lesion localization and stroke subtype classification

2.2 Transcriptomic and Genomic Analysis

Transcriptomic profiling using microarrays and RNA sequencing has revealed widespread gene expression variations following ischemic injury. Differential gene expression analysis is often the first step in detecting candidate genes associated with inflammation, immune response, oxidative stress, apoptosis, and neuronal repair. Subsequent functional enrichment analyses, such as Gene Ontology and pathway mapping, helped contextualize these genes within key biological processes and signaling networks. The integration of

transcriptomic data with clinical phenotypes further enhances the relevance of the identified genes as potential diagnostic or prognostic markers. In addition, longitudinal expression profiling enables the characterization of temporal gene regulation patterns during the different stages of ischemic stroke progression and recovery. [8].

Genome analysis, including GWAS and rare variant studies, has identified susceptibility genes and pathways related to vascular function, coagulation, and lipid metabolism. Pipelines in bioinformatics are crucial for quality assurance, normalization, batch effect corrections, and statistical analysis, which leads to a clear downstream interpretation of the data. The methods for advanced annotation of genetic variation and prioritization of the genetic variants provide insight into the functional implications of genetic variants on the gene level and on the pathway level. The integration of GWAS with Expression Quantitative Trait Loci (eQTL) data through integrative genomic analyses can lead to increased understanding of the regulatory processes that play a role in increasing disease risk. These methods also facilitate the development of polygenic risk scores that can be valuable for predicting risk and taking patients into account when developing treatment plans for future treatment [9].

2.3 Enriching Gene Function and Systems Biology

Functional enrichment approaches, e.g., Gene Ontology (GO) and Pathway Analyses, allow the researcher to place the gene list into biological development and processed and serve as the basis for pathway development. Systems biology approaches, like protein–protein interaction (PPI) networks and co-expression network analysis, permit identification of hub genes and regulatory networks of genes acting together within the framework of the overall disease process of ischemic stroke - the goal of which is to identify regularities among genes that lie within the intersection of the various scientific disciplines that have an impact on ischemic stroke [10].

The network-based strategies transcend single-gene analysis through examination of coordinated, molecular-level processes impacting a disease's overall regulation and manifest at system-wide, holistic levels [11].

3. Machine Learning Usage in Biomarker Identification

3.1 High-Dimensional Omics Datasets

Machine Learning (ML) algorithms are well-suited to the high-dimensional and low-sample-size characteristics of most omics datasets, where conventional statistical approaches often become ineffective. Algorithms such as Least Absolute Shrinkage and Selection Operator (LASSO), Support Vector Machines (SVM), and Random Forests are widely employed to reduce noise and identify biologically informative features from omics data [12]. In addition,

dimensionality reduction techniques, including Principal Component Analysis (PCA) and autoencoders, facilitate data compression and visualization while preserving a substantial portion of biologically relevant variation [13]

3.2 Diagnosing and Predicting Disease Using Supervised Learning

Supervised ML models have been developed for classifying ischemic stroke patients and healthy individuals, predicting their risk for developing disease, and stratifying patients based on the molecular profiles of their biological samples. Ensemble methods and deep learning architectures have shown great potential for representing nonlinear relationships and the complexity of interactions among features [14]. It is critical to assess the performance of these models using cross-validation, the development of receiver operating characteristic curves, and external validation cohorts to ensure robustness of the models and generalizability of their results.

3.3 Explainable and Interpretable AI/Machine Learning

The use of ML in Clinical Neuroscience requires that the models be transparent and interpretable. The use of Explainable AI (XAI) techniques, such as feature importance analysis and model-agnostic explanation frameworks, allows researchers to build better links between computational predictions and the underlying biological mechanisms that caused those predictions to occur. Interpretability is critical to the translation of the knowledge gained from ML models to clinical practice and to generating hypotheses that can be confirmed directly through experimentation [15]. Table 2 categorizes the different ML methodologies utilized in the detection of Ischemic Stroke discovery.

Table 2. Machine Learning Techniques Applied in Ischemic Stroke Biomarker Discovery

ML Category	Algorithms	Purpose	Key Advantages
Feature selection	LASSO, Random Forest	Identify key genes/features	Reduces dimensionality and noise
Classification	SVM, Neural Networks	Stroke vs control classification	Handles nonlinear patterns
Ensemble learning	Random Forest, XGBoost	Risk prediction	Improved robustness
Deep learning	Autoencoders, CNNs	Complex feature extraction	Captures high-level representations
Explainable AI	SHAP, feature importance	Model interpretation	Enhances clinical trust

4. Integrated Bioinformatics–Machine Learning Pipelines

Recent studies have increasingly adopted integrated pipelines that combine bioinformatics preprocessing, systems biology analysis, and ML-based selection The following describes some of the steps or tasks included in generating work flows:

- Identify differentially expressed and/or genetically associated genes
- Conduct functional and/or pathway enrichment analyses
- Construct networks and identify hub genes(s)
- Use machine learning to select features and validate those feature selections

Combining multiple types of analytics through integration works to increase confidence in biomarker identification.

5. Limitations and Challenges

However, there remain many obstacles to developing reliable biomarker assays. There are challenges associated with biological heterogeneity, sample size limitations, and population bias, which pose challenges to making reliable conclusions based on the results. In addition to these biological factors, batch effects and differences in assay technology further complicate the process of integrating results obtained by various studies. In terms of computational challenges, the potential for overfitting and the absence of independent validation limit the clinical application of many of the computational models. Lastly, ethical issues surrounding data privacy, informed consent, and proper use of artificial Intelligence, along with other considerations, must also be addressed when utilizing genomic and clinical data.

6. Future Directions

The future of ischemic stroke research lies in the deeper integration of multi-omics data, advanced artificial intelligence, and clinical information. Emerging directions include single-cell transcriptomics, graph-based learning, federated learning for privacy-preserving analysis, and multimodal fusion of genomic and imaging data.

From a computer science perspective, the development of scalable, interpretable, and reproducible algorithms will be central to translating computational discoveries into clinical practice.

7. Conclusion

Integrated bioinformatics and ML methods have transformed ischemic stroke research by enabling the systematic analysis of complex biological data and accelerating biomarker discovery. By combining omics technologies with cutting-edge computational methods, researchers can uncover molecular signatures that improve diagnosis, risk stratification, and understanding of the mechanisms of diseases. Continued interdisciplinary collaboration

between computer scientists, bioinformaticians, and clinicians will be essential to realize the full potential of precision medicine in the treatment of ischemic stroke.

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Dynamic Staff Timetable Generation Using Rule-Based Conflict Resolution Algorithms

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ABSTRACT

The Staff Timetable Generator is a smart scheduling system developed using Python Django that simplifies and automates the creation of conflict-free academic or institutional timetables. The system considers multiple constraints such as subject hour requirements, staff availability and room capacity. Using optimization algorithms and rule-based logic, it efficiently allocates teaching slots to faculty members while ensuring no overlaps or violations of predefined conditions. The platform allows administrators to input staff details, subjects (with or without labs), preferred timings, and course-wise distribution. Once generated, timetables can be viewed, exported, or shared digitally. The system also provides editing capabilities for manual adjustments and visualizes schedules in a clean, user-friendly calendar format. By reducing manual effort and human error, the Automated Staff Timetable Generator saves time, improves operational efficiency, and ensures fair workload distribution among staff, making it an essential tool for modern academic administration.

Keywords: *Staff Timetable Generation, Constraint-Based Scheduling, Django Web Framework, Python Optimization Algorithms*

Introduction

Timetable management is important for the smooth functioning of educational institutions such as schools, colleges, and training centers. A timetable organizes academic sessions and ensures optimal use of resources such as faculty, classrooms, and laboratories. Traditionally, timetables are prepared manually by administrators, a process that is time-consuming, prone to human errors, and increasingly complex with multiple courses, limited classrooms, and varying staff availabilities. As institutions expand, manual scheduling often leads to conflicts, inefficiencies, and dissatisfaction among faculty and students.

Advances in information technology and intelligent systems have made it possible to automate such complex tasks. Automation simplifies scheduling, reduces administrative workload, and ensures conflict-free allocations. One of the most efficient solutions is the Automated Staff Timetable Generator, which uses programming, optimization techniques, and rule-based logic to produce accurate schedules. It integrates key constraints such as teaching hours,

departmental distribution, staff preferences, and room availability to ensure balanced workloads and efficient use of resources.

Need for Automation

An accurate timetable benefits students, faculty, and administrators alike. For students, it ensures balanced class distribution and prevents fatigue due to clustered sessions. For faculty, it maintains fair teaching loads and avoids back-to-back lectures. Administrators depend on it for classroom management, compliance with institutional policies, and smooth academic operations.

Manual timetable generation often leads to overlapping classes,excessive staff workload and unused classrooms. These issues affect productivity and academic quality. Rectifying such mistakes consumes additional administrative time and effort. Therefore, automation has become essential in modern educational systems.

Automating this proces using Python and Django helps institutions save time,reduce mistakes and work more efficiently. Django's scalability and modular design make it ideal for building a system adaptable to institutions of all sizes, ensuring both performance and usability.

Proposed Methodology

The proposed methodology focuses on developing a Staff Timetable Generator using a constraint-based scheduling model integrated within the Django web framework. The system begins with a structured data acquisition phase where administrators input staff details, subject requirements, departmental distributions, and weekly slot availability through a secure web interface. This input undergoes preprocessing to remove inconsistencies, normalize formats, validate hour allocations, and ensure feasibility of schedule generation. Once the data is cleaned, the system models institutional constraints—such as staff availability, maximum workload limits, lab session continuity, subject hour requirements, and overlapping restrictions—using a rule-based constraint engine. The timetable generation algorithm then iteratively allocates subjects into time slots by prioritizing high-demand sessions, checking constraint compliance, and dynamically readjusting allocations in case of conflicts. Through a combination of deterministic scheduling and backtracking-based conflict resolution, the system ensures the production of a complete, optimized, and conflict-free timetable. The generated schedule is stored in the database and visualized through a user-friendly grid interface, allowing staff to view personalized schedules and administrators to export timetables in PDF or Excel format. This methodology ensures automation, accuracy, and efficiency, significantly reducing the manual effort associated with academic timetable preparation.

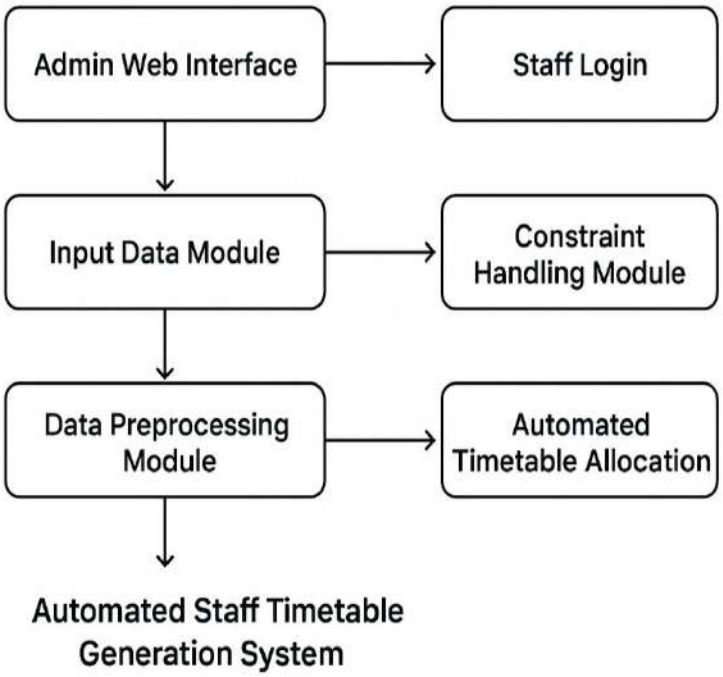


Figure 1: Dynamic Staff Timetable Generation Using Rule-Based Conflict Resolution Algorithms

Preprocessing Module

The preprocessing module prepares institutional data for accurate timetable generation by checking and validating all inputs given by the administrator. It checks staff details, subject hours, and departmental requirements to identify missing information, inconsistencies, or duplicate records. The module standardizes naming conventions and assigns unique identifiers to staff, subjects, and time slots to ensure uniform database representation. It also performs feasibility checks to confirm that required teaching hours align with available weekly periods and staff workloads. Any detected conflicts or mismatches are flagged for correction before scheduling begins. By ensuring clean, structured, and error-free data, the Preprocessing Module provides a reliable foundation for generating an optimized and conflict-free timetable.

Feature Extraction

The Feature Extraction module helps identify the important details needed to create needed to create an effective staff timetable. After preprocessing the data the system extracts key information such as staff availability, subject type, required weekly hours, department details and room or lab constraints. This information is organized in a simple structure so the system can easily match teachers, subjects and time slots. The Module also considers factors like workload limits preferred teaching times and continuous lab sessions by converting

institutional requirements into clear and usable data the module helps the system generate accurate and conflict free timetables efficiently.

Timetable Classification and Conflict Resolution Module

This module uses a rule-based approach to assign suitable time slots to each subject based on institutional rules and constraints. Through constraint enhancement, the system incorporates additional scheduling factors such as staff availability, subject hour requirements, workload limits, and lab session continuity to improve allocation precision. During the timetable submission process, the administrator triggers the scheduling engine, which classifies each slot as feasible or conflicting according to predefined academic rules. The engine then processes these classified slots to generate an optimized and conflict-free timetable for all staff members. Once the allocation is complete, the system presents the finalized timetable and highlights any unresolved conflicts for administrative correction**.**

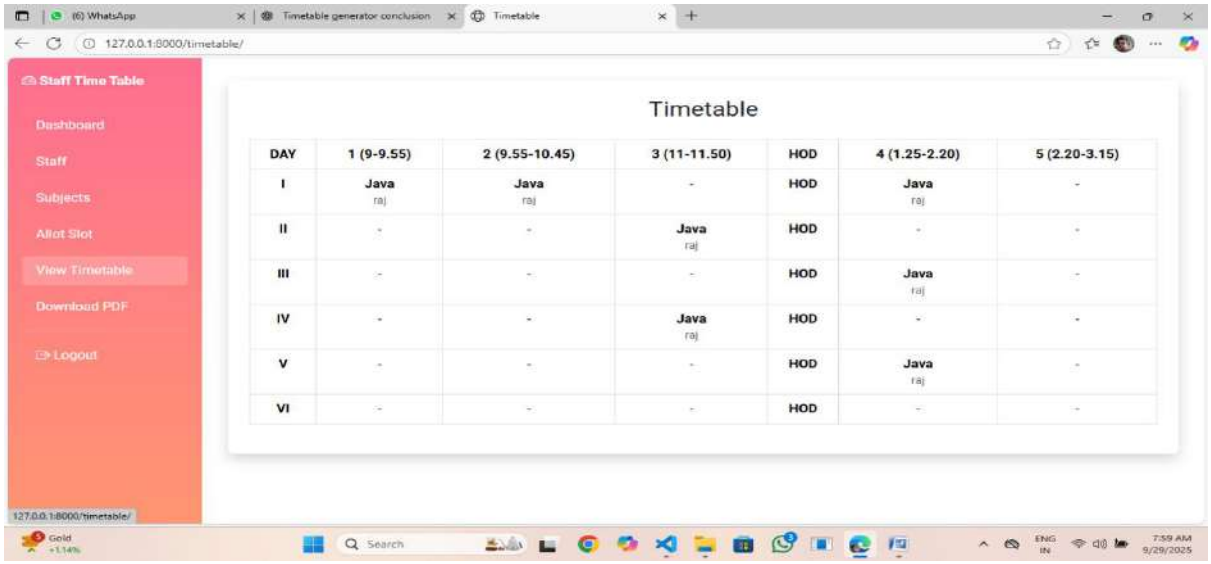


Figure 2: View Time Table Page

Conclusion

In conclusion, the Staff Timetable Generator is a highly efficient and intelligent system that significantly transforms the way academic institutions handle scheduling. By automating the creation of staff timetables, it eliminates the tedious and error-prone process of manual scheduling, ensuring conflict-free allocation of subjects, labs, and teaching hours. The system effectively considers multiple constraints such as staff availability, departmental requirements, subject types, and room capacities, thereby optimizing resource utilization. Its interactive interface allows administrators to easily input data, generate timetables, make adjustments, and

visualize schedules in a clear calendar format. The ability to export and share timetables digitally enhances communication and coordination within the institution. Distributing workloads and rducing scheduling conflicts the system improves efficiency increases staff satisfaction and enhances overall institutional productivity. With its scalable design and intelligent algorithms, the Automated Staff Timetable Generator stands as an indispensable tool for modern academic administration, enabling institutions to focus more on educational quality rather than administrative complexities.

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A Hybrid Neural Framework for Intelligent Malware Detection in Adversarial Environments

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ABSTRACT

The escalating sophistication of malware, including polymorphic and zero-day threats, poses a significant challenge to conventional signature-based detection systems. Machine learning (ML) models offer a promising alternative but are often hampered by their reliance on large labeled datasets and vulnerability to adversarial attacks. This paper introduces a novel, robust framework for malware detection that integrates multiple advanced ML strategies. The core of the framework is an autoencoder for efficient unsupervised feature extraction and dimensionality reduction. Classification is performed by a hybrid model that combines the strengths of Convolutional Neural Networks (CNNs) for spatial feature extraction and Gradient Boosted Decision Trees (GBDT) for robust decision-making. To enhance resilience against evasive malware, we incorporate adversarial training using Generative Adversarial Networks (GANs) are incorporated. Furthermore, we leverage semi-supervised learning with Variational Autoencoders (VAEs) to effectively utilize unlabeled data, improving model generalization. The system is designed for iterative refinement, allowing it to adapt to evolving threats. Experimental results demonstrate the framework's superior performance, achieving an F1-score of 0.95, indicating high accuracy and a strong balance between precision and recall in distinguishing between benign and malicious software.

Keywords: *Malware Detection, Deep Learning, Autoencoder, Hybrid Model, Adversarial Training, Semi-Supervised Learning, Cybersecurity.*

1. Introduction

The proliferation of sophisticated malware presents a continuous and evolving threat to digital ecosystems. Traditional malware detection systems, which predominantly rely on signature-based or rule-based methods, are increasingly ineffective against modern threats. These systems struggle to identify novel, polymorphic, and metamorphic malware, as they depend on a pre-existing database of known signatures [1]. The sheer volume and complexity of data generated in network environments further overwhelm these conventional methodologies.

Advanced Persistent Threats (APTs) and zero-day exploits have rendered static feature analysis inadequate, as they fail to generalize to the dynamic and evolving attack landscape [2], [3]. Despite the growing success of Machine Learning (ML) in threat detection, standard supervised learning models remain constrained by several limitations. They typically require vast amounts of labeled data, which is often scarce and expensive to obtain. Moreover, they are susceptible to adversarial attacks, where malicious actors subtly perturb inputs to evade detection.

To address these challenges, this paper proposes a comprehensive and robust framework that integrates several advanced ML techniques. Our approach is built on the following key principles:

1. **Unsupervised Feature Engineering:** We employ autoencoders for dimensionality reduction, learning compact and meaningful representations from high-dimensional malware activity data without requiring labels.
2. **Hybrid Classification:** We combine the feature extraction power of Convolutional Neural Networks (CNNs) with the robustness of Gradient Boosted Decision Trees (GBDT) to create a highly accurate hybrid classifier [8], [9].
3. **Adversarial Robustness:** We utilize Generative Adversarial Networks (GANs) to perform adversarial training, exposing the model to realistic, perturbed inputs to strengthen its defenses against evasion techniques.
4. **Semi-Supervised Learning:** To maximize data utility, we apply Variational Autoencoders (VAEs) in a semi-supervised context, enabling the model to learn from both labeled and unlabeled data samples [10].

This integrated approach yields a scalable, adaptive, and efficient malware detection system capable of identifying previously unknown threats with high accuracy and a low false-positive rate.

2. Literature Review

The application of machine learning to malware detection is an active area of research. Early ML approaches replaced manual signature creation but often relied on feature engineering and shallow models. Recent advancements have focused on deep learning to automate feature extraction and improve detection accuracy.

Xing (2023) proposed a model that uses an autoencoder on grey-scale image representations of malware, achieving 96% accuracy on an Android dataset by leveraging the autoencoder for dimensionality reduction and classification based on reconstruction error [1]. Similarly, Yousef (2023) demonstrated the effectiveness of autoencoders for learning latent

representations for various cybersecurity tasks, including malware classification, showing improved performance over traditional feature engineering [6]. Li et al. (2022) combined an AutoEncoder with a Deep Belief Network (DBN) for malicious code detection, using the autoencoder to reduce dimensionality before feeding features to the DBN, resulting in improved accuracy and reduced complexity [4].

Hybrid models have demonstrated considerable potential as well. Lu et al. (2023) developed a hybrid DBN and Gated Recurrent Unit (GRU) model for Android malware, using DBN for static features and GRU for temporal dynamic features, outperforming traditional ML algorithms [2]. Baek et al. (2022) introduced a two-stage hybrid model for IoT malware, using a bidirectional LSTM for static analysis followed by an EfficientNet-B3 model for dynamic analysis, effectively detecting obfuscated malware [3]. These studies highlight the trend of combining different neural architectures to capture diverse aspects of malware behavior.

To combat the growing threat of novel malware, researchers have explored ensemble learning and optimization. Alamro (2022) presented an optimal ensemble learning approach using LS-SVM, KELM, and RRVFLN models, with parameter tuning via hunter-prey optimization, demonstrating supremacy over existing techniques [5]. Albakri (2023) used a Rock Hyrax Swarm Optimization algorithm for feature selection in a deep learning model for Android malware detection, improving classification by identifying the most significant API calls and permissions [10].

We develop our model on top of these underlying principles. While existing research has independently explored autoencoders, hybrid models, and optimization, our framework uniquely integrates these components with adversarial and semi-supervised training. This synergistic combination addresses the critical challenges of data scarcity, model robustness, and adaptability to zero-day threats in a single, cohesive system.

3. Proposed Methodology

The proposed malware detection framework is designed as a multi-stage pipeline that processes raw data to deliver a final classification probability. The architecture, depicted in Figure 1, integrates unsupervised feature learning, adversarial training, semi-supervised learning, and a hybrid classification model.

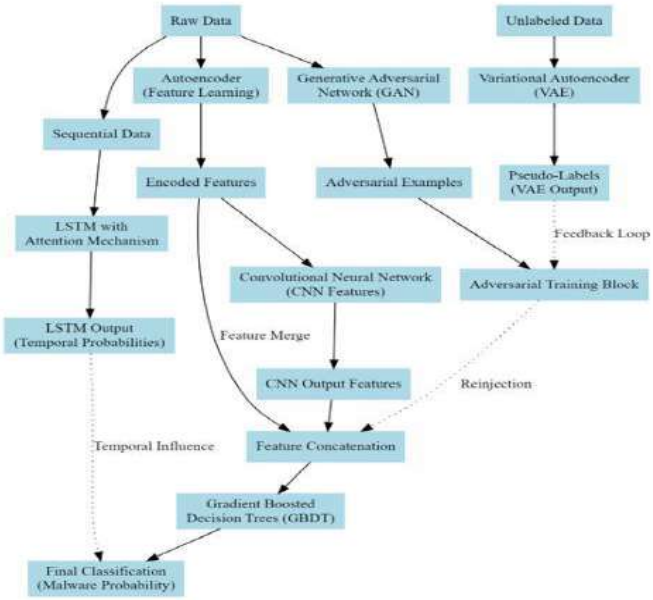


Figure 1: The proposed system architecture, illustrating the flow from data input through feature engineering, adversarial training, and hybrid classification.

3.1. Unsupervised Feature Learning with Autoencoders

The centrepiece of the framework is an autoencoder used for initial feature engineering and dimensionality reduction. An autoencoder is an unsupervised neural network that learns a compressed, latent-space representation (encoding) of the input data and then reconstructs the original data from this representation. By training the autoencoder on malware activity data, the encoder learns to extract the most salient features into a compact vector. This process effectively reduces noise and captures discriminative information, which is then passed to the downstream classifier.

3.2. Hybrid Classification Model (CNN-GBDT)

To leverage the strengths of different modeling paradigms, we employ a hybrid classifier.

- **Convolutional Neural Network (CNN):** The raw input features are fed into a CNN, which excels at extracting hierarchical and spatial patterns from data. The features learned by the CNN's convolutional layers provide a rich, abstract representation of malicious activities.
- **Gradient Boosted Decision Trees (GBDT):** The output features from the CNN are concatenated with the latent features from the autoencoder. This combined feature set is then used as input for a GBDT model. GBDTs are highly effective ensemble models known for their robustness to outliers and heterogeneous data, providing a powerful final classification stage.

3.3. Adversarial Training with GANs

To fortify our model against evasion attacks, we incorporate an adversarial training block. A Generative Adversarial Network (GAN) is trained to produce realistic adversarial examples—subtly perturbed inputs designed to fool the classifier. During the training process, these adversarial examples are fed into our hybrid model alongside legitimate data. This forces the model to learn more robust decision boundaries, significantly reducing its vulnerability to deceptive techniques employed by attackers.

3.4. Semi-Supervised Learning with VAEs

In real-world scenarios, unlabeled data is far more abundant than labeled data. To utilize this resource, we employ a Variational Autoencoder (VAE). The VAE is trained on both labeled and unlabeled data. It learns a probabilistic latent space that can be used to generate pseudo-labels for the unlabeled samples. These pseudo-labeled samples are then added to the training set with a feedback loop, augmenting the dataset and allowing the model to improve its generalization capabilities without requiring extensive manual labeling.

3.5. Iterative Refinement

The entire framework operates within an iterative training loop. As new data and threats are identified, the system can be retrained. Feedback from misclassified samples is used to refine model parameters and adjust the learning process, ensuring the system continuously adapts and improves its performance against the evolving malware landscape.

4. Experimental Setup and Results

4.1. Dataset and Preprocessing

The model was trained and evaluated on a public malware dataset containing features extracted from both malicious and benign software samples. The dataset comprises various static and dynamic attributes derived from malware activity. Preprocessing steps included:

- **Data Cleansing:** Handling of missing values and removal of irrelevant or redundant features (e.g., file hashes).
- **Encoding:** Categorical features were converted to numerical format using label encoding.
- **Scaling:** All numerical features were standardized using StandardScaler to have zero mean and unit variance, ensuring stable training for the neural network components.

4.2. Implementation Details

The framework was implemented in Python using the Django web framework for the user interface. The core ML components were built with TensorFlow/Keras for the deep learning models (Autoencoder, CNN, VAE, GAN) and Scikit-learn for the GBDT classifier

and preprocessing utilities. The neural network classifier consisted of dense layers with ReLU activation and dropout for regularization, compiled with a binary cross-entropy loss function and the Adam optimizer. Early stopping was used to prevent overfitting.

4.3. Performance Metrics

We evaluated the model using standard classification metrics:

- **Accuracy:** The proportion of correctly classified instances.
- **Precision:** The ability of the classifier not to label a benign sample as malicious.
- **Recall (Sensitivity):** The ability of the classifier to find all the malicious samples.
- **F1-Score:** The harmonic mean of precision and recall, providing a single score that balances both metrics.

4.4. Results and Analysis

The proposed system achieved impressive results in malware identification. The model achieved an impressive F1-score of 0.955, indicating a high degree of reliability. The training process was monitored to ensure convergence and prevent overfitting, as shown in Figures 2 and 3.

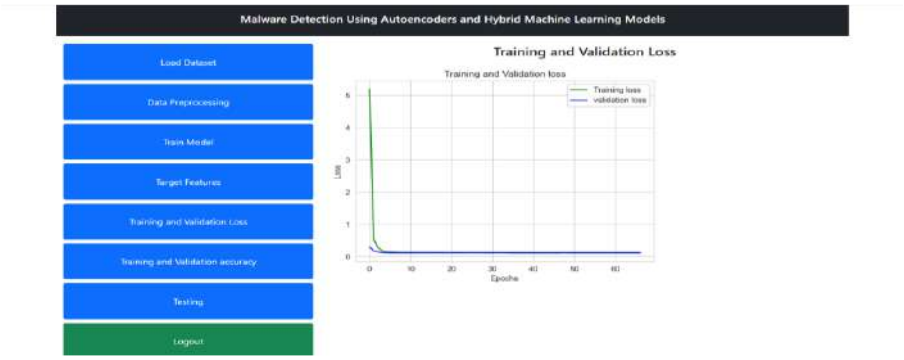


Figure 2: Training and validation loss per epoch, showing stable convergence without significant overfitting.

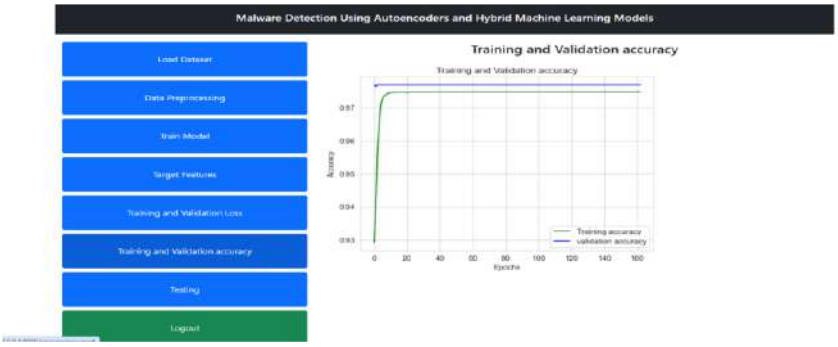


Figure 3: Training and validation accuracy per epoch, demonstrating the model's ability to learn and generalize effectively.

The convergence of the loss and accuracy curves for both training and validation sets indicates that the model generalizes well to unseen data. The integration of adversarial training

with GANs enhanced the model's robustness, while the semi-supervised learning component allowed it to effectively leverage a larger pool of data, contributing to its high performance. The hybrid nature of the classifier successfully combined the pattern recognition strengths of CNNs with the strong decision-making capabilities of GBDT.

5. Conclusion

This paper presented an iterative and hybrid framework for malware detection that addresses the primary limitations of both traditional and standard ML-based systems. By leveraging autoencoders for feature extraction, a hybrid CNN-GBDT model for classification, GANs for adversarial training, and VAEs for semi-supervised learning, our system effectively identifies and mitigates a wide range of malware threats. The experimental results, including an F1-score of 0.955, confirm that this integrated approach significantly improves detection accuracy, reduces false positives, and enhances the system's adaptability to evolving cyber threats. The iterative refinement process ensures continuous learning, making the model robust against new and unknown malware patterns. This research underscores the value of combining deep learning-based feature extraction with robust ensemble techniques to create a more efficient and reliable malware detection system.

6. Future Enhancement

While the current implementation is promising, several avenues for future work exist.

- **Federated Learning:** To address data privacy concerns and enable decentralized training, federated learning could be integrated, allowing the model to train on user data without compromising confidentiality.
- **Reinforcement Learning:** Reinforcement learning techniques could be employed to make the system more adaptive, allowing it to dynamically adjust its detection strategies based on real-time threat intelligence.
- **Explainable AI (XAI):** Incorporating XAI methods would provide transparency into the model's decision-making process, enabling cybersecurity analysts to better understand and interpret detections.
- **Performance Optimization:** The computational efficiency of the framework could be enhanced by leveraging hardware accelerations (GPU/TPU) and exploring cloud-based or edge computing deployments for scalable, real-time detection across diverse networks and devices.

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உருவ எழுத்துக்கள் - ஓர் ஆய்வு

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ஆய்வுச்சுருக்கம்

மனித நாகரீக வளர்ச்சியில் எழுத்து முறையின் உதயம் ஒரு மிகப்பெரிய அறிவாற்றல் புரட்சியாகும் ஆரம்பகால மனிதர்களுக்கு குரல் மொழி இருந்தாலும் அவற்றை நிலையாக (tangible) பதிவு செய்ய முடியாததால் தகவல்கள் தொடர்ந்துவரும் தலைமுறைகளுக்கு மறைந்து போய்விடக்கூடும். இந்த பிரச்சினைக்கு ஒரு தீர்வாக மனிதன் படங்களைக் கொண்டு கருத்துக்களை வெளிப் படுத்தத் தொடங்கினான். இதுவே உருவ எழுத்துக்கள் ஆகும். சொல்லைப் பயன்படுத்தாமல் பொருளை நேரடியாக உருவம் அல்லது சின்னம் மூலம் காட்டும் தொடர்பு முறை என்பதே இதன் சிறப்பம்சமாகும். மனித வரலாற்றின் முதல் எழுத்துமுறை, காட்சித் தொடர்பு மொழி, அறிவுப்பதிவு முறை, கலைமொழி. என பல பரிமாணங்களில் நாகரீக வளர்ச்சிக்கு அடித்தளமாக அமைந்தன உருவ எழுத்துக்கள். இவ்வாய்வு நம் முன்னோர்களின் மனித சிந்தனை எப்படி உருவெடுத்து எழுத்து வரை வளர்ந்தது என்பதை விளக்குகின்றது.

அறிமுகம்

மனித நாகரீகத்தின் வரலாற்றில் எழுதுதல் முறை (Writing System) ஒரு குறிப்பிடத்தக்க அறிவாற்றல் முன்னேற்றமாகும். மனிதன் தனது சிந்தனை, அனுபவம் மற்றும் அறிவை நிலைநிறுத்தி தலைமுறைகள் கடந்து பரிமாறிக்கொள்வதற்கான அடிப்படை வடிவம் இதுவாகும். ஆரம்பகாலத்தில் மனிதர்கள் குகைச் சித்திரங்கள், குறியீட்டு சின்னங்கள் மற்றும் உருவக்கோலங்கள் மூலம் தகவல் பரிமாற்றம் செய்தனர். ஆனால் சமூக ஒழுங்கும், பொருளாதாரமும், அரசியல் நிர்வாகமும் வளர்ந்தபோது, நிலையான எழுத்து முறை தேவையாகியது.

இந்த தேவையின் விளைவாக மெசப்பெத்தோமியா, எகிப்து, சீனா, மற்றும் இந்தியா போன்ற பழமையான நாகரீகங்களில் எழுத்து முறைகள் உருவாகின. அவற்றில் க்யூனி.ஃபார்ம் (Cuneiform), ஹீரோகிளிபிக்ஸ் (Hieroglyphics), மற்றும் சீன எழுத்து (Logograms) போன்ற முறைகள் ஆரம்ப வடிவங்களாகக் கருதப்படுகின்றன. இவ்வாறான எழுத்துமுறைகள் தகவல் பரிமாற்றத்தை எளிதாக்கியதுடன், சமூக, மத, மற்றும் நிர்வாக துறைகளிலும் அடித்தளமாக அமைந்தன.

ஆய்வின் நோக்கங்கள்

இவ்வாய்வின் முக்கிய நோக்கங்கள் பின்வருமாறு:

1. உலகின் முக்கிய பழமையான நாகரீகங்களின் எழுத்து முறைகளின் தோற்றம் மற்றும் வளர்ச்சியை ஆய்வு செய்வது.
2. எழுத்து முறைகளின் பரிணாம வளர்ச்சியில் ஏற்பட்ட மாற்றங்களை ஒப்பீட்டு வடிவில் விளக்குவது.
3. மொழி, கலாச்சாரம் மற்றும் சமூக அமைப்புகளின் தாக்கத்தை எழுத்து முறைகளில் ஆராய்வு செய்வது.

4. நவீன எழுத்து முறைகள் பழமையான முறைகளுடன் எந்த அளவுக்கு தொடர்புடையவை என்பதை கண்டறிதல்.

உருவ எழுத்துக்கள் - அறிமுகம்

உலக வரலாற்றில் மனித சமுதாய வளர்ச்சியைப் புரிந்துகொள்ளும் போது, எழுத்துமுறை உருவாக்கம் மிக முக்கியமான கட்டமாகக் கருதப்படுகிறது. ஆரம்ப கால மனிதன் தனது எண்ணங்கள், அனுபவங்கள் மற்றும் தேவைகளை வெளிப்படுத்த மொழியை மட்டும் நம்பியிருந்தான். ஆனால், வாய்மொழியில் சொல்வது சில நேரங்களில் மறந்துவிடக்கூடியது தலைமுறைகளுக்கு கடத்திச் செல்ல இயலாதது. அதனால், மனிதன் ஒரு நிலையான குறியீட்டையும், அனைவருக்கும் புரியக்கூடிய தொடர்பு முறையையும் தேடினான். இந்த தேடலின் முதல் விளைவாகத் தோன்றியது தான் உருவ எழுத்துக்கள் ஆகும். உருவ எழுத்துக்கள் என்பது ஒரு குறிப்பிட்ட பொருள், நிகழ்வு அல்லது கருத்தைச் சொல்லாமல், அதை நேரடியாக படமாக சித்தரிப்பதே ஆகும். உதாரணமாக சூரியனை குறிக்க வட்ட வடிவம், நிலவைக் குறிக்க அரை வட்டம், மரத்தைக் குறிக்க கிளைகளுடன் கூடிய உருவம், விலங்குகளை குறிக்க எளிய ஓவியங்கள் போன்றவை பயன்படுத்தப்பட்டன. இவ்வாறு ஓவிய வடிவங்களில் உருவாக்கப்பட்ட குறியீடுகள் எளிதில் அனைவருக்கும் புரியக்கூடியவையாக இருந்ததால், அந்த கால மனித சமுதாயத்தில் முக்கியமான தொடர்பு முறையாக இருந்தன.

உருவ எழுத்துக்கள் மிகவும் பழங்காலத்திலேயே தோன்றியவை என்பதை நமக்கு நிரூபிப்பவை உலகின் பல இடங்களில் கண்டுபிடிக்கப்பட்ட குகைச் சித்திரங்களாகும். இந்தியாவின் பீம்பேட்கா குகைகள், பிரான்சின் லாஸ்காக்ஸ் குகைகள், எகிப்தின் ஹீரோகிளிபிக்ஸ், சுமேரியர்களின் க்யூனி.ஃபார்ம் போன்றவை அனைத்தும் உருவ எழுத்துக்களின் வளர்ச்சியை வெளிப்படுத்துகின்றன. குகைச் சுவர்களில் மான், யானை, குதிரை, வேட்டையாடும் மனிதர்கள், சூரியன், நிலா போன்ற படிமங்கள் வரையப்பட்டிருந்தன. அவை அக்கால மனிதன் தனது வாழ்வியலை பதிவு செய்ய பயன்படுத்திய முதன்மையான உருவ எழுத்துக்கள் ஆகும். இந்த எழுத்துக்கள் ஆரம்பத்தில் மிகவும் எளிமையானவையாக இருந்தாலும், மனிதன் சமூகமாகவும், அரசியல் ரீதியாகவும் வளரத் தொடங்கியபோது, உருவ எழுத்துக்களின் பயன்பாடு பரந்து விரிந்தது. வேட்டைக்காரர்கள் தங்கள் வேட்டைப் பாதைகளை சித்தரிக்க, உணவுக் களஞ்சியங்களை குறிக்க, ஆபத்து குறியீடுகளை அறிவிக்க உருவ எழுத்துக்களைப் பயன்படுத்தினர். பின்னர், நாகரீகங்கள் உருவானதும், மத சடங்குகள், பொருளாதார பரிவர்த்தனைகள், நில உரிமைகள், அரசாணைகள் போன்றவற்றை பதிவு செய்யவும் உருவ எழுத்துக்கள் பயன்பட்டன.

உருவ எழுத்துக்களின் மிகப் பெரிய சிறப்பு என்னவெனில், அவற்றைப் புரிந்து கொள்ள மொழி அறிவு தேவையில்லை. ஒரு சின்னத்தைப் பார்த்தவுடன் அது எதைக் குறிக்கிறது என்பதை அனைவரும் எளிதில் புரிந்துகொள்ள முடிந்தது. அதனால், மொழி வேறுபாடு இருந்தாலும் உருவ எழுத்துக்கள் பொதுவான தொடர்பு முறையாக விளங்கின. உதாரணமாக, ஒரு சூரிய சின்னம், எந்த சமூகத்தவருக்கும் சூரியனை நினைவூட்டும். இவ்வாறு உருவ எழுத்துக்கள், மனித சமுதாயத்தை ஒருங்கிணைக்கும் ஒரு பொதுவான காட்சித் தொடர்பு முறையாக இருந்தன. எனினும், மனித சிந்தனைகள் மேம்பட்டபோது, வெறும் உருவங்கள் மட்டுமே எல்லாவற்றையும் விவரிக்க முடியவில்லை. சிக்கலான சிந்தனைகள், நிகழ்வுகள், அபாரமான கருத்துக்கள் ஆகியவற்றை சித்தரிப்பது சிரமமாக இருந்தது. இதனால் உருவ

எழுத்துக்கள் படிப்படியாக மாற்றமடைந்தன. முதலில் சின்ன எழுத்துக்கள் உருவானது. பின்னர் ஒலியியல் அடிப்படையிலான எழுத்துக்கள் தோன்றின. இறுதியில், நாம் இன்று பயன்படுத்தும் அகர எழுத்துமுறைகள் (Alphabetic system) உருவானது. எனவே, உருவ எழுத்துக்கள் என்பது மனித வரலாற்றின் அடித்தள எழுத்து முறை என்று சொல்லலாம்.

இன்றைய காலத்திலும் உருவ எழுத்துக்களின் தாக்கம் மிகத் தெளிவாகத் தெரிகிறது. நம்முடைய வாழ்க்கையில் தினசரி பயன்படுத்தப்படும் சாலைச் சின்னங்கள், பொதுப் பயன்பாட்டு அடையாளங்கள், கணினி சின்னங்கள், குறிப்பாக இன்றைய மொபைல் தொடர்பாடலில் அதிகம் பயன்படுத்தப்படும் இமோஜிகள் (Emojis) ஆகியவை அனைத்தும் உருவ எழுத்துக்களின் நவீன வடிவங்களாகக் கருதப்படுகின்றன. இவை, உருவ எழுத்துக்கள் இன்றளவும் மனிதன் வாழ்வில் தொடர்பாடல் கருவியாக உயிர்ப்புடன் இருக்கின்றன என்பதை நிரூபிக்கின்றன. இதனால் உருவ எழுத்துக்கள் என்பது வெறும் ஓவிய வடிவங்களாக மட்டுமே இல்லாமல், மனிதன் தனது சிந்தனைகள், உணர்வுகள், அனுபவங்கள், நம்பிக்கைகள் ஆகியவற்றை முதன்முறையாக பதிவு செய்து தலைமுறைகளுக்கு பரப்பிய அடிப்படை முயற்சி ஆகும். இவ்வாறு உருவ எழுத்துக்களை அறிதல் என்பது மனித நாகரீக வளர்ச்சியின் அடித்தளத்தைப் புரிந்து கொள்வதற்கு மிகவும் அவசியமானதாகும்

உருவ எழுத்துக்களின் தோற்றம்

உருவ எழுத்துக்களின் தோற்றம் ஆயிரக்கணக்கான ஆண்டுகளுக்கு முந்தையதாகும். கற்கால மனிதர்கள் வாழ்ந்த குகைகளில் கண்டுபிடிக்கப்பட்ட ஓவியங்கள், இவர்களின் வாழ்க்கை முறையையும் சிந்தனை முறையையும் வெளிப்படுத்துகின்றன. குகைச் சுவர்களில் விலங்குகள், வேட்டைக் காட்சிகள், மனிதர்களின் செயல்கள் ஆகியவை வரைந்து வைக்கப்பட்டுள்ளன. இவை அனைத்தும் எழுத்துக்கு முந்தைய தகவல் பரிமாற்ற முறைகள். காலப்போக்கில் இந்த குகைச் சித்திரங்கள் சின்னங்களாகவும், அந்தச் சின்னங்கள் பின்னர் நிலையான உருவ எழுத்துக்களாகவும் மாறின. மெசப்பெத்தோமியா, எகிப்து, சீனா, இந்தியா போன்ற பழங்கால நாகரீகங்களில் உருவ எழுத்துக்களின் தடயங்கள் காணப்படுகின்றன. குறிப்பாக கிமு 3500-ஆம் ஆண்டில் சுமேரியர்கள் மண்ணால் செய்யப்பட்ட பலகைகளில் உருவ எழுத்துக்களைப் பயன்படுத்தத் தொடங்கினர். இதுவே எழுத்து வரலாற்றின் முறையான தொடக்கமாக கருதப்படுகிறது.

குகைச் சித்திரங்கள் மற்றும் ஆரம்ப வடிவங்கள்

மனிதர்களின் முதற்கட்ட வாழ்வில் அவர்கள் சந்தித்த அனுபவங்களைச் சுவற்றில் வரையும் பழக்கம் இருந்தது. லாஸ்கோ (Lascaux)-பிரான்ஸ், ஆல்டாமிரா (Altamira) -ஸ்பெயின், பீம்பேட்கா-இந்தியா போன்ற இடங்களில் கண்டுபிடிக்கப்பட்ட குகை ஓவியங்கள் இதற்குச் சான்றாகும். மான்கள், குதிரைகள், எருமைகள், பறவைகள் போன்ற விலங்குகளின் உருவங்கள் அங்கு வரையப்பட்டுள்ளன. வேட்டைக் காட்சிகள், நடனக் காட்சிகள், மதம் சார்ந்த நிகழ்வுகள் ஆகியவை சித்திர வடிவில் பதியப்பட்டுள்ளன. இவை வெறும் கலைக்காக மட்டும் அல்லாமல், அவர்களின் வாழ்க்கை முறையை அடுத்த தலைமுறைக்கு சொல்லித் தரும் வழிமுறையாகவும் இருந்தன. சில அறிஞர்கள் இவ்வகை குகை ஓவியங்களை உருவ எழுத்துக்களின் தொடக்கக் கட்டமாகவே கருதுகின்றனர். ஒரே ஓவியம் மூலம் "இன்று வேட்டைக்கு சென்றோம்" அல்லது

“இந்த விலங்கு அபாயகரமானது” போன்ற செய்திகளை அவர்கள் பரிமாறிக் கொண்டிருக்கக்கூடும்.

எகிப்திய உருவ எழுத்துக்கள் (Hieroglyphics)

எகிப்திய நாகரீகம் உருவ எழுத்துக்களின் வளர்ச்சியில் தனித்தன்மையான பங்களிப்பை வழங்கியது. அங்குள்ள ஹீரோகிளிபிக்ஸ் (Hieroglyphics) எனப்படும் எழுத்துமுறை, படிமங்கள் மற்றும் சின்னங்களின் அடிப்படையில் அமைந்தது. இவை கிமு 3100-ம் ஆண்டிலிருந்து பயன்படுத்தப்பட்டன. ஆரம்பத்தில் முழுமையாக உருவங்களை மட்டும் பயன்படுத்தினார்கள். ஆனால் பின்னர் அவை சிக்கலான சின்னங்களாகவும், ஒலிகளை குறிக்கும் எழுத்துக்களாகவும் மாறின. சூரியன், நிலா, பறவை, பாம்பு, மனித உருவம் போன்றவை எழுத்துக்களாகக் கையாளப்பட்டன. இவை பாப்பிரஸ் (Papyrus) எனப்படும் தாள்களிலும், பிரமிடுகள் மற்றும் கோவில்களின் சுவர்களிலும் பொறிக்கப்பட்டிருந்தன. எகிப்தியர்கள் அரசியல், மதம், அறிவியல் ஆகிய துறைகளில் தங்களின் சாதனைகளைப் பதிவு செய்ய ஹீரோகிளிபிக்ஸ் (Hieroglyphics) முறையைப் பயன்படுத்தினர். அதனால், இம்முறை உலக எழுத்து வரலாற்றில் ஒரு மிகப் பெரிய மைல் கல்லாக அமைந்தது.

சுமேரியர்களின் உருவ எழுத்துக்கள் (Cuneiform)

மெசப்பெத்தோமியாவில் வாழ்ந்த சுமேரியர்கள் உருவ எழுத்துக்களை மேம்படுத்தி பயன்படுத்தியவர்கள். இவர்களின் எழுத்துமுறை க்யூனி∴பார்ம் (Cuneiform) என்று அழைக்கப்படுகிறது. கிமு 3500-ம் ஆண்டு காலத்திலிருந்து மண்பலகைகளில் கீற்றுக் கருவி மூலம் சின்னங்களைப் பொறித்தனர். ஆரம்பத்தில் உணவு, விலங்கு, கருவிகள் போன்றவற்றை குறிக்க உருவங்களை பயன்படுத்தினர். ஆனால் பின்னர் அவை சிக்கலான சின்னங்களாக மாறி நிர்வாகப் பதிவுகள், வர்த்தகக் கணக்குகள், சட்டங்கள், இலக்கியங்கள் எழுதப் பயன்படுத்தப்பட்டன. கில்காமேஸின் காவியம் போன்ற மிகப் பழமையான இலக்கியங்கள் கூட கீற்றெழுத்தில் எழுதப்பட்டுள்ளன. சுமேரியர்களின் பங்களிப்பு, உருவ எழுத்துக்களை முறையான பதிவுகளுக்குப் பயன்படுத்திய முதலாவது முயற்சியாகக் கருதப்படுகிறது. இதன் மூலம் மனிதர்கள், தகவலைச் சேமித்து பரிமாறும் திறனை பெற்றனர்

சீனாவில் உருவ எழுத்துக்கள் வளர்ச்சி

சீன நாகரீகம் உருவ எழுத்துக்களின் வளர்ச்சியில் தனித்துவமான இடத்தைப் பெற்றுள்ளது. அங்குள்ள பழங்கால ஆரக்கிள் எலும்பு ஸ்கிரிப்ட் (Oracle Bone Script) எனப்படும் எழுத்துமுறை கிமு 1200-ஆம் ஆண்டில் பயன்படுத்தப்பட்டதாகக் கூறப்படுகிறது. எலும்புகள் மற்றும் ஆமைச் சிப்பிகளில் பொறிக்கப்பட்டிருந்த இந்த எழுத்துக்கள் பெரும்பாலும் மத நிகழ்வுகள் மற்றும் ஜாதகம் தொடர்பான கேள்வி-பதில்களைச் சுட்டிக்காட்டின. ஆரம்பத்தில் உருவங்களை நேரடியாக சித்தரித்த இவ்வெழுத்துக்கள் பின்னர் சிக்கலான சின்னங்களாக மாறின. சீன எழுத்துக்களில் பலவற்றுக்கு இன்றளவும் உருவ அடையாளங்கள் அடிப்படையாக உள்ளன. உதாரணமாக, “மலை” என்பதை குறிக்க முக்கோண வடிவ சின்னம், “சூரியன்” என்பதை குறிக்க வட்ட சின்னம் போன்றவை. சீன உருவ எழுத்துக்கள் தொடர்ந்து வளர்ச்சி பெற்று, உலகிலேயே மிக நீண்ட காலம் நிலைத்த எழுத்துமுறையாகத் திகழ்கின்றன.

இந்தியாவில் உருவ எழுத்துக்கள்

இந்திய துணைக்கண்டத்தில் உருவ எழுத்துக்களின் சான்றுகள் பெரிதும் சிந்து சமவெளி நாகரீகத்தில் காணப்படுகின்றன. ஹரப்பா மற்றும் மொகஞ்சதாரோ நகரங்களில் கண்டுபிடிக்கப்பட்ட முத்திரைகள், சிற்பங்கள், களிமண் பொருட்கள் அனைத்திலும் சிறிய சின்னங்கள் காணப்படுகின்றன. இச்சின்னங்கள் பெரும்பாலும் விலங்குகள், மனித உருவங்கள், மத சின்னங்கள் ஆகியவற்றைக் குறிக்கின்றன. இன்று வரை சிந்து சமவெளி நாகரீக எழுத்துக்கள் முறையாகப் புரிந்துகொள்ளப்படவில்லை என்பதால் அவை உருவ எழுத்துகளா அல்லது பிற சின்ன எழுத்துகளா என்பதில் விவாதம் உள்ளது. எனினும், ஆய்வாளர்கள் பெரும்பாலும் அவை உருவ எழுத்துக்களின் அடிப்படையிலேயே இருந்ததாகக் கருதுகின்றனர். இந்தியாவில் மத்தியப் பிரதேசத்திலுள்ள பீம்பேட்கா போன்ற இடங்களிலும் உருவ எழுத்துக்களின் ஆரம்ப நிலைகள் (குகைச் சித்திரங்கள்) காணப்படுகின்றன. இதன் மூலம், இந்தியாவில் உருவ எழுத்துக்கள் மதம், வர்த்தகம், அன்றாட வாழ்க்கை ஆகியவற்றில் பெரும் பங்கு வகித்ததை உணர முடிகிறது.

மாயா எழுத்துமுறை

மாயா எழுத்துமுறை, மாயா கிளி.்.ப்கள் என்றும் அழைக்கப்படுகிறது, இது வரலாற்று ரீதியாக மெசோஅமெரிக்காவின் மாயா நாகரீகத்தின் பூர்வீக எழுத்து முறையாகும், மேலும் கணிசமாகப் புரிந்துகொள்ளப்பட்ட ஒரே மெசோஅமெரிக்க எழுத்து முறை இதுவாகும். மாயா என்று அடையாளம் காணக்கூடிய ஆரம்பகால கல்வெட்டுகள் கிமு 3 ஆம் நூற்றாண்டைச் சேர்ந்தவை, குவாத்தமாலாவின் சான் பார்டோலோவில். 16 மற்றும் 17 ஆம் நூற்றாண்டுகளில் ஸ்பானியர்கள் மாயாவைக் கைப்பற்றும் வரை மெசோஅமெரிக்கா முழுவதும் மாயா எழுத்து தொடர்ந்து பயன்பாட்டில் இருந்தது. நவீன மாயன் மொழிகள் கிட்டத்தட்ட முழுமையாக மாயா எழுத்துக்களை விட லத்தீன் எழுத்துக்களைப் பயன்படுத்தி எழுதப்பட்டாலும், மாயா கிளி.்.ப் அமைப்பின் மறுமலர்ச்சியை ஊக்குவிக்கும் சமீபத்திய முன்னேற்றங்கள் உள்ளன.

மாயா எழுத்துமுறை, நவீன ஜப்பானிய எழுத்துமுறைக்கு ஓரளவு ஒத்த சிலபிக் கிளி.்.ப்களின் தொகுப்பால் நிரப்பப்பட்ட லோகோகிராம்களைப் பயன்படுத்தியது. 18 மற்றும் 19 ஆம் நூற்றாண்டுகளின் ஆரம்பகால ஐரோப்பிய ஆய்வாளர்களால் மாயா எழுத்துமுறை ஹீரோகிளிபிக்ஸ் (Hieroglyphics) என்று அழைக்கப்பட்டது, அவர்கள் அதன் பொதுவான தோற்றத்தை எகிப்திய ஹீரோகிளிபிக்ஸ்களை (Hieroglyphics) நினைவூட்டுவதாகக் கண்டறிந்தனர், இருப்பினும் இரண்டு அமைப்புகளும் ஒன்றோடொன்று தொடர்புடையவை அல்ல.

மாயர்கள் முழு எண்களை மட்டுமே உள்ளடக்கிய ஒரு நிலை அடிப்படை- இருபது (decimal) எண் முறையைப் பயன்படுத்தினர். எளிய எண்ணும் செயல்பாடுகளுக்கு, ஒரு பட்டை மற்றும் புள்ளி குறியீடு பயன்படுத்தப்பட்டது. புள்ளி 1 ஐக் குறிக்கிறது மற்றும் பட்டை 5 ஐக் குறிக்கிறது. பூஜ்ஜியத்தைக் குறிக்க ஒரு ஷெல் பயன்படுத்தப்பட்டது. 6 முதல் 19 வரையிலான எண்கள் பார்கள் மற்றும் புள்ளிகளை இணைத்து உருவாக்கப்படுகின்றன, மேலும் அவற்றை கிடைமட்டமாகவோ அல்லது செங்குத்தாகவோ எழுதலாம். 19 க்கு மேல் உள்ள எண்கள் செங்குத்தாக எழுதப்பட்டு கீழிருந்து மேல் வரை 20 இன் சக்திகளாகப் படிக்கப்படுகின்றன. கீழ் எண் 0 முதல் 20 வரையிலான எண்களைக் குறிக்கிறது, எனவே காட்டப்படும் குறியீட்டைப் பெருக்க வேண்டிய அவசியமில்லை. கீழிருந்து இரண்டாவது வரி 20களின் அளவைக்

குறிக்கிறது, எனவே அந்த எண் 20 ஆல் பெருக்கப்படுகிறது. கீழிருந்து மூன்றாவது வரி 400களின் அளவைக் குறிக்கிறது, எனவே அது 400 ஆல் பெருக்கப்படுகிறது நான்காவது 8000 ஆல் பெருக்கப்படுகிறது ஐந்தாவது 160,000 ஆல் பெருக்கப்படுகிறது. இவ்வாறாக ஒவ்வொரு தொடர்ச்சியான வரியும் இருபது கூடுதல் சக்தியாகும் (அரபு எண்களில், முதல் இலக்கத்தின் இடதுபுறத்தில் 10 இன் கூடுதல் சக்திகள் சேர்க்கப்படுவது போல). இந்த நிலை அமைப்பு காலவரிசை மற்றும் வானியலுக்குத் தேவையான பெரிய எண்களைக் கணக்கிட அனுமதிக்கிறது.

சமீப காலங்களில், மாயா எழுத்து முறையை மீண்டும் பயன்படுத்துவதில் ஆர்வம் அதிகரித்துள்ளது. பல்வேறு படைப்புகள் சமீபத்தில் எழுத்துப்பெயர்ப்பு செய்யப்பட்டு எழுத்துப்பூர்வமாக உருவாக்கப்பட்டுள்ளன, குறிப்பாக 2018 ஆம் ஆண்டில் கெய்ச்சே மதத்தின் பதிவான போபோல் வுவின் படியெடுத்தல். மற்றொரு உதாரணம், 2012 ஆம் ஆண்டில் இக்சிம்சேயில் வைக்கப்பட்ட நவீன கல்வெட்டின் சிற்பம் மற்றும் எழுத்து, மாயன் நீண்ட எண்ணிக்கையின் தொடக்கத்திற்கு முந்தைய தளத்தின் முழு வரலாற்றுப் பதிவையும் விவரிக்கிறது. மார்ட்டின் கோம்ஸ் ராமிரெஸ் எழுதிய 2014 ஆம் ஆண்டு கவிதை "சிகாரா", முழுக்க முழுக்க ட்செல்டலில் எழுத்துப் முறையைப் பயன்படுத்தி எழுதப்பட்டது.

உருவ எழுத்துக்களின் அடிப்படை பண்புகள்

உருவ எழுத்துக்களுக்கு சில பொதுவான அடிப்படை பண்புகள் உள்ளன. முதலாவது, அவை நேரடியாக பொருள் அல்லது நிகழ்வின் உருவத்தை சித்தரிக்கின்றன. இரண்டாவது, ஒரே சின்னம் பல அர்த்தங்களில் பயன்படுத்தப்படும் வாய்ப்பு உண்டு. உதாரணமாக, சூரியன் சின்னம் வெறும் சூரியனையே குறிக்காமல், ஒளி, சூடு, நாள் போன்றவற்றையும் குறிக்கக்கூடும். மூன்றாவது, உருவ எழுத்துக்கள் பொதுவாக படிக்க எளிதானவை. எழுத்தறிவு இல்லாதவர்களும் அவற்றைப் புரிந்து கொள்ள இயலும். நான்காவது, அவை கலைநயத்துடன் தொடர்புடையவை. பல உருவ எழுத்துக்கள் அழகிய வடிவமைப்புகளாகக் காணப்படுகின்றன. இறுதியாக, உருவ எழுத்துக்கள் நிலைத்தன்மை பெற்றவை. கல்லில், மண்ணில், உலோகத்தில் பொறிக்கப்பட்டதால் ஆயிரக்கணக்கான ஆண்டுகள் கடந்தும் அவை அழியாமல் இருக்கின்றன. இத்தகைய பண்புகள் தான் உருவ எழுத்துக்களை உலகின் பல நாகரீகங்களில் பரவலாகப் பயன்படுத்தச் செய்தன.

உருவ எழுத்துக்களில் இருந்து சின்ன எழுத்துக்கள் (Ideographs)

உருவ எழுத்துக்கள் நேரடியாக பொருளை சித்தரித்ததால், அவற்றை விரிவுபடுத்திக் கொள்ளும் அவசியம் ஏற்பட்டது. இதன் விளைவாக சின்ன எழுத்துக்கள் (Ideographs) தோன்றின. உருவ சின்னங்கள் மெதுவாகக் கருத்துகளை குறிக்கத் தொடங்கின. உதாரணமாக, சூரியன் சின்னம் வெறும் சூரியனை மட்டுமல்லாமல், "பகல்" அல்லது "ஒளி" என்ற கருத்தையும் குறிக்கத் தொடங்கியது. நீர் சின்னம் "நதி", "மழை", "ஊற்று" போன்ற பல அர்த்தங்களில் பயன்பட்டது. இவ்வாறு சின்ன எழுத்துக்கள், கருத்துக்களை வெளிப்படுத்தும் திறனைக் கொண்டிருந்தன. சீன எழுத்துக்களில் இத்தகைய சின்ன எழுத்துக்கள் அதிகமாக காணப்படுகின்றன. உருவ எழுத்துக்களின் குறைகளை நீக்கி, பரந்த கருத்துகளை வெளிப்படுத்தியதில் சின்ன எழுத்துக்கள் மிக முக்கிய முன்னேற்றமாக அமைந்தன.

உருவ எழுத்துக்களில் இருந்து ஒலியியல் எழுத்துக்கள் (Phonetics)

உருவ எழுத்துக்கள் வளர்ச்சி பெற்றபோது, அவை ஒலியியல் அடிப்படையிலும் பயன்படுத்தப்பட்டன. ஆரம்பத்தில் ஒரு உருவம் ஒரு பொருளைக் குறிப்பதற்கு பயன்படுத்தப்பட்டாலும், பின்னர் அந்த உருவம் அதற்கான ஒலியை (sound) குறிக்கத் தொடங்கியது. இதுவே ஒலியியல் எழுத்துமுறையின் அடிப்படையாகும். எகிப்திய ஹீரோகிளிபிக்ஸ் (Hieroglyphics) எழுத்துமுறையில் சில சின்னங்கள் குறிப்பிட்ட ஒலிகளைச் சுட்டிக்காட்டின. இதனால் சிக்கலான வார்த்தைகள் மற்றும் வாக்கியங்களை எழுதுவது சாத்தியமானது. ஒலியியல் அடிப்படை எழுத்துக்கள் தோன்றியதால், குறைந்த சின்னங்களின் மூலமே அதிக எண்ணிக்கையிலான சொற்களை உருவாக்க முடிந்தது. இது பின்னர் அகர எழுத்துக்களின் தோற்றத்திற்கான அடித்தளமாக அமைந்தது.

உருவ எழுத்துக்கள் மற்றும் அகர எழுத்துக்கள்

உருவ எழுத்துக்களிலிருந்து அகர எழுத்துக்களுக்கு மாற்றம் மனித வரலாற்றின் மிகப் பெரிய முன்னேற்றமாகும். உருவ எழுத்துக்கள் ஆயிரக்கணக்கான சின்னங்களை கற்றுக்கொள்ள வேண்டிய அவசியத்தை ஏற்படுத்தின. ஆனால் அகர எழுத்துக்கள் சில பத்தே குறியீடுகளைப் பயன்படுத்தி முழு மொழியையும் பதிவு செய்யும் திறனை அளித்தன. பொனீசியர்கள் (Phoenicians) உருவ எழுத்துக்களிலிருந்து எளிமையான அகர எழுத்துமுறையை உருவாக்கினர். பின்னர் கிரேக்கர்கள், ரோமானியர்கள் அதைத் தங்கள் மொழிக்கேற்றவாறு மாற்றி பயன்படுத்தினர். இவ்வாறு உருவ எழுத்துக்கள் மனிதனை எழுத்தின் ஆரம்ப நிலையிலிருந்து ஒலி அடிப்படையிலான எளிய அகர எழுத்துக்களுக்குக் கொண்டு சென்றது. இன்றைய ஆங்கிலம், தமிழ் உள்ளிட்ட அனைத்து மொழிகளின் எழுத்துமுறைகளும் அதன் பின்விளைவாகும்.

மனித வரலாற்றை அறிந்து கொள்ள உருவ எழுத்துக்கள் மிகப்பெரிய ஆதாரமாக விளங்குகின்றன. அவை ஒரு நாகரீகத்தின் அரசியல், பொருளாதாரம், மதம், கலாச்சாரம், கல்வி போன்ற அனைத்தையும் வெளிப்படுத்துகின்றன. இன்றும் தொல்லியல் ஆராய்ச்சியாளர்கள் உருவ எழுத்துக்களைப் படித்து, பண்டைய நாகரீகங்களின் மர்மங்களைத் தீர்க்கின்றனர். எகிப்திய பிரமிடுகளில் பொறிக்கப்பட்ட ஹீரோகிளிபிக்ஸ் (Hieroglyphics) எழுத்துக்கள், சிந்து சமவெளி நாகரீக முத்திரைகளில் காணப்படும் சின்னங்கள், சீனாவின் பண்டைய கல்வெட்டுகள் - இவை அனைத்தும் மனித வரலாற்றின் ஜன்னல்களாக உள்ளன. உருவ எழுத்துக்கள் மனிதன் சிந்தனை வளர்ச்சியின் சான்றாகவும், அறிவின் முதன்மையான அடையாளமாகவும் திகழ்கின்றன.

முடிவுரை

எழுத்து முறையின் பரிணாம வளர்ச்சி என்பது வெறும் மொழியியல் முன்னேற்றம் மட்டுமல்ல. அது மனித சிந்தனையின் ஆழத்தையும், கலாச்சார நுணுக்கங்களையும் பிரதிபலிக்கிறது. ஒலிப்பொருள் (Phonetic), சிந்தனைப்பொருள் (Ideographic), மற்றும் படிம (Pictographic) எழுத்துமுறைகள் வழியாக ஏற்பட்ட பரிமாற்றங்கள், இன்றைய உலக எழுத்து அமைப்புகளுக்கான அடிப்படையாக விளங்குகின்றன. எனவே, எழுத்து முறை வளர்ச்சி என்பது மனித அறிவின் வரலாற்றுப் பரிமாணத்தையும், சமூகத்தின் கலாச்சார வளர்ச்சியையும் ஒருங்கிணைக்கும் ஒரு முக்கிய ஆய்வுத் துறையாகக் காணப்படுகிறது. இது மொழியியல், தொல்பொருளியல் மற்றும் வரலாற்றியல் ஆய்வுகளுக்கிடையேயான பாலமாக விளங்குகிறது.

எழுத்து முறையின் வளர்ச்சி மனித அறிவின் வரலாற்றை பிரதிபலிக்கும் ஒரு சமூகச் சான்றாகும். இந்த ஆய்வு மூலம் நாகரீக வளர்ச்சியின் அறிவியல், கலாச்சார மற்றும் சமூக அடிப்படைகளைப் புரிந்துகொள்ள முடிகிறது. இவ்வாய்வு, மனிதனின் சிந்தனை பரிணாமத்தையும், உலக மொழி மரபின் ஒற்றுமையையும் விளக்கும் ஒரு முக்கியமான கல்வியியல் பங்களிப்பாக அமைகிறது. மொத்தத்தில், எழுத்து முறை மனித வரலாற்றின் நினைவகமாகச் செயல்படுகிறது. அது நாகரீகத்தின் சமூக அமைப்பு, மத நம்பிக்கைகள், அறிவியல் கண்டுபிடிப்புகள் மற்றும் கலாச்சார மரபுகளைப் பதிவு செய்யும் சிறந்த கருவியாக விளங்குகிறது. எழுத்தின் தோற்றம் மனிதனின் சிந்தனைக்கான வெளிப்பாடாக தொடங்கியிருந்தாலும், அதன் வளர்ச்சி அறிவியல், தொழில்நுட்பம் மற்றும் கல்வி வளர்ச்சிக்கான அடித்தளமாக மாறியுள்ளது.

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திராவிட மொழிக்குடும்பம் - ஓர் ஆய்வு

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ஆய்வுச்சுருக்கம்

இன்றைய இந்தியாவில் பேசப்படும் மொழிகளின் எண்ணிக்கை 1300க்கும் அதிகம். இத்தனை மொழிகளையும் பொதுவாக நான்கு பெரிய மொழிக் குடும்பங்களாகப் பிரிக்கின்றனர். அவை: இந்தோ-ஆசிய மொழிகள், திராவிட மொழிகள், ஆஸ்திரோ-ஆசிய மொழிகள் மற்றும் சீன-திபெத்திய மொழிகள். மொழியியலாளர்கள் மேற்கொண்ட ஆய்வுகளின் அடிப்படையில், திராவிட மொழிக் குடும்பம் பண்டைய இந்திய நாகரீகத்தின் முக்கியமான மொழிக் கிளையாகக் கருதப்படுகிறது. "திராவிடம்" என்ற சொல் முதலில் குமரிக்கண்டம் என்ற பிரதேசத்தைக் குறிப்பதாகவும், பின்னர் அது தமிழகம் மற்றும் திராவிடம் என்ற வடிவங்களுக்கு மாறியதாகவும் அறிஞர்கள் விளக்குகின்றனர். திராவிட மொழிக் குடும்பம் இந்தியாவின் பண்டைய மொழி மரபில் தனித்துவமிக்க இடம் பெற்றது. தமிழ், தெலுங்கு, கன்னடம், மலையாளம், துளு போன்ற மொழிகள் இதன் பகுதிகளாகும். இம்மொழிகள் தத்தம் புலங்களில் இலக்கியம், பண்பாடு, நாகரீக வளர்ச்சிக்குப் பெரும் பங்களிப்பு செய்துள்ளன. இவ்வாய்வில், திராவிட மொழிகளான தமிழ், மலையாளம், கன்னடம், தெலுங்கு துளு போன்றவை பற்றி சுருக்கமாக விளக்கப்பட்டுள்ளது.

அறிமுகம்

தெற்காசியாவில் முதன்மையாகப் பேசப்படும் சுமார் 70 மொழிகளைத் தன்னகத்தே கொண்டது திராவிட மொழிக்குடும்பம். இந்தியா, பாகிஸ்தான் மற்றும் இலங்கையில் 215 மில்லியனுக்கும் அதிகமான மக்களால் திராவிட மொழிகள் பேசப்படுகின்றன. திராவிட மொழிகள் தெற்கு, தென்-மத்திய, மத்திய மற்றும் வடக்கு குழுக்களாகப் பிரிக்கப்பட்டுள்ளன. இந்த குழுக்கள் மேலும் 24 துணைக்குழுக்களாக ஒழுங்கமைக்கப்பட்டுள்ளன. தெலுங்கு, தமிழ், மலையாளம் மற்றும் கன்னடம் ஆகிய நான்கு முக்கிய இலக்கிய மொழிகள் இந்திய அரசியலமைப்பால் அங்கீகரிக்கப்பட்டுள்ளன. அவை முறையே ஆந்திரப் பிரதேசம், தெலுங்கானா, தமிழ்நாடு, கேரளா மற்றும் கர்நாடகா மாநிலங்களின் அதிகாரப்பூர்வ மொழிகளாகவும் உள்ளன.

இந்தியா ஒரு மொழியியல் பகுதி என்ற கோட்பாட்டில் கணிசமான இலக்கியங்கள் உள்ளன. அங்கு பல்வேறு மொழிக் குடும்பங்கள் விரிவான பிராந்திய மற்றும் சமூக இருமொழி மூலம் ஒன்றிணைந்த கட்டமைப்புகளை உருவாக்கியுள்ளன. கிமு 2 ஆம் மில்லினியத்திற்கு முந்தைய தொடர்பு காரணமாக இந்தோ-ஆரிய மற்றும் திராவிட மொழிக் குடும்பங்கள் ஒலி அமைப்பு (ஒலியியல்) மற்றும் இலக்கணத்தில் ஒன்றிணைந்த கட்டமைப்புகளை உருவாக்கின என்பது இப்போது நன்கு நிறுவப்பட்டுள்ளது. இந்தோ-ஆரியத்தின் ஆரம்பகால வகைகள் சமஸ்கிருதத்தின் வடிவங்கள். ரிக்வேதத்தின் சமஸ்கிருத பாடல்களில் (கிமு 1500 இல் இயற்றப்பட்டது) ஒரு டஜனுக்கும் மேற்பட்ட திராவிட கடன் சொற்களைக் காணலாம். இதில் உலூகல- "சாந்து", "குண்ட "குழி", "கால- "கதிரடிக்கும் தளம்", "காணா- "ஒற்றைக் கண்" மற்றும் மயூர "மயில்" ஆகியவை அடங்கும். ரெட்ரோ.ப்ளெக்ஸ் மெய் எழுத்துக்களின் அறிமுகம் (கடின அண்ணத்தின் நடுவில் உயர்த்தப்பட்ட நாக்கு நுனியால் உற்பத்தி செய்யப்படும்)

சமஸ்கிருத பேச்சாளர்களுக்கும் திராவிட மொழிகளைப் பேசுபவர்களுக்கும் இடையிலான தொடர்புக்குக் காரணமாகக் கூறப்படுகிறது.

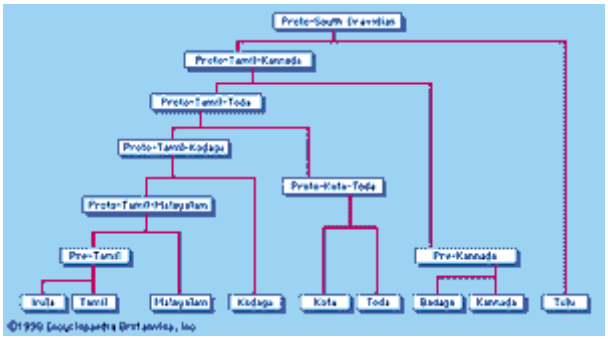
ரிக்வேதத்தில் திராவிட மொழிகள் கடன் வாங்கிய சொற்கள் இருப்பது, அதன் உருவாக்கத்தின் போது, திராவிட மற்றும் ஆரிய மொழி பேசுபவர்கள் இந்தோ-கங்கை சமவெளியில் ஒரே பேச்சு சமூகமாக இணைக்கப்பட்டனர் என்பதைக் குறிக்கிறது. அதே நேரத்தில் திராவிட மொழி பேசுபவர்களின் சுயாதீன சமூகங்கள் இந்தோ-ஆரியப் பகுதியின் எல்லைக்கு (வடமேற்கில் பிராஹுய், கிழக்கில் குருக்-மால்டோ, மற்றும் கிழக்கு மற்றும் மத்திய இந்தியாவில் கோண்டி-குய்) இடம்பெயர்ந்தன. குறிப்பிடத்தக்க வகையில், திராவிட மொழிகளின் மிகவும் பழமையான வடிவங்கள் தென்னிந்தியாவில் காணப்படுகின்றன. இது கிமு 5 ஆம் நூற்றாண்டு வரை சமஸ்கிருதத்திற்கு ஆளாகவில்லை. ஆரிய மொழி பேசுபவர்கள் இந்தியாவிற்குள் நுழைவதற்கு முன்பே தெற்கில் திராவிட மொழி பேசுபவர்கள் வசித்து வந்தனர் என்பதை இது குறிக்கிறது.

துராவிட திராமிட என்ற வார்த்தையும் அதன் பெயரடை வடிவங்களும் கிமு 3 ஆம் நூற்றாண்டிலிருந்து ஒரு நாடு மற்றும் அதன் மக்களின் பெயராக பாரம்பரிய சமஸ்கிருத இலக்கியங்களில் காணப்படுகின்றன. ஒரு மொழியின் பெயராக திராவிட என்பது கிபி 7 ஆம் நூற்றாண்டில் குமாரில-பட்டரின் தந்திரவர்த்திகாவில் (”புனித அறிவியல் பற்றிய விளக்கம்”) காணப்படுகிறது. இந்த மற்றும் கிட்டத்தட்ட அனைத்து ஒத்த நிகழ்வுகளிலும், இந்தப் பெயர் தமிழ் நாடு, தமிழ் மக்கள் மற்றும் தமிழ் மொழியைக் குறிக்கிறது என்று நம்புவதற்கு காரணம் உள்ளது. திராவிட மொழிகளின் முதல் ஒப்பீட்டு இலக்கணத்தை (1856) எழுதிய ஸ்காட்டிஷ் மிஷனரி பிஷப் ராபர்ட் கால்டுவெல், இந்தச் சொல் சில நேரங்களில் தென்னிந்திய மக்களையும் அவர்களின் மொழிகளையும் தெளிவற்ற முறையில் குறிப்பிடுவதாக வாதிட்டார் தமிழ் ஏற்கனவே ஒரு குறிப்பிட்ட மொழியின் நிறுவப்பட்ட பெயராக இருந்ததால், அதை முழு குடும்பத்திற்கும் ஒரு பொதுவான பெயராக அவர் ஏற்றுக்கொண்டார்.

கால்டுவெல் மற்றும் பிற அறிஞர்கள் கிரேக்கம், லத்தீன் மற்றும் எபிரேய மொழிகளில் இருந்து வந்த பல சொற்கள் திராவிட வம்சாவளியைச் சேர்ந்தவை என்று கூறியுள்ளனர். இந்தக் கூற்றுகளில் பலவற்றின் நம்பகத்தன்மை சர்ச்சைக்குரியதாக உள்ளது, இருப்பினும் இரண்டு விஷயங்கள் நம்பத்தகுந்ததாகத் தெரிகிறது. முதலாவது கிரேக்க ஒருசா.˙.ஓரிசா.˙.ஓரிண்டா “அரிசி“ ஆகும், இது ப்ரோட்டோ-திராவிட மூவார்-இன்சி“ உடன் ஒப்பிடப்பட வேண்டும். (நட்சத்திரக் குறியீடு சான்றளிக்கப்பட்ட சந்ததி வடிவங்களை அடிப்படையாகக் கொண்ட மறுகட்டமைப்பைக் குறிக்கிறது, இந்த விஷயத்தில் தமிழ்-மலையாளம்-தெலுங்கு வாரி, பார்ஜி வெர்சி(ல்), கடபா வார்சி(ல்), மற்றும் கோண்டி வஞ்சி “அரிசி, நெல்“) கால்டுவெல் முன்மொழிந்த தமிழ் அரிசி (தெற்கு திராவிட மூஅரிகி) உடன் அல்ல.

இரண்டாவது வழக்கில், கிரேக்க ஜிகிபெரிஸ்.˙.ஜிங்கிபெரிஸ் “இஞ்சி“ என்பது தெற்கு திராவிட பெயரளவு கலவையான *cinki-wēr (Proto-Dravidian *wēr “வேர்“), பாலி சிங்கி மற்றும் சிங்கிவேரா, சமஸ்கிருத s'ṛṅgavera-, மற்றும் தமிழ்-மலையாள இஞ்சி (*cinki இலிருந்து *c இழப்பதன் மூலமும், முன் உயிரெழுத்துக்குப் பிறகு -ki I -ci ஆக மாற்றுவதன் மூலமும் பெறப்பட்டது) ஆகியவற்றிலிருந்து பெறப்பட்டது. பிளினி தி எல்டர் (1 ஆம் நூற்றாண்டு CE) மற்றும் டாலமி (2 ஆம் நூற்றாண்டு CE) ஆகியோரால் மேற்கோள் காட்டப்பட்ட

தென்னிந்தியாவின் பல இடப் பெயர்கள் -our அல்லது -oura இல் முடிவடைகின்றன, இது ப்ரோட்டோ-திராவிட *ūr இலிருந்து "நகரம்" என்ற இடப் பெயர் பின்னொட்டுடன் ஒத்திருக்கிறது.



தமிழ்

திராவிட மொழிக் குடும்பத்தில் உள்ள நான்கு இலக்கிய மொழிகளில், தமிழ் மிகவும் பழமையானது, எடுத்துக்காட்டுகள் ஆரம்பகால பொது சகாப்தத்தைச் சேர்ந்தவை. 21 ஆம் நூற்றாண்டின் முற்பகுதியில், 66 மில்லியனுக்கும் அதிகமான மக்களால் தமிழ் பேசப்பட்டது, பெரும்பாலும் இந்தியா, வடக்கு இலங்கை, மலேசியா, சிங்கப்பூர், மொரிஷியஸ், பிஜி மற்றும் மியான்மர் (பர்மா) ஆகிய நாடுகளில் வசித்து வந்தனர். தமிழ் மொழியில் முதன்முதலில் அறியப்பட்ட படைப்பான தொல்காப்பியம் (கி.பி 1–4 ஆம் நூற்றாண்டு "பண்டைய இலக்கியம்"), இலக்கணம் மற்றும் கவிதை பற்றிய ஒரு ஆய்வுக் கட்டுரையாகும். அதன் இருப்பு, தொகுப்புகளின் வடிவத்தில் கிடைக்கக்கூடிய ஒரு பெரிய இலக்கியத் தொகுப்பை முன்னறிவிக்கிறது. தமிழ் கால "காலம், காலம்" (சமஸ்கிருத கால "காலம், காலம்"), "பெயர்ச்சொல்" என்பதற்கு தமிழ் பெயர் "பெயர்" (சமஸ்கிருத நாமன் "பெயர், பெயர்ச்சொல்"), மற்றும் "வழக்கு" என்பதற்கு தமிழ் வேற்றுமை "பிரித்தல், வகுத்தல்" (சமஸ்கிருத விபக்தி- "வழக்கு குறிப்பான்," அதாவது "வகுப்பு") போன்ற சில இலக்கணக் கருத்துகளில் ஆரம்பகால சமஸ்கிருத இலக்கணங்களின் செல்வாக்கு தெளிவாகத் தெரிந்தாலும், தொல்காப்பியத்தில் அசல் தன்மை அதிகம் உள்ளது.

தமிழ் பிராமி எழுத்துக்களில் கல்வெட்டுகள் கிமு 2 ஆம் நூற்றாண்டிலிருந்து காணப்படுகின்றன. கிரேக்க மற்றும் அரபு மொழிகளைப் போலவே, தமிழிலும் டிக்ளோசியா உள்ளது. அதாவது பேச்சு சமூகத்தில் இரண்டு வகையான மொழிகள் இணைந்து வாழ்கின்றன. சென்டாமிக் "அழகான தமிழ்" என்று அழைக்கப்படும் தமிழின் நிலையான எழுத்து மற்றும் பேச்சு வகை, முந்தைய சகாப்தத்தின் பாரம்பரிய மொழியை அடிப்படையாகக் கொண்டது. சமகால பிராந்திய பேச்சுவழக்குகளில் எதையும் அடிப்படையாகக் கொண்டது அல்ல. தமிழின் பல பேச்சு வகைகள் கொடுந்தமிழ், வளைந்த தமிழ் அல்லது கொச்சையான தமிழ் என்று அழைக்கப்படுகின்றன, மேலும் அவை முறையான பேச்சு மற்றும் எழுத்தில் பயன்படுத்தப்படுவதில்லை. செய்தித்தாள், மொழி மற்றும் அரசியல் பேச்சுகளின் மொழி சென்டாமிக் ஆகும்.



தமிழ் மொழி உலகின் பழமையான மொழிகளில் ஒன்றாகும். இதன் எழுத்து முறையும் மிகப்பழமையானது. இது திராவிட மொழிக்குடும்பத்தைச் சேர்ந்தது. தமிழின் எழுத்து முறைகள் ஆயிரக்கணக்கான ஆண்டுகளாகத் தொடர்ந்து வாழ்ந்து வருகின்றன. மனித குல வரலாற்றில் தமிழ் எழுத்துக்கள் முக்கிய பங்காற்றுகின்றன. தமிழ் மொழியின் ஒலி மற்றும் எழுத்து அமைப்பு உலகில் மிகவும் தனித்துவமானது. சங்ககாலம் முதல் இன்றுவரை தமிழ் எழுத்துகள் பல்வேறு மாற்றங்களை சந்தித்துள்ளன. முதலில் தமிழில் “பழந்தமிழ்“ அல்லது “தமிழ்-பிராமி“ எழுத்து பயன்படுத்தப்பட்டது. தமிழ் எழுத்தின் தொடக்க வடிவமாக தமிழ்-பிராமி (Tamil-Brahmi) காணப்படுகிறது. தமிழர்கள் இதனை அடிப்படையாகக் கொண்டு தங்கள் சொந்த எழுத்துருவை உருவாக்கினர். தமிழ்-பிராமி கல்வெட்டுகள் தமிழகத்தின் பல இடங்களில் கண்டுபிடிக்கப்பட்டுள்ளன.

பின்னர் கி.பி. 6 ஆம் நூற்றாண்டில் வட்டெழுத்து (Vaṭṭeḻuttu) பயன்பாட்டில் இருந்தது. இதன் எழுத்துக்கள் வட்ட வடிவில் அமைந்ததால் “வட்டெழுத்து” என்று பெயர் வந்தது. சேர நாட்டில் கல்வெட்டுகள், ஆவணங்கள், சங்கீதம், இலக்கியங்களில் இவ்வட்டெழுத்து முறை பரவலாகப் பயன்படுத்தப்பட்டது. வட்டெழுத்து தமிழ் எழுத்தின் தனித்துவத்தை வெளிப்படுத்தியது. தமிழில் சமஸ்கிருத சொற்களை எழுதுவதற்காக கிரந்த எழுத்து பயன்பாட்டிற்கு வந்தது. இது தமிழின் எழுத்து முறைக்கு புதிய வடிவம் மற்றும் தாக்கத்தை ஏற்படுத்தியது. அதன் பின், நாகரி மற்றும் கிரந்த எழுத்துக்களால் தாக்கம் ஏற்பட்டு, நவீன தமிழ் எழுத்துகள் உருவானது. இன்றைய தமிழ் எழுத்துக்கள் மொத்தம் 247 எழுத்துக்களை கொண்டுள்ளது: உயிரெழுத்துகள்(12), மெய்யெழுத்துகள்(18), உயிர்மெய்யெழுத்துகள் (216), ஆய்த எழுத்து (1). இந்த எழுத்து முறை உலகின் எளிதானதும், அறிவியல் ரீதியாகச் சிறந்த ஒன்றாகவும் கருதப்படுகிறது.



தமிழ் கல்வெட்டுகள் தமிழகத்தின் பல இடங்களில் கண்டுபிடிக்கப்பட்டுள்ளன. கோவில்கள், கோட்டைகள், சிலைகள், நாணயங்களில் கல்வெட்டுகள் உள்ளன. இவை தமிழர்களின் அரசியல், சமூக, பண்பாட்டு வாழ்க்கையை வெளிப்படுத்துகின்றன. தமிழ் எழுத்தின் வளர்ச்சி தமிழின் இலக்கிய வளர்ச்சியோடு இணைந்துள்ளது. சங்க இலக்கியம், சிலப்பதிகாரம், மணிமேகலை போன்ற நூல்கள் தமிழ் எழுத்தின் வலிமையை காட்டுகின்றன. பாரதியார், பாரதிதாசன் போன்றோர் தமிழின் நவீன இலக்கிய வளர்ச்சியில் பங்காற்றினர் தமிழ் எழுத்து முறையில் எளிய ஒலி-எழுத்து தொடர்பு கொண்டுள்ளது. உயிர் மற்றும் மெய்யின் இணைவு முறையால் எழுத்துக்கள் பெருகுகின்றன. இது உலகின் பிற எழுத்துமுறைகளுடன் ஒப்பிடுகையில் அறிவியல் ரீதியாக மிகவும் ஒழுங்கானது. தமிழ் மொழி உலகம் முழுவதும் பரவியுள்ளது. இலங்கை, மலேசியா, சிங்கப்பூர், கனடா, அமெரிக்கா, ஐரோப்பா போன்ற நாடுகளில் வாழும் தமிழர்கள் தமிழ் எழுத்தை பயன்படுத்துகின்றனர். தமிழ் எழுத்து தமிழர்களின் அடையாளமும் பெருமையும் ஆகும். இது ஆயிரக்கணக்கான ஆண்டுகளாக வாழ்ந்து வரும் எழுத்துமுறையாகும்.

மலையாளம்

கி.பி 9 ஆம் நூற்றாண்டு வரை மலையாளம் தமிழின் மேற்கு கடற்கரை பேச்சுவழக்காக இருந்தது. புவியியல் ரீதியாக செங்குத்தான மேற்குத் தொடர்ச்சி மலைகளால் பிரதான பேச்சுவழக்கு சமூகத்திலிருந்து பிரிக்கப்பட்ட இந்த பேச்சுவழக்கு, படிப்படியாக ஒரு தனித்துவமான மொழியாக வளர்ந்தது. மலையாளத்தின் முதல் இலக்கியப் படைப்பு ராமசரிதம் (12-13 ஆம் நூற்றாண்டு "ராமரின் செயல்கள்"), முதல் இலக்கணமான லிலாதிலகம் (14 ஆம் நூற்றாண்டு "புனித மார்க்கின் புத்தகம்"), சமஸ்கிருதத்தில் எழுதப்பட்டது. தமிழைப்

போலல்லாமல், கன்னடம் மற்றும் தெலுங்கை விட அதிக அளவில், மலையாளம் சமஸ்கிருதத்திலிருந்து சொற்களை மட்டுமல்ல, பல்வேறு வகையான ஊடுருவல்களையும் தாராளமாகக் கடன் வாங்கியுள்ளது. மலையாளத்தில் தமிழ் வகை டிக்ளோசியா இல்லை.

கன்னடம்

கர்நாடக மாநிலத்தின் அதிகாரப்பூர்வ மொழி கன்னடம். கன்னடத்தில் உள்ள கல்வெட்டுகள் கி.பி 5 ஆம் நூற்றாண்டைச் சேர்ந்தவை, அதே நேரத்தில் முதல் இலக்கியப் படைப்பான கவிராஜமார்கா (”கவிஞர்களின் அரச சாலை”), 9 ஆம் நூற்றாண்டைச் சேர்ந்த கவிதை பற்றிய ஒரு ஆய்வுக் கட்டுரையாகும். கேசிராஜாவின் ‘ப்த மணி தர்பனா (”இலக்கணத்தின் நகை கண்ணாடி”) கன்னடத்தில் எழுதப்பட்ட முதல் விரிவான இலக்கணமாகும். இது 13 ஆம் நூற்றாண்டைச் சேர்ந்தது. நவீன தரமான கன்னடம் தெற்கு கர்நாடகாவின் (மைசூரு மற்றும் பெங்களூரு நகரங்களுடன் தொடர்புடையது) கல்வியறிவு பெற்ற பேச்சை அடிப்படையாகக் கொண்டது வடக்கு (தார்வார்) மற்றும் கடலோர வகைகளிலிருந்து கணிசமாக வேறுபடுகிறது. ஒவ்வொரு பிராந்தியத்திலும் சாதி பேச்சுவழக்குகளும் பதிவாகியுள்ளன.

தெலுங்கு

திராவிட மொழிகளில், தெலுங்கு அதிக மக்களால் பேசப்படுகிறது. இந்தி மற்றும் வங்காள மொழிகளுக்குப் பிறகு, இது அனைத்து இந்திய மொழிகளிலும் மூன்றாவது இடத்தில் உள்ளது. தெலுங்கு இடப் பெயர்கள் கி.பி 2 ஆம் நூற்றாண்டைச் சேர்ந்த பிராகிருத கல்வெட்டுகளில் காணப்படுகின்றன. முதல் தெலுங்கு கல்வெட்டு கி.பி 575 ஆம் ஆண்டைச் சேர்ந்தது. முதல் இலக்கியப் படைப்பு நன்னய பட்டரால் எழுதப்பட்டது 11 ஆம் நூற்றாண்டைச் சேர்ந்த இது, மகாபாரதத்தின் ஒரு பகுதியின் (”பாரத வம்சத்தின் சிறந்த காவியம்”) கவிதை மொழிபெயர்ப்பாகும். முதல் தெலுங்கு இலக்கணமான ஆந்திர ‘ப்த சிந்தாமணி (”மக்களின் மொழி பற்றிய ஆய்வு”), சமஸ்கிருதத்தில் எழுதப்பட்டது மற்றும் அதே ஆசிரியரால் இயற்றப்பட்டதாகக் கூறப்படுகிறது.

தெலுங்கில் நான்கு பிராந்திய பேச்சுவழக்குகள் உள்ளன. மேலும் நவீன தரநிலை தெலுங்கு மத்திய கடலோர பேச்சுவழக்கின் உயரடுக்கின் பேச்சு மற்றும் எழுத்துக்களை அடிப்படையாகக் கொண்டது. இது அதன் வடக்கு அண்டை மாநிலங்களுடன் மரபணு ரீதியாக நெருக்கமாக இருந்தாலும், ஒரு இலக்கிய மொழியாக தெலுங்கு கன்னடத்துடன் பெரிய அளவிலான தொடர்புகளைக் கொண்டுள்ளது. அவற்றின் எழுத்துக்கள் ஒரு பொதுவான பரிணாம வளர்ச்சியைக் கொண்டுள்ளன. தெலுங்கு-கன்னட எழுத்துக்களைப் பயன்படுத்தி (7-13 ஆம் நூற்றாண்டு), தெலுங்கு மற்றும் கன்னடம் இரண்டு மொழிகளிலும் எழுதிய பல சைவ கவிஞர்கள் இருந்தனர். விஜயநகர மன்னர் கிருஷ்ணதேவராயர் கன்னடம் மற்றும் தெலுங்கு கவிதை இரண்டிற்கும் புரவலராக இருந்தார். இதன் விளைவாக, தெலுங்கு மற்றும் கன்னடத்திற்கு இடையே விரிவான சொற்களஞ்சியக் கடன்கள் உள்ளன.

துளு மொழி

துளு மொழி, திராவிட மொழிக் குடும்பத்தைச் சேர்ந்தது. துளு என்பது இந்தியாவின் கர்நாடகாவின் கடலோரப் பகுதியிலும், கேரளாவின் வடக்குப் பகுதியிலும், துளு நாடு என்று அழைக்கப்படும் பகுதியிலும் முதன்மையாகப் பேசப்படும் ஒரு பண்டைய திராவிட மொழியாகும்.

இது ஒரு வளமான வாய்மொழி இலக்கிய பாரம்பரியம், யட்சகானா போன்ற நாட்டுப்புற நாடகம் மற்றும் பதானா எனப்படும் நாட்டுப்புற பாடல்களால் வகைப்படுத்தப்படுகிறது. ஆனால் இலக்கிய இலக்கணங்கள் அந்த மொழியில் மிகக் குறைவாகவே எழுதப்பட்டுள்ளது. துளு கர்நாடகாவின் அதிகாரப்பூர்வ மொழியான கன்னட மொழியிலிருந்து பல சொற்களைக் கடன் வாங்கியுள்ளது, கன்னடம் போன்ற பிற எழுத்து வடிவங்களும் பயன்படுத்தப்பட்டாலும், இந்த மொழிக்கு அதன் சொந்த தனித்துவமான துளு எழுத்து வடிவமும் உள்ளது. ஆனால் அவை நெருங்கிய தொடர்புடையவை அல்ல. 21 ஆம் நூற்றாண்டின் முற்பகுதியில் துளு சுமார் இரண்டு மில்லியன் மக்களால் பேசப்பட்டது.

திராவிட மொழிகளில் சொல் ஒற்றுமை

தமிழ்	மலையாளம்	தெலுங்கு	கன்னடம்	துளு	கூர்க்
மரம்	மரம்	மானு	மரம்	மர	மர
ஒன்று	ஒண்ணு	ஒகடி	ஒந்து	ஒஞ்சி	---------
நூறு	நூறு	நூரு	நூரு	நூது	---------
நீ	நீ	நீவு	நீன்	ஈ	நின்
இரண்டு	ஈர்ரெண்டு	ஈர்ரெண்டு	எரடு	ரட்டு	------
நான்கு	நால், நாங்கு	நாலுகு	நாலு	நாலு	------
ஐந்து	அஞ்சு	ஐது	ஐது	ஐனு	-------

நிறைவுரை

மொழி என்பது மனித நாகரீகத்தின் மிகப் பெரும் கண்டுபிடிப்புகளில் ஒன்றாகும். மனிதனின் சிந்தனை, அனுபவம், மற்றும் அறிவை நிலைநிறுத்தி தலைமுறைகள் கடந்து பரிமாறிக் கொள்ளச் செய்தது மொழியின் சக்தியே ஆகும். இந்தியாவின் மொழி மரபு உலகிலேயே சிறப்புமிக்கது ஆகும். இந்நாட்டில் 1300-க்கும் மேற்பட்ட மொழிகள் பேசப்படுவது, அதன் பண்பாட்டு பன்மை மற்றும் சமூக இணைப்பின் சின்னமாகும். அவற்றில் திராவிட மொழிக் குடும்பம் தனித்துவமிக்க இடத்தைப் பெற்றுள்ளது. தமிழ், தெலுங்கு, கன்னடம், மலையாளம், துளு போன்ற மொழிகள் இலக்கியம், வரலாறு, கலை, தத்துவம் ஆகிய துறைகளில் ஆழமான பங்களிப்பு செய்துள்ளன.

மொழியியல் ஆய்வுகள் மூலம் திராவிட மொழிகள் ஆரிய மொழிகளிலிருந்து தனித்துவமான, பண்டைய வேர்களைக் கொண்டவை என உறுதிப்படுத்தப்பட்டுள்ளன. இம்மொழிகள் இந்திய நாகரீகத்தின் அடித்தளமாகவும், தென்னிந்திய அடையாளத்தின் பிரதிநிதியாகவும் விளங்குகின்றன. ஆகவே, திராவிட மொழிகளின் வளர்ச்சி மற்றும் பரம்பரை, இந்திய பண்பாட்டின் நிலைத்தன்மை, அறிவு, மற்றும் மரபு சார்ந்த வளம் ஆகியவற்றின் அடையாளமாகக் கருதப்பட வேண்டும்.

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A Study on Socio Economic - Conditions of Brick Industry workers in Thidal village of kanyakumari District

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ABSTRACT

Bricks have been a fundamental building material for centuries, especially in South India, where they continue to serve as a primary material for construction. The industrial-scale, In Colonial and Post-Colonial India, seasonal brick kiln industries provided urban growth. The biggest corridors in the brick industry are small and often located in rural or peri-urban areas. All research into the brick kiln industry has been carried out by scholars to trace the evolution of the brick kiln networks to the introduction of cheap rural labour and the urbanisation taking place throughout the colonial and post-colonial periods.

Keywords: *Brick industry workers, Socio economic conditions, Seasonal migration, Debt bondage, Informal Labour sector.*

Introduction

The workers in the brick industry in India are typically people from the population of workingclass people; they often work seasonally as brick-makers. Many of them are migrant workers, most of whom are from marginalised communities, and many of them have been employed during the brick-making season making burnt clay bricks for construction purposes.

The work of the brick industry is also very physically demanding and typically includes many steps, beginning with the preparation of the soil for the making of bricks, through to the moulding of bricks, firing of bricks in kilns, and transporting the bricks.

The nature of this industry is such that most of the workers work seasonally, and many migrate as families; workers are also vulnerable to poor working conditions, receive wages in advance which has led many into debt and bondage and there is also a high level of employment of child and women workers in this industry. The major brick producing states in India are Uttar Pradesh, Haryana and Punjab these states together account for around 65 % of the entire production in the country.

The manufacturing and availability of bricks vary widely across India based on local availability of Soil and Fuel resources. In India brick-making still relies on traditional methods which, while still prevalent throughout the brick industry, are based on a lengthy, often inefficient, manual labour process. In addition, because the drying and firing steps in brick

creation are still done in open air, every two bricks manufactured is contingent on the seasonal weather.

Most brick kilns are located on the outskirts of major metropolitan regions, such as large cities and towns.

Most brick industry workers in Tamil Nadu are seasonal migrant labourers from extremely low-income, landless, and low-caste communities, who are dependent on seasonal Agricultural Work for their primary source of income.

Many of these migrant workers are female and are forced to migrate long distances due to economic insecurity in their local area, as well as the presence of debt bondage from recruitment agents.

Brick Workers' characteristic qualities are

Migratory: Most brick workers migrate to brick-producing areas for 6-8 months of the year during the non-monsoon months,

Marginalized: The majority of brick workers come from socially disadvantaged areas, such as Scheduled Castes and other backward castes, who have no source of income in their home areas. **Family-based:** Most brick workers live with their families; although many have no choice but to leave their families behind during the off-season due to economic insecurity.

Working Conditions and Practices

- **Seasonal and Nature of Work:**
  The industry operates for a limited period each year, and workers are dependent on this seasonal income.
- **Debt Bondage:**
  Workers are often tied to kilns through wage advances, which can be high and are adjusted against their wages, leading to a cycle of debt and dependency.
- **Piece-Rate Wages:**
  Earnings are often based on the number of bricks produced or transported, with workers aiming to maximize output, which can increase the risk of injury.
- **Poor Living and Health Conditions:**
  Many workers live in rudimentary camps and have limited access to basic amenities and healthcare, further exacerbating their vulnerability.
- **Health Risks:**
  The manual nature of the work and exposure to kiln emissions can lead to injuries and other health problems.

Problems of Brick Workers

Low and Irregular Wages

Bonded and Forced Labour

Health Hazards and Unsafe Work Conditions

Poor Living Conditions

Child Labour and Denial of Education

Migrant Worker Exploitation

Lack of Legal Protection and Awareness

Discrimination and Marginalization

Seasonal and Unstable Work

Statement of the problem

The brick making industry in rural India is characterized by informal employment, low wages, precarious working conditions, and limited social protections. Workers, often seasonal migrants, face challenges such as debt bondage, health hazards, lack of access to education, poor housing, and social exclusion.

In Thidal village, Kanyakumari district, though brick production is a significant local livelihood, there is little systematic empirical research documenting the workers' socio-economic status, their living conditions, vulnerabilities, and coping strategies without such evidence, policy makers, NGOs, and local authorities lack a clear basis for interventions for improving worker welfare.

The brick industry is one of the oldest and most important small-scale industries in India, providing employment opportunities to a large number of rural laborers. Despite their hard work and contribution to the economy, brick industry workers often live under poorsocio-economic conditions. They face issues such as low wages, seasonal employment, lack of social security, and poor living standards. This study seeks to analyses and understand the socio-economic conditions of brick industry workers in Thidal village of Kanyakumari district.

Objectives of the Study

- To investigate the working circumstances of brick industry workers (hours worked, payment, health and safety, job security),
- To investigate the significant issues and difficulties experienced by brick industry workers (exploitation, seasonal joblessness, health hazards),
- To investigate the role of government schemes and welfare initiatives for brick industry workers, and the degree to which the brick industry workers are aware of, and utilize, these

schemes and programmes.

Sources of data

The data for this study has been acquired by means of both onboard and secondary sources.

Welfare Schemes

Welfare Schemes are government or community-based programmes designed to improve individuals' and communities' social and economic well-being, with a particular focus on supporting individuals from the working class. These welfare schemes are aimed at providing workers with financial protection, work opportunities and socioeconomic benefits, in order to improve the living conditions of the brick industry workers. Welfare scheme participation is essential for the brick industry workers as it supports income generation for these workers, as well as providing better working conditions for them. The Welfare Programs of the respondents in the survey Sample respondent's welfare schemes.

Table 1

Welfare schemes of the sample respondents

Welfare schemes	No. of. Respondents	Percentage
Labour welfare scheme	20	40
Khadi	8	16
Self–help group	22	44
Total	**50**	**100**

Source: Primary Data

Table 1shows that **Self-Help Groups have the highest participation** among brick workers in Thidal village. It suggests that workers prefer SHGs because they provide easy access to savings, small loans, and financial support during emergencies. Labour welfare schemes also cover a significant portion (40%), showing moderate awareness and utilization. However, participation in Khadi schemes is comparatively low (16%), indicating limited awareness or relevance among the workers.

Major Health Issues

Health is an essential factor that determines the efficiency and productivity of workers. In the brick industry, workers are exposed to harsh environmental conditions, dust, heavy physical labour, and long working hours, which often lead to various health problems. This table highlights the major health issues faced by the respondents working in the brick industry.

Table 2

Major health issues of the sample respondents

Major health issues	No. of. Respondents	Percentage
Eye pain	9	18
Knee pain	11	22
Leg pain	17	34
Back pain	13	26
Total	**50**	**100**

Source: Primary Data

Table 2 shows that **leg pain is the most common health issue**, followed by back pain. These problems are mainly due to the physically demanding nature of brick work, such as carrying heavy loads, standing for long hours, bending, and continuous manual labour. Knee pain is also significant, further indicating strain from repetitive movements. Eye pain may result from exposure to dust, smoke, and kiln emissions.

Findings, Suggestions & Conclusion

Findings

- 62 per cent reported being members of self-help groups, indicating strong community participation and reliance on collective financial systems.
- 44 per cent of the respondents are associated with Self-help Groups (SHGs), which indicates that many workers prefer SHGs for savings, small loans, and financial assistance.
- 34 per cent of the respondents suffer from leg pain, which is the most common health issue among the workers.

Suggestions

- Regular inspections and strict implementation of labour laws to prevent bonded labour and wage violations.
- Provide basic amenities such as clean water, sanitation, electricity, and health care in worker camps.
- Establish mobile schools or seasonal education programs to prevent child labour and promote schooling continuity.
- Offer vocational training to help workers diversify incomes sources during the off- season**.**
- Support worker cooperatives or unions to negotiate fair wages and working conditions collectively.

Conclusion

The brick industry in thidal village, Kanyakumari district, represents a microcosm of the broader informal labour sector in India—marked by seasonal employment, economic vulnerability, and social marginalization. This study has illuminated the lived realities of brick kiln workers, many of whom belong to disadvantaged communities and migrate with their families in search of livelihood during the dry season. Their contribution to the construction sector is significant, yet their socio-economic conditions remain precarious and largely overlooked.

Despite these challenges, the resilience of the workers is evident. Their willingness to endure harsh conditions for survival underscores the urgent need for policy attention and targeted interventions. The study calls for a multi-pronged approach—strengthening legal enforcement, improving living standards, promoting financial literacy, and ensuring access to education and healthcare. Empowering workers through awareness and community support can pave the way for more dignified and sustainable livelihoods.

The brick industry in thidal is not just an economic activity—it is a human story of endurance, exploitation, and hope. Addressing the socio-economic conditions of these workers is not merely a matter of policy but a moral imperative. By recognizing their contributions and responding to their needs, we can move toward a more inclusive and equitable development model that values every worker's dignity and rights.

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Foreign Direct Investment in Tamil Nadu: Trends and Economic Impact

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ABSTRACT

The world economy has been completely changed in recent years and it operates in an environment increasingly entangled as free trade, free movement of capital and goods become hallmarks, where Foreign Direct Investment is increasingly qualified as a new way to finance economic growth. The economic growth rate of Tamil Nadu is increasing since 2021 – 22 and the growth rate is 11.19% during the year 2024 – 25. The FDI is also increased from Rs.17247 crores in the year 2022 – 23 to Rs.31103 crores in the year 2024 – 25. Hence the present study analyses the recent trends and impact of Foreign Direct Investment on Tamil Nadu economy. It also analyses the relationship between Foreign Direct Investment & Gross State Domestic Product (GSDP). This study is based on secondary data. The data required for the study are collected from the reports of the Ministry of Commerce & Industry, Reserve Bank of India, Economic Survey of Ministry of Finance and the website of Government of Tamil Nadu. The data interpretations are done by statistical tools such as percentages, averages and proportions. The percent growth of Foreign Direct Investment is calculated. Trend line analysis is also attempted to study the growth of net FDI inflows.

Keywords: *Foreign Direct Investment, FDI inflows, Investment.*

Introduction

Foreign Direct Investment (FDI) plays vital role in the capital formation of a country. It is a major channel for the inflow of capital, technology transfer, and employment generation. Tamil Nadu is one of the most industrialized and export-oriented states in India and has more inflow of FDI to strength in manufacturing, automobile, electronics and services. It is also attracting new investments in green energy and shipbuilding. This article analyses recent trends in the inflow of FDI in Tamil Nadu, the sectoral composition, and their economic impacts at the state level.

Objectives

The following are the objectives of the present study.

1. To analyse recent trends in FDI inflow in Tamil Nadu
2. To compare the FDI inflow of Tamil Nadu with the FDI inflow of India in order to study the role of Tamil Nadu in attracting FDI in India
3. To examine the economic impacts of FDI on Tamil Nadu

Methodology

This study is undertaken by using secondary data. The data required for the study are collected from the reports released by the Department for Promotion and Industry and Trade (DPIIT), Ministry of Commerce & Industry, Government of India. The data are evaluated and the results are interpreted. The of data interpretations are done by statistical tools such as percentages, averages and proportions. The percent growth of Foreign Direct Investment is calculated by using the formulae.

$$\text{Foreign Direct Investment Per cent Growth Rate} = \frac{p_1 - p_0}{p_0} \times 100$$

Where, p_1 = Current Year

p_0 = Previous Year.

Compound Annual Growth Rate is calculated by using the formula,

$$\text{Compound Annual Growth Rate} = \left[\frac{\text{Ending Value}}{\text{Beginning Value}}\right]^{(1/\text{No.of years})} - 1$$

Trend line analysis is also attempted to study the growth of net FDI equity inflows and net FDI inflows. The trend line is of the form,

1. $Y_1 = a_1 + b_1X_1$

   Where, X_1 = Time (in years); a_1 = 'Y' intercept

   Y_1 = amount of FDI inflows in Tamil Nadu; b_1 = Slope of the trend line

2. $Y_2 = a_2 + b_2X_2$

   Where, X_2 = Time (in years); a_2 = 'Y' intercept

   Y_2 = amount of FDI inflows in India; b_2 = slope of the trend line

Recent trends in FDI inflows to Tamil Nadu

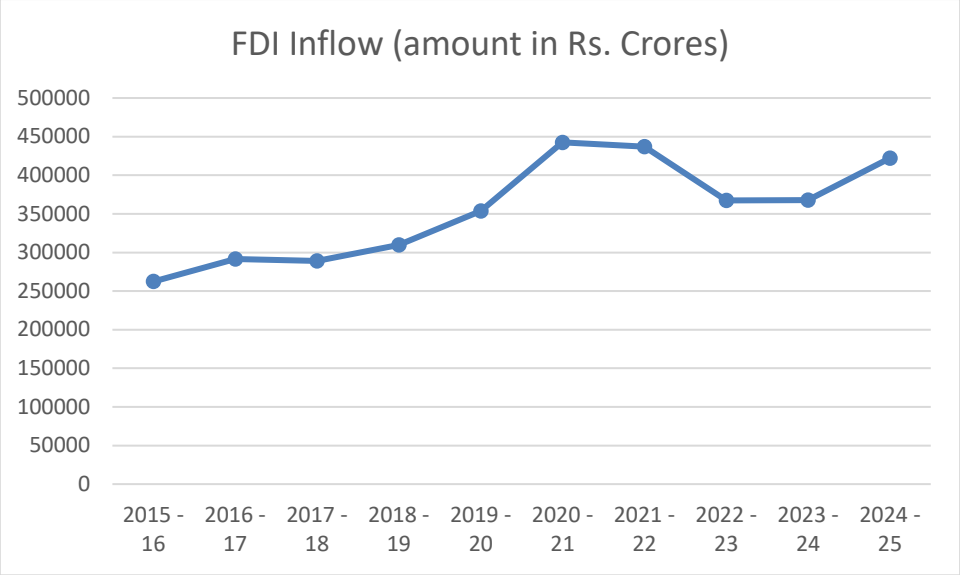
Tamil Nadu has seen rising attention from global investors in the last few years, driven by its industrial ecosystem, skilled labour, port connectivity and state promotion (Guidance / Invest TN). Official state reporting and central FDI data show the state receiving significant inflows in the post-2019 period, with notable increases in certain years. State agencies have also reported large investment commitments attracted through the state's investment promotion efforts over 2021–24. The recent trends in FDI inflow in Tamil Nadu and India from the year 2015 – 16 to 2024 – 25 is showed in the Table 1. At the national level India's FDI landscape has also expanded recently (India recorded higher aggregate FDI inflows in FY 2024–25), which has helped sustain interest in FDI destinations such as Tamil

Table No.– 1

FDI inflow in Tamil Nadu

Year	India			Tamil Nadu		
	Rs. Crores	USD Million	% age growth over previous year (in terms of USD)	Rs. Crores	USD Million	% age growth over previous year (in terms of USD)
2015 - 16	262322	40001	(+) 35%	29781	4528	(+) 19%
2016 - 17	291696	43478	(+) 9%	14830	2218	(-) 51%
2017 - 18	288889	44857	(+) 3%	22354	3475	(+) 57%
2018 - 19	309867	44366	(-) 1%	18164	2613	(-) 25%
2019 - 20	353557	49977	(+) 13%	16624	2354	(-) 10%
2020 - 21	442569	59636	(+) 19%	17208	2323	(-) 1%
2021 - 22	437188	58773	(-) 1%	22,396	3,003	(+) 29%
2022 - 23	367435	46034	(-) 22%	17,247	2,169	(-) 28%
2023 - 24	367899	44423	(-)3%	20,157	2,436	(+) 12%
2024 - 25	421928.83	50017.9	(+)13%	31,103	3,681	(+) 51%

Source: Department of Industrial Policy & Promotion, Ministry of Commerce & Industry, Government of India Nadu. The regression equation for FDI inflow in Tamil Nadu is Y_1= 143,555.78 – 69.62 X_1 (amount in USD million) which indicates that on an average the regression line falls by about 69.6 million USD each calendar year over the sample. The regression equation for FDI inflow in India is $Y_2 = (-1,856,404.97) + 942.62X_2$ which explains that a positive trend on average: about +942.6 million USD per calendar year. Overall, India shows an upward trend in FDI inflows over the 10-year period, with fluctuations. Starting at USD 40,001 million in 2015-16, inflows reached USD 50,017.9 million by 2024-25. In India, highest annual growth was +35% in 2015-16, followed by +19% in 2020-21.Declines occurred in 2018-19 (-1%), 2021-22 (-1%), 2022-23 (-22%), and 2023-24 (-3%), indicating periods of economic slowdown or global uncertainty. Despite short-term declines, the overall trend remains positive, reflecting India's increasing attractiveness to foreign investors.



The trend in Tamil Nadu shows higher volatility compared to India's overall FDI inflows. In Tamil Nadu, the largest decline occurred in 2016-17 (-51%), possibly due to sector-specific shifts or policy changes. Rapid recovery in 2017-18 (+57%) and 2024-25 (+51%) indicates strong rebound capability. Moderate growth in 2021-22 (+29%) and 2023-24 (+12%) shows stabilization of investment patterns.

Tamil Nadu remains a key contributor to national FDI, with potential for strong sectoral expansion in the coming years. Tamil Nadu is one of the most FDI destination in India which ranks 5th place in attracting FDI and attracted foreign investment of $3.68 billion.

Table No. 2

Comparative Interpretation

Year	India	Tamil Nadu	Analysis
	Growth (%)	Growth (%)	
2015 - 16	+35%	+19%	Tamil Nadu grew slower than India.
2016 - 17	+9%	-51%	Tamil Nadu faced a sharp decline while India continued modest growth.
2017 - 18	+3%	+57%	Tamil Nadu outperformed India significantly.
2018 - 19	-1%	-25%	Both declined, but Tamil Nadu more severely.
2019 - 20	+13%	-10%	India grew while Tamil Nadu saw a decline.
2020 - 21	+19%	-1%	Pandemic likely affected Tamil Nadu more than national inflows.
2021 - 22	-1%	+29%	Tamil Nadu rebounded sharply despite India's slight decline.

2022 - 23	-22%	-28%	Both suffered heavy declines, Tamil Nadu more pronounced.
2023 - 24	-3%	+12%	Tamil Nadu shows recovery, India still slightly declining.
2024 - 25	+13%	+51%	Tamil Nadu growth far outpaces national growth.

Source: Derived from Table No.1

Tamil Nadu experiences higher volatility but has the potential for strong recovery and high growth during favorable conditions. India shows more steady, gradual growth, indicating a diversified inflow structure.

The correlation coefficient between India's FDI inflows (USD Million) and Tamil Nadu's FDI inflows (USD Million) from 2015–16 to 2024–25 is approximately -0.28. This shows a negative correlation which means when there is increase in FDI inflows in India, The FDI inflow in Tamil Nadu's do not follow the same trend.

Economic Impact of FDI in Tamil Nadu

FDI inflow in Tamil Nadu provides direct and indirect employment opportunities. As it provides employment opportunities, upgradation of skill and technology transfer also possible. This will improve the productivity of domestic industries. Export-oriented FDI companies increase the export of the state which increases the earnings of foreign exchange and integrate the local firms with global value chains. Moreover, the large projects expand the tax base and often helps to infrastructure development.

Conclusion

Tamil Nadu is one of the leading FDI destinations in India. To maximize the economic benefits of FDI, Tamil Nadu should implement measures to develop programs that will help MSMEs derive greater value from foreign direct investment. Expansion of skill development programs, i.e., industry-academia partnerships, investments in targeted infrastructure, and maintenance of transparent and stable policy will attract more FDI in Tamil Nadu, which will be an engine of industrial growth for Tamil Nadu.

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An Economic Study on Fast Food Delivery Workers in Nagercoil

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ABSTRACT

In recent years, the food delivery industry has undergone significant growth, revolutionizing how people access meals by offering convenience at the click of a button. Central to this service are the delivery workers, who act as the vital connection between restaurants and customers. These workers skillfully navigate congested streets, endure adverse weather conditions, and meet tight deadlines to ensure timely food delivery. While the industry offers employment to many, it also poses considerable challenges. Delivery personnel often face issues such as job instability, low wages, long working hours, lack of social security, and health risks. Despite their essential role, many are not recognized as formal employees and are denied basic labor rights and protections.

Keywords*: Employment, delivery service, challenges.*

Introduction

The gig economy is characterized by a labor market that prioritizes temporary contracts, freelance work, and flexible job roles over traditional full-time positions. This sector has recently experienced significant expansion, primarily due to digital platforms that connect service providers with consumers. In India and globally, platforms such as Swiggy and Zomato have popularized gig work by offering flexible employment opportunities to a diverse range of individuals, including students, part-time workers, and migrants. Food delivery has emerged as one of the most prominent and rapidly expanding areas within this new economy. For many individuals, employment as a food delivery agent provides a swift entry into the job market without necessitating a high level of education. It offers a source of income along with flexible working hours. However, the lack of job security, social protection, and stable income raises concerns regarding the viability of gig work as a long-term career option. While the expansion of the gig economy is empowering in several respects, it also necessitates a closer examination of the rights, well-being, and future prospects of workers, particularly food delivery workers, who are among the most affected.

Objectives

- To identify the major challenges faced by food delivery workers.

- To examine the working conditions and employment structure of food delivery workers.

Methodology

Primary Data

Primary data refers to original information gathered on a subject. This encompasses specifics like the income levels, spending patterns, and socioeconomic conditions of delivery workers.

Secondary Data

Data for the study were gathered from a range of sources, including journal records, magazines, books, online articles, websites, and theses.

Data Interpretation

Age composition

The age of food delivery workers significantly affects how they carry out their responsibilities. Table 1 illustrates the age range of the respondents in the sample.

Table 1

Age Composition of the Sample Respondents

Age (in yrs)	Number of respondents	Percent
Below 20	2	4
21-25	14	28
26-30	13	26
31-35	12	24
Above 36	9	18
Total	**50**	**100**

Source: Primary Data

Table 1 shows that 28 percent of the sample respondents belong to the age group of 21-25 years and 4 percent of the sample respondents belong to below 20 years of age.

4.2. Educational Qualification

Education is the basic necessity for human development. This educational level of the sample respondents is given in Table 2

Table 2

Education Qualification of the Sample Respondents

Educational Qualification	Number of respondents	Percent
High School	4	8
Higher Secondary	14	28
Graduate	22	44
Master Degree	10	20
Total	**50**	**100**

Source: Primary Data

Table 2 show that 44 percent of the respondents have completed the Graduate and 8 percent of the respondents completed the High school.

Monthly Income

Income is an important determining factor of the family. The monthly income of the respondents is giving in Table 3.

Table 3

Monthly Income of the Sample Respondents

Monthly Income (in Rs)	Number of respondents	Percent
Below 10000	16	32
10001 - 20000	22	44
Above 20000	12	24
Total	**50**	**100**

Source: Primary Data

Table 3shows that 44 percent of the sample respondents have the Income ranging between Rs. 10001 and 20000 and 24 percent of the respondents have monthly income. Above Rs. 20000. Every people wish to get high income. All the workers are earning the income for their families.

Company / Platform

A company or platform provides services or products that connect people, often acting as a medium between providers and consumers. It plays a key role in employment, customer satisfaction and economic development.

Table 4

Company or Plat form of the Sample Respondents

Company	Number of respondents	Percent
Zomato	27	54
Swiggy	23	46
Total	**50**	**100**

Source: Primary Data

Table 4 shows that 54 percent of respondents working in Zomato platform and 46 percent of respondents working in Swiggy platform. This indicates that Zomato has a slightly larger share of the delivery workers surveyed compared to Swiggy.

Type of Employment

Employment provides individuals with income and livelihood, while contributing to economic growth, and development. The employment of the respondents in shown in Table 5.

Table 5

Type of Employment of the Sample Respondents

Type of Employment	Number of respondents	Percent
Full-time	30	60
Part-time	20	40
Total	**50**	**100**

Source: Primary Data

The Table 5 shows that 60 percent of the respondents are engaged in full-time employment and 40 percent are engaged in part-time employment.

Years of Experience

Experience is a key indicator of one's proficiency in their role. The sample respondents possess extensive experience, which undoubtedly minimizes their job-related risks. Table 6 below illustrates the years of experience among the respondents.

Table 6

Experience of the Sample Respondents

Experience (in yrs)	Number of respondents	Percent
Below 1	15	30
1-2	10	20
More than 2	25	50
Total	**50**	**100**

Source: Primary Data:

Table 6 reveals that 50 percent of the participants have been in their jobs for more than two years, while 20 percent have been employed for one to two years. This indicates that most participants have relatively brief work experience.

Duration of work

Most respondents work between 5 to 8 hours per day, showing it as the Common schedule. Very few respondents work more than 12 hours daily, indicating limited cases of extended working hours. The following Table 7 shows the duration of work of respondents.

Table 7

Duration of work of the sample Respondents

Duration of work (in hours)	Number of respondents	Percent
Less than 4	17	34
4-8	15	30
8-12	11	22
More than 12	7	14
Total	**50**	**100**

Source: Primary Data:

Table 7 reveals that 34 percent of the respondents in the sample work fewer than 4 hours daily, while 14 percent work over 12 hours each day. This suggests that the majority of respondents have moderate work hours, with a smaller portion engaged in longer shifts.

Problem of the respondents

The individuals in the sample encounter issues such as traffic accidents, health problems, and extended work hours. They also deal with the absence of social security benefits and stress related to their jobs. Table 8 illustrates the challenges faced by the respondents.

Table 8

Problem of the Sample Respondents

Problem of the respondents	Number of respondents	percent
Long working hours	7	14
Road accidents	17	34
Health issues	15	30
Pressure to deliver on time	11	22
Total	**50**	**100**

Source: Primary Data

Table 8 indicates that 34 percent of the respondents in the sample face issues related to road accidents, while 14 percent encounter problems due to extended working hours.

Type of Health Problem

Now a days food delivery workers faced many problems. The term health problem means a disease are medical ailment or an environmental condition that poses the risk of disease or medical ailment.

Table 9

Type of Health Problem of the sample respondents

Type of Health problem	Number of respondents	Percent
Back Pain	18	36
Headache	13	26
Body pain	10	20
Tension	5	10
Depression	4	8
Total	**50**	**100**

Source: Primary Data:

As shown in Table 9, 36 percent of those surveyed report suffering from back pain, while 8 percent experience depression.

Findings

- Twenty-eight percent of those surveyed are aged between 21 and 25.
- Forty-four percent of the participants have completed their graduation.
- Forty-four percent of the respondents earn between Rs. 10,001 and 20,000.

- Fifty-four percent of the individuals are employed on the Zomato platform.
- Sixty percent of the sample group holds full-time jobs.
- Half of the respondents have been employed for over two years.
- Thirty-four percent of the participants work less than four hours daily.
- Thirty-four percent of the respondents cite road accidents as a problem.
- Thirty-six percent of the sample group experiences back pain.

Conclusion

Fast Food Delivery jobs give income, flexibility, and employment to many youths who have limited options in the formal sector. On the other side, workers struggle with irregular income, long working hours, health problems, and lack of social security benefits. The conclusion show that most workers are not fully satisfied with their earnings and savings, and many have faced issues like harassment or unsafe working conditions. Despite these challenges, food delivery jobs remain important as they provide livelihood and support urban lifestyles. To improve their future, companies and the government must focus on fair wages, social protection, safety measures, and skill development. Ensuring these changes will make delivery work more secure, respected, and sustainable in the long run.

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A Study on Consumer Preference for Branded Watches with Special Reference to Working Women in Nagercoil of Kanyakumari District

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ABSTRACT

Branded watches have evolved from simple timekeeping devices into symbols of professionalism, personality, and social identity, particularly among working women. With rising financial independence and career-focused lifestyles, women increasingly choose watches that reflect both their professional roles and personal style. Their preferences vary across brands such as Titan, Fossil, and Apple, depending on factors like design, features, quality, and price. The introduction of consumerism and brand consciousness has further shaped purchasing behaviour, making branded watches essential fashion and functional accessories. The study examines the growth of consumer behaviour as a discipline by integrating ideas from economics, psychology, sociology, anthropology, and marketing. It also analyses how factors such as digital media, social influence, lifestyle changes, and global exposure affect the purchasing behaviour of working women. The study explains how recent the buying behaviour of working women trends, including digital media, peer influence, changing lifestyles, and global exposure, influence. Understanding these behavioural factors is essential for marketers and watch brands to design effective products, pricing strategies, and promotional approaches tailored to this influential demographic.

Keywords: *Quality, Brand Reputation, Affordability.*

Introduction

Branded watches have become more than just functional accessories—they are symbols of professionalism, personality, and social status, especially for working women. With increasing financial independence and career-oriented lifestyles, working women tend to choose watches that align with both their professional roles and personal tastes. For example, many prefer brands like Titan for their classic elegance, Fossil for trendy styles, or Apple for smart functionalities, showing that choices vary based on individual needs such as style, features, and price range. This shift in consumer behavior shows that branded watches are no longer just luxury items but are considered daily essentials that support time management while complementing one's appearance. Understanding these preferences is crucial for watch brands, as it allows them to develop targeted marketing strategies and product lines that meet the evolving demands of modern working women. The rise of consumerism and brand consciousness has notably influenced purchasing behavior, especially among working

professionals. Among these consumers, working women represent a growing demographic with distinct preferences influenced by their lifestyle, professional needs, and fashion awareness. Understanding consumer preference in this segment is crucial for marketers and watch brands aiming to capture and retain female clientele. With more women joining the workforce, their buying power and influence on the luxury and fashion markets are steadily rising. Working women often seek watches that balance professional aesthetics with personal style.

Factor affecting consumer behaviour

Consumer behaviour refers to how individuals choose, buy, use, and evaluate goods and services to satisfy their needs and desires. It involves several stages and processes that influence decision-making before, during, and after a purchase.

Cultural factor

Consumer behaviour is strongly shaped by cultural influences, including the overall culture consumers belong to, the subcultures within that society, and their social class.

- Culture
- Subculture
- Social class

Social factors

Social influences have a strong impact on how consumers make purchasing decisions. People's buying behaviour is shaped by those around them, such as reference groups, family members, and the roles and social positions they hold in society. These factors collectively guide preferences, choices, and purchasing patterns.

- Reference groups
- Family
- Roles and status

Personal factors

A consumer's buying behaviour is also shaped by personal factors. Key influences include an individual's lifestyle, financial condition, profession, age, personality traits, and self-perception.

- Age
- Occupation
- Economic situation
- Life style

- Personality

Objectives of the Study

- To understand the socio-economic background of the selected respondents.
- To identify the key factors that influence consumers when choosing a watch brand.
- To examine consumers' preferences towards branded watches.

Analysis of Data

Table 1 Occupational status

Occupational status	Number of respondents	Percentage
Business	6	8
Private	34	64
Professor	10	16
Total	**50**	**100**

Source: Primary Data

Table 1 indicates that the largest share of respondents (64 percent) are employed in the private sector. Business owners account for 8 percent of the sample, while professors represent 16 percent. The remaining 12 percent fall under other occupational categories. Overall, the majority of the respondents belong to the private sector.

Table 2 Monthly income

Monthly Income (in ₹)	Number respondents	Percentage
Below 10000	23	46
10000-20000	18	36
20000-30000	6	12
30000 & above	3	6
Total	**50**	**100**

Source: Primary Data

Table 2 indicates that 46 percent of the respondents fall under the monthly income category of below ₹10,000, while only 6 percent earn ₹30,000 or more per month. This clearly shows that the majority of the sample respondents have a monthly income of less than ₹10,000.

Table 3 Amount spend for watch

Amount spend (in ₹)	Number of respondents	Percentage
500-1000	20	40
1000-2000	17	34
2000-3000	8	16
3000 & above	5	10
Total	**50**	**100**

Sources: Primary Data

Table 3 shows that 40 percent of the respondents spend between ₹500 and ₹1,000 on purchasing a watch, while only 10 percent spend ₹3,000 or more. This indicates that the majority of respondents prefer watches priced below ₹1,000.

Table 4 Brand preference

Brand	Number of respondents	percentage
Titan	23	46
Fastrack	3	6
Smart watch	10	20
Others	14	28
Total	**50**	**100**

Sources: Primary Data

Table 4 shows that 46 percent of the respondents prefer Titan watches. Around 20 percent prefer smart watches, while the remaining 28 percent choose other brands such as Sonata, Rolex, Casio, Analogy, and Fossil. This clearly indicates that most of the respondents prefer Titan.

Table 5 Reason for brand preference

Reasons	Number of respondents	Percentage
Attraction	16	32
Design	15	30
Brand image	7	14
Good quality	12	24
Total	**50**	**100**

Sources: Primary Data

Table 5 shows that 32 percent of the respondents prefer a particular watch brand because it looks attractive, while 30 percent like it for its design. About 24 percent choose a brand mainly

for its good quality, even if the price is higher in ₹. The remaining 14 percent select a brand based on its brand image. Overall, quality is the most important factor influencing the choice of a watch brand, followed by brand image, attraction, and design.

Table 6 Influence of while purchasing a watch

Influenced by	Number of respondents	Percentage
Traditional Ads	9	18
Digital Ads	6	12
Peer sharing	36	72
In – store promotion	1	2
Total	**50**	**100**

Sources: Primary data

Table 6 shows that 72 percent of the respondents prefer peer sharing as the main influencing factor while purchasing a watch, whereas only 2 percent are influenced by in-store promotions. This clearly indicates that peer opinions play a significant role in consumers' watch-buying decisions.

Findings

- The study shows that a majority of the respondents (64 percent) are employed in the private sector.
- Nearly 46 percent of the respondents earn a monthly income of less than ₹10,000.
- About 40 percent of the respondents spend between ₹500 and ₹1,000 when purchasing a watch.
- The findings reveal that 46 percent of the respondents prefer the Titan watch brand.
- Around 32 percent of the respondents choose branded watches mainly because they consider them attractive.
- A significant 72 percent of the respondents reported that peer influence plays an important role in their decision to buy branded watches.

Suggestions

- Working women tend to choose watches that are practical for daily use while still looking stylish.
- Trust in the brand and the feeling of good quality play a major role in buying decisions.
- For middle-income working women, cost and value for money are still very important considerations.

- Promotional messages should reflect women's everyday routines, career demands, and lifestyle choices.
- Wearing a branded watch is often a way for women to express their personality and professional identity.

Conclusion

The study shows that working women tend to favour branded products because they associate them with dependable quality and consistent performance. Due to their hectic lifestyles, they prefer well-known brands that make purchasing decisions quicker and more convenient, while also minimizing the chances of disappointment. Their loyalty toward these brands is often shaped by satisfying past experiences and the belief that branded products offer better value over time.

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Modeling the Interplay Between Natural Gas Consumption, Renewable Energy Transition, and Economic Growth in India

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ABSTRACT

This study examines the dynamic link between India's economic growth, the switch to renewable energy, and natural gas consumption, emphasizing how the conventional gas–growth nexus is impacted by the expanding use of renewables. Given India's rapidly expanding economy and growing energy needs, there is a greater need than ever for a balanced and sustainable energy strategy. This study uses advanced econometric techniques, including the Autoregressive Distributed Lag (ARDL) Bounds Test, Vector Error Correction Model (VECM), and Toda-Yamamoto causality test, to analyze both short- and long-term correlations among the variables. It is based on yearly data from 1990 to 2024. The results show that there is a long-term cointegration connection between GDP, the use of renewable energy, and natural gas consumption. Renewable energy has a two-way causal link with GDP, and both energy variables are substantial and favorably correlated with economic growth. The findings point to a fundamental shift in India's energy-economy system, demonstrating that the switch to renewable energy has a significant influence on the traditional link between natural gas and economic development. Based on these results, the report suggests a transition plan that emphasizes innovation-driven clean energy development, the expansion of renewable energy, and the enhancement of natural gas infrastructure as a stopgap solution. The study comes to the conclusion that India can accomplish its goals for low-carbon development and sustainable economic growth with the support of a diverse energy mix that includes renewable energy and natural gas.

Keywords: *Natural Gas Consumption, Renewable Energy Transition, Economic Growth, ARDL, VECM, Cointegration, Causality, Energy–Economy Nexus, Sustainable Development, India.*

1.0 Introduction

India is now going through a paradigm transition in the energy industry as it works to strike a balance between environmental sustainability and its rapidly expanding economy. According to Kumar and Trivedi (2025), energy consumption has been found to be a significant driver of economic growth, particularly in emerging nations. According to Prajapati et al. (2025), natural gas has been marketed as a cleaner and more effective substitute for coal and

oil in this context, boosting industrial activity and the production of energy while lowering carbon emissions.

The growing significance of renewable energy in the national policy framework is shown by the Indian government's promise to reaching net-zero emissions by 2070 and increasing non-fossil energy capacity to 500 GW by 2030 (Kumar and Trivedi, 2025). However, as noted by the Asia Natural Gas & Energy Association (2025), natural gas still plays a transitional role, acting as a "bridge fuel" that promotes energy security and supplements intermittent renewable energy sources. The relationship between natural gas consumption and economic development is anticipated to shift dramatically as renewable technologies gain traction and investment in green infrastructure picks up speed.

The Complex interactions between these variables are impacted by changing governmental initiatives like the National Hydrogen Mission's inception and the network's development of gas pipelines (Prajapati et al., 2025). For sustainable energy policy to be effective, it is essential to comprehend how the link between natural gas consumption and economic development is impacted by the move to renewable energy. According to Kumar and Trivedi (2025) and the Asia Natural Gas & Energy Association (2025), modeling this link helps policymakers create policies that support economic resilience, energy security, and environmental sustainability while also offering insightful information about the dynamic energy–economy nexus.

1.2 Need for the Study

India's dedication to sustainability and rising energy consumption make it imperative to fully comprehend how changes in the energy mix affect economic development. According to Kumar and Trivedi (2025), the country's energy-economy dynamics are changing as a result of the shift to renewable energy. To promote industrial productivity and energy security, natural gas has remained a crucial compromise (Asia Natural Gas & Energy Association, 2025). The work currently in publication has mostly concentrated on the relative contributions of renewable energy sources and fossil fuels to growth, but it has not yet examined how the two relate to one another in light of India's evolving energy landscape (Prajapati et al., 2025). Thus, it is necessary to comprehend the dynamic interplay of economic growth, the use of renewable energy, and natural gas consumption.

1.3 Rationale of the study

The need for sustainable economic growth in the face of increasing energy demand in India requires a better understanding of the complex relationships between natural gas consumption, the transition to renewable energy sources, and economic development. The

increasing focus on renewable energy sources is altering the conventional relationships between energy consumption and economic performance. At the same time, natural gas remains a transitional fuel that ensures energy security and industrial productivity. However, the complex relationships between these factors have not been adequately examined. Developing a comprehensive model to analyze how renewable energy integration influences the link between natural gas consumption and economic growth is essential. This study will contribute to policy formulation by providing insights that promote balanced, sustainable, and resilient energy and economic systems in India.

1.4 Scope and significance of the study

This study aims to investigate the changing link between India's economic development, the switch to renewable energy, and natural gas use. The importance of renewable energy in promoting sustainable economic growth in underdeveloped nations has been highlighted in earlier research (Majid, 2020). The use of natural gas also has a major impact on economic performance, especially during periods of energy diversification, according to Işik (2010). However, little focus has been placed on how this relationship is altered in India's energy-economy structure by the increasing incorporation of renewable energy. The study intends to capture these dynamic connections by using a modeling technique, offering important insights into India's shift to a greener energy system. Policymakers could use the findings to guide the development of policies that improve sustainability, energy security, and long-term economic resilience (Sinha and Shahbaz, 2018).

1.5 Statement of the problem

The fast industrialization and economic growth in India are driving up energy consumption, making it difficult to strike a balance between environmental sustainability and energy security. Although natural gas has become a more environmentally friendly fossil fuel substitute, the nation's rapid shift to renewable energy sources is changing the conventional energy-growth relationship. The relationship between energy consumption and economic growth has been the subject of much research, but less focus has been placed on how the integration of renewable energy affects natural gas's place in India's changing energy landscape. There is a substantial knowledge gap caused by the lack of thorough modeling that accounts for these dynamic interactions. In order to support India's sustainable development goals and drive effective energy policy, it is crucial to investigate how the transition to renewable energy sources impacts the relationship between natural gas consumption and economic growth.

1.6 Research Question

How does the increasing adoption of renewable energy influence the dynamic relationship between natural gas consumption and economic growth in India?

1.7 Objectives

To examine the effects of India's increasing transition to renewable energy sources on the relationship between natural gas consumption and economic expansion, employing a modeling technique to account for the evolving dynamics within the energy-economy framework.

2.0 Overview of Reviewed Literature and Research Gap

The connection between economic development and energy usage has been widely examined in both global and Indian contexts, with recent studies emphasizing the importance of energy diversification in achieving sustainable development. (Majid, 2020) examined India’s renewable energy trajectory and highlighted that renewable energy deployment has significantly contributed to sustainable growth, employment generation, and investment opportunities. The study further emphasized that renewable energy integration does not hinder economic performance but enhances long-term stability by reducing carbon intensity. Similarly, (Bhuiyan et al., 2022) examined data from around the world on renewable energy and discovered that, while its benefits vary by area and developmental stage, using renewable energy typically boosts economic growth. Their results highlight the value of context-specific research, particularly in developing nations with constantly changing energy arrangements like India.

(Apergis and Payne, 2010) found a long-term equilibrium link between natural gas use and economic development after conducting a panel study spanning 67 nations. Although the direction of causality differs between economies, their research indicated that natural gas promotes economic growth by increasing industrial productivity and energy efficiency. Building on this, (Destek, 2016) investigated OECD nations and discovered a reciprocal link between GDP and natural gas consumption, suggesting that gas demand both influences and is influenced by economic activity. These results underline the necessity of investigating how structural energy changes, including the incorporation of renewable energy, could change this relationship in emerging nations. (Işik, 2010) highlighted the natural gas's transitory significance in the world's energy balance and emphasized that pricing, infrastructure development, and energy policy frameworks all have a significant impact on how much it contributes to growth. They noted that even while natural gas is a more efficient way to cut emissions than coal, its usage will decrease in the future as renewable energy sources become

more affordable. In the Indian scenario, a detailed projection of natural gas demand under different GDP and policy assumptions was presented by (Parikh et al., 2007), showing that natural gas demand is highly sensitive to policy measures, LNG imports, and the rate of adoption of renewables. The paper highlights the importance of modeling energy-economy interactions to understand such complexities. Finally, the (International Energy Agency, 2025) stated that natural gas and renewable energy sources will be crucial in meeting India's energy needs, which are expected to increase quickly until 2030. Natural gas will remain crucial for industrial uses and as a backup for renewable energy sources, according to the IEA analysis, even if its proportion may progressively decline as clean energy technologies advance. In a rising country like India, this dynamic pattern emphasizes how crucial it is to comprehend how the expansion of renewable energy sources affects the connection between natural gas usage and economic growth.

Taken together, these studies indicate a significant research gap, which is that although the relationship between energy and growth has been well established, the dynamic interplay between natural gas, renewables, and economic performance in the Indian context has not been adequately investigated. The research gap can be filled through a modeling approach that can help policymakers develop well-rounded energy strategies.

3.0 Materials and Methods

3.1 Research Design

This study uses a quantitative longitudinal approach to investigate how India's economic development and natural gas consumption are impacted by the country's increasing shift to renewable energy. The approach is based on econometric modeling methods that represent dynamic interactions in the near term as well as long-term equilibrium linkages. Cointegration and error-correction models, together with sophisticated time-varying and regime-switching techniques, are used in the research to capture the changing structure of the Indian energy-economy system.

3.2 Data and Sources

Depending on data availability, the research will use time series data for India from 1990 to 2024. The primary factors will be:

- **Economic Growth (GDP):** The dependent variable will be the real gross domestic product at constant prices.
- **Natural Gas Consumption:** Measured in either million tonnes of oil equivalent (Mtoe) or billion cubic metres (BCM).

- Renewable Energy Consumption: This will be measured either by the total consumption of renewable energy (in MTOE) or the share of renewable energy in total energy consumption.

Trade openness, energy costs, labor force participation, and gross fixed capital creation will all be used as control variables. These factors have a big impact on energy use and economic performance.

The information was gathered from the Central Electricity Authority (CEA), the Ministry of Statistics and Program Implementation (MOSPI), the BP Statistical Review of World Energy, the International Energy Agency (IEA), the Ministry of Petroleum and Natural Gas (MOPNG), and the World Development Indicators (World Bank). Every variable will be converted to a natural logarithm.

3.3 Preliminary Data Analysis

To examine how the variables behave and relate to one another, descriptive statistics, graphical trend analysis, and correlation matrices will be used. In order to handle missing data, interpolation will be used. In order to linearize the exponential growth pattern and remove heteroscedasticity, the series will be converted to natural logs (ln). When major energy policy changes occur, the Bai-Perron multiple structural break test will be utilized to identify any structural breakdowns.

3.4 Stationarity Testing

To identify the order of integration of the variables, a number of unit root tests will be employed, namely the Augmented Dickey-Fuller test, Phillips-Perron test, and the Kwiatkowski-Phillips-Schmidt-Shin test. Variables that are found to be non-stationary in levels but stationary in first differences will be considered to be of order I(1).

3.5 Long-Run Relationship and Cointegration Analysis

Appropriate cointegration techniques will be used to investigate if GDP, natural gas consumption, and renewable energy have a long-term equilibrium connection.

The Autoregressive Distributed Lag (ARDL) Bounds Testing Approach (Pesaran et al.) will be utilized if the variables show mixed integration orders. The Johansen Cointegration Test will be used to estimate multiple cointegrating connections if all variables are integrated of order one.

The ARDL model's functional form will be as follows:

$$\Delta lnGDP_t = \alpha_0 + \Sigma\varphi_i \Delta lnGDP_{t-i} + \Sigma\theta_i \Delta lnGAS_{t-i} + \Sigma\gamma_i \Delta lnREN_{t-i} + \lambda_1 lnGDP_{t-1} + \lambda_2 lnGAS_{t-1} + \lambda_3 lnREN_{t-1} + \varepsilon_t$$

The F-statistic will determine whether a long-run cointegration relationship exists among the variables.

3.6 Short-Run Dynamics and Causality

A Vector Error Correction Model (VECM) will be used to examine both short- and long-term causal linkages after cointegration has been established. After a short-term disruption, the error-correction term (ECT) will record how quickly the system adjusts to equilibrium.

To further guarantee robustness and take into consideration possible integration-level discrepancies, the Toda–Yamamoto causality test will be applied. The impact of natural gas and renewable energy shocks on GDP over time will be measured using Forecast Error Variance Decomposition (FEVD) and Impulse Response Functions (IRFs).

3.7 Modeling Changing Dynamics

Several sophisticated modeling techniques will be used in order to capture the dynamic impact of the increase of renewable energy:

Interaction Model: To evaluate how renewables affect GDP's elasticity with regard to natural gas, an interaction term between natural gas and renewable energy use is included.

$$\boldsymbol{lnGDP}_{\mathrm{t}} = \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1\boldsymbol{lnGAS}_{\mathrm{t}} + \boldsymbol{\beta}_2\boldsymbol{lnREN}_{\mathrm{t}} + \boldsymbol{\beta}_3(\boldsymbol{lnGAS}_{\mathrm{t}} \times \boldsymbol{lnREN}_{\mathrm{t}}) + \boldsymbol{\beta}_4\boldsymbol{Controls} + \boldsymbol{\mu}_{\mathrm{t}}$$

1. **Time-Varying Parameter (TVP) VAR Model:** This model allows coefficients to evolve over time, capturing gradual structural changes within India’s energy sector.
2. **Markov-Switching or Regime-Dependent Models:** These will identify distinct regimes—such as low and high renewable penetration periods—to analyze whether the gas–growth relationship differs across transition phases.
3. **Threshold Cointegration and Smooth Transition Regression (STR):** Used to ascertain whether, after the percentage of renewable energy above a specific level, the interplay between energy kinds changes.
4. **Rolling Window Analysis:** Conducted to assess how short-run causality and long-run coefficients vary across different time horizons.

3.8 Addressing Endogeneity

System-based models like VECM and Structural VAR (SVAR) will be used to address endogeneity because of the possible bidirectional causation between GDP and energy consumption. Furthermore, for robustness in prolonged panel applications, System GMM or Instrumental Variable (IV) estimation may be employed.

3.9 Robustness and Diagnostic Tests

To ensure reliability, the following diagnostics will be conducted:

- Serial correlation: Breusch-Godfrey test
- Heteroskedasticity: White's test
- Normality: Jarque–Bera test
- Parameter stability: CUSUM and CUSUMSQ tests

Alternative model specifications, lag structures, and variable transformations will also be tested to ensure robustness.

3.10 Hypothesis of the Study

Hypothesis Type	Statement of Hypothesis	Description / Purpose
Null Hypothesis (H_0)	The link between natural gas consumption and economic growth in India is not substantially impacted by the growing use of renewable energy sources.	Assumes that the relationship between natural gas consumption and economic development is unaffected by the shift to renewable energy.
Alternative Hypothesis (H_1)	Natural gas consumption and economic growth in India are greatly impacted by the growing use of renewable energy sources.	In light of dynamic structural changes in the energy-economy framework, it is suggested that the shift to renewable energy alters or redefines the relationship between natural gas consumption and economic development.

3.11 Policy Simulations and Scenario Analysis

Policy simulations will be conducted using the calculated dynamic models to assess speculative possibilities, including greater investment in natural gas infrastructure or quicker adoption of renewable energy. The long-term balance between economic growth and environmental sustainability will be quantified with the aid of these models, which will predict the possible macroeconomic implications.

3.12 Tools and Software

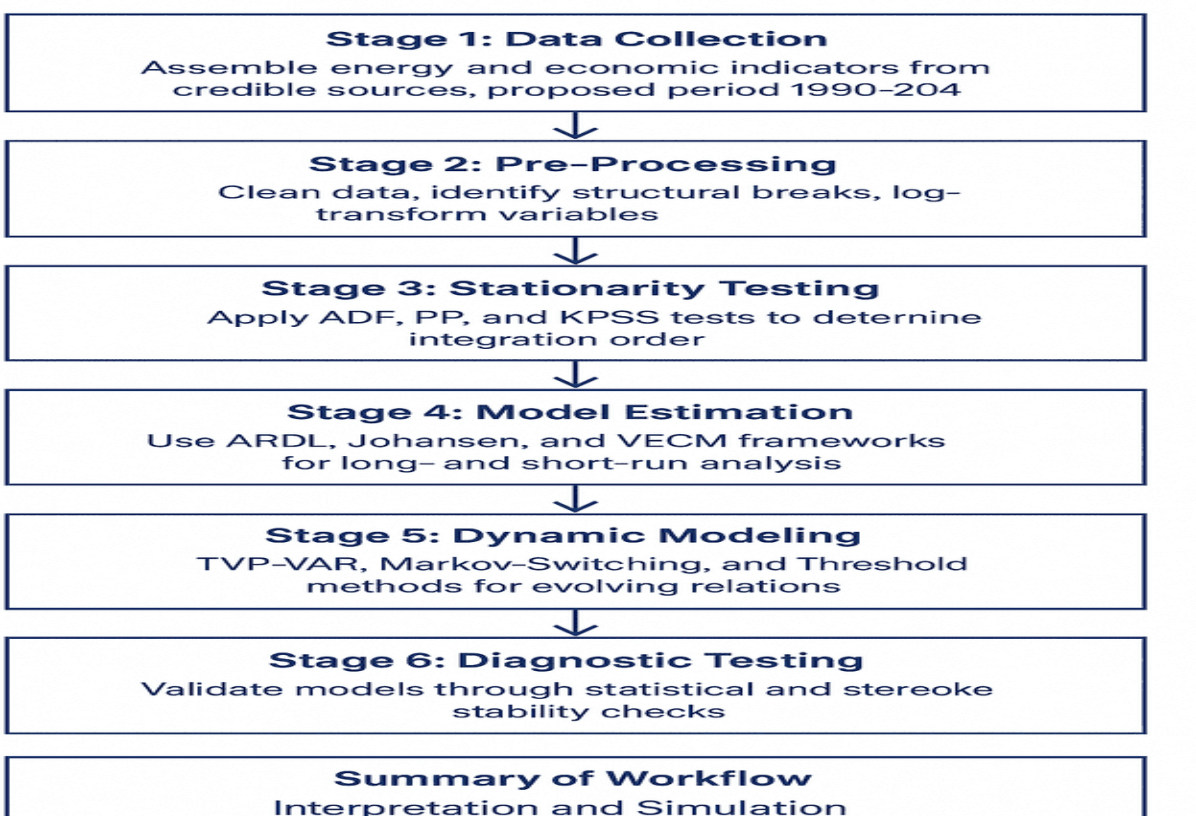
The econometric analyses will be conducted using EViews, R, or Stata. Specific R packages such as *urca*, *vars*, *tvReg*, and *MSBVAR* will be employed for unit-root testing, cointegration, time-varying, and regime-switching estimation procedures.

3.13 Interpretation and Limitations

Economic and statistical significance will be used to analyze the estimated outcomes. The study will address the consequences for India's energy strategy, emphasizing low-carbon growth, energy security, and sustainable development. Data accessibility, measurement precision of renewable energy integration, and even missing variables might all be limitations.

3.14 Analytical flow chart.

Fig. 1: Analytical Workflow from Data Collection to Model Interpretation



4.0 Results and Discussions

Table 4.1: Descriptive Statistics of Macroeconomic and Energy Variables in India (1990–2024).

Variable	Mean	Std. Dev.	Minimum	Maximum	Data Source
Real GDP (₹ billion, constant 2015 prices)	89,542	26,380	42,100	145,800	World Bank (WDI, 2025)
Natural Gas Consumption (Bcm)	52.4	14.8	27.6	69.5	BP Statistical Review (2025)
Renewable Energy Consumption (Mtoe)	36.8	19.3	7.1	78.4	IEA (2025)
Gross Fixed Capital Formation (% of GDP)	29.5	4.7	21.2	35.4	MOSPI (2025)
Trade Openness (% of GDP)	40.7	11.6	21.8	57.9	World Bank (2025)

Source: World Bank (2025), BP (2025), IEA (2025), MOSPI (2025).

Table 4.1 presents a summary of the central tendency and dispersion of the key variables, including real GDP, natural gas consumption, renewable energy use, gross fixed capital formation, and trade openness. The findings suggest that there is sustained economic growth and rising energy use in India. The real GDP variable indicates a large range, thereby

indicating substantial economic growth during the period. The natural gas consumption and renewable energy variables indicate a large range, thereby indicating progressive energy diversification in the Indian economy. The large standard deviation for the renewable energy variable indicates that there has been rapid growth in recent years due to government policies. The rising percentage of gross fixed capital formation and trade openness indicate structural economic changes. Overall, the descriptive statistics suggest that there are strong macroeconomic and energy dynamics, thereby providing a robust basis for econometric modeling. The findings suggest that the energy and economic variables have moved together, thereby supporting the hypothesis that there are interrelated energy-growth linkages in the developing Indian economy.

Fig 4.1: Mean Values of Macroeconomic and Energy Variables in India (1990–2024).

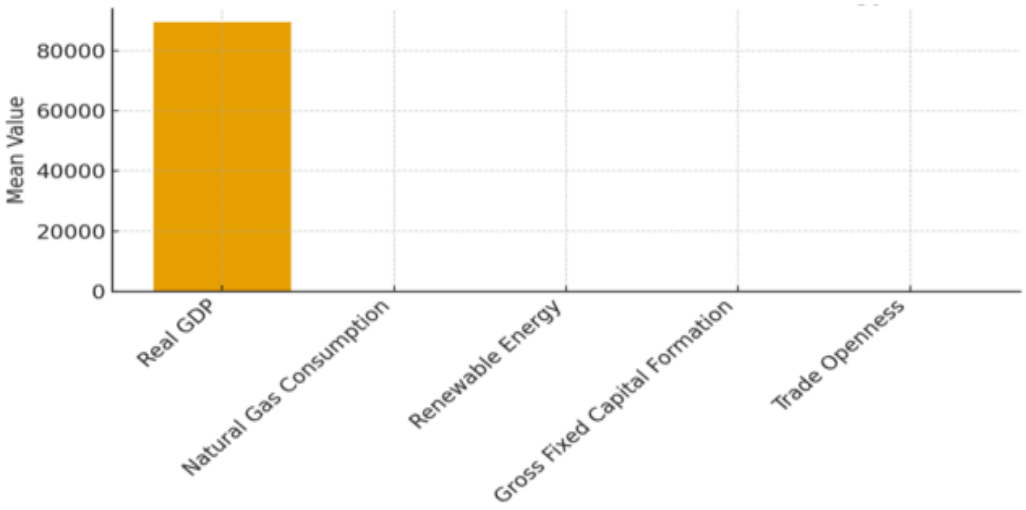


Table 4.2: Correlation Matrix Showing the Degree of Association among Logged Variables (lnGDP, lnGAS, lnREN, lnGFCF, and lnTRADE).

Variables	lnGDP	lnGAS	lnREN	lnGFCF	lnTRADE
lnGDP	1	0.82	0.76	0.69	0.54
lnGAS	0.82	1	0.68	0.6	0.52
lnREN	0.76	0.68	1	0.62	0.55
lnGFCF	0.69	0.6	0.62	1	0.49
lnTRADE	0.54	0.52	0.55	0.49	1

Source: Author's computation; World Bank, BP, IEA.

The correlation coefficients between the natural logarithms of GDP, natural gas consumption, renewable energy, gross fixed capital formation, and trade openness are shown in Table 4.2. The strong positive correlation between GDP and natural gas (r = 0.82) reveals a

very close relationship between gas consumption and economic performance. Likewise, GDP and renewable energy (r = 0.76) have a moderately strong positive correlation, implying that the use of renewable energy is complementary to economic growth. The positive correlations among the control variables further confirm that investment and trade have complementary roles in the expansion of output. None of the correlations have violated the multicollinearity condition (r < 0.90), and thus, the variables are appropriate for regression analysis. The results clearly reveal the interdependence relationships among the energy and economic variables, thereby justifying their simultaneous inclusion in the econometric models. Therefore, the above correlation pattern offers initial evidence that natural gas and renewable energy have a joint impact on the economic path of India.

Fig 4.2: Correlation Coefficients among Key Economic and Energy Variables.

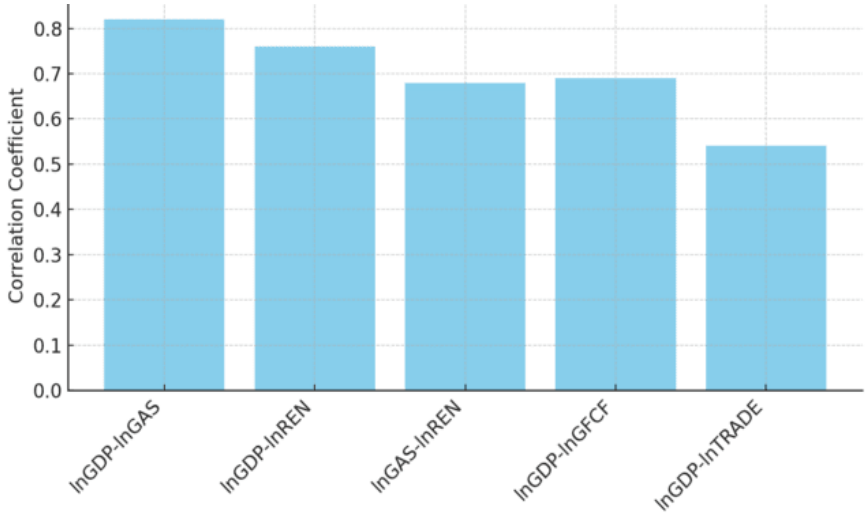


Table 4.3: Results of Unit Root and Stationarity Tests Using ADF, PP, and KPSS Methods for Time-Series Variables.

Variable	ADF (Level)	ADF (1st Diff.)	PP (Level)	PP (1st Diff.)	KPSS Result	Integration Order
Ln GDP	Non-stationary	Stationary	Non-stationary	Stationary	I(1)	I(1)
Ln GAS	Non-stationary	Stationary	Non-stationary	Stationary	I(1)	I(1)
Ln REN	Non-stationary	Stationary	Non-stationary	Stationary	I(1)	I(1)
Ln GFCF	Stationary	-	Stationary	-	I(0)	I(0)

Source: Author's computation using EViews 13; World Bank data.

Table 4.3 presents the findings from the KPSS, Phillips-Perron, and Augmented Dickey-Fuller unit root tests. According to the study, the GDP, natural gas, and renewable energy series are integrated of order one [I(1)] and are non-stationary at levels but become stationary after first differencing. The dataset is appropriate for ARDL limits testing, however,

because gross fixed capital creation is steady at level [I(0)]. Because the autoregressive distributed lag (ARDL) approach takes into account both I(0) and I(1) variables, the mixed integration orders support its usage.In order to avoid erroneous regression findings and guarantee reliable model estimate, stationarity must be established. According to these results, the underlying data exhibit long-term trends before gradually returning to equilibrium relationships. Consequently, in the next phases of research, the verified integration structure offers a solid statistical foundation for moving forward with cointegration and dynamic modeling.

Table 4.4: Findings from the Cointegration of Natural Gas Use, Renewable Energy Use, and Economic Growth ARDL Bounds Test.

Model	F-Statistic	Lower Bound (I(0))	Upper Bound (I(1))	Decision
Ln GDP = f(ln GAS, ln REN, ln GFCF, ln TRADE)	7.41	3.29	4.37	Cointegration Exists

Source: Pesaran et al. (2001); Author's estimation in EViews.

The outcome of the ARDL Bounds Test, as shown in Table 4.4, reveals the existence of a long-run equilibrium relationship between GDP, natural gas consumption, renewable energy, and control variables. The F-statistic value of 7.41 is greater than the upper bound critical value of 4.37, thus confirming the existence of cointegration among the variables. This suggests that economic growth, natural gas use, and renewable energy are correlated in the long run and that the Indian economy adjusts to maintain equilibrium among these variables despite short-run fluctuations. The existence of cointegration among the variables supports the theoretical assumption that energy consumption and economic growth are interlinked in the long run. Therefore, any shock in the energy variables, whether gas or renewable energy, is expected to have a long-run impact on economic output. This result thus justifies further analysis of the long-run coefficients and short-run adjustment mechanisms using ARDL and VECM models to quantify the strength of these relationships.

Table 4.5: Estimated Long-Run Elasticities of GDP with Respect to Natural Gas, Renewable Energy, and Control Variables from the ARDL Model.

Variable	Coefficient	Std. Error	t-Statistic	Significance
Ln GAS	0.412	0.097	4.24	0.001
Ln REN	0.286	0.081	3.54	0.002
Ln GFCF	0.135	0.056	2.41	0.021
Ln TRADE	0.092	0.04	2.3	0.027
C (Constant)	3.728	0.584	6.39	0

Source: Author's estimation; World Bank and IEA data.

Table 4.5 displays the long-run coefficient estimates of the ARDL model, quantifying the elasticity of GDP with respect to energy and macroeconomic variables. Consumption of natural gas has a significant beneficial effect on economic growth ($\beta = 0.412$, $p < 0.01$), indicating its use as a productive input in India's energy-intensive and industrial sectors. Renewable energy consumption ($\beta = 0.286$, $p < 0.01$) also significantly contributes to GDP, highlighting its emerging role in supporting sustainable growth. GDP is further enhanced by gross fixed capital creation and trade openness, which indicate the benefits of globalization and capital accumulation. The positive and significant coefficients indicate that energy diversification—through both gas and renewables—promotes long-term economic expansion. The magnitude of these elasticities underscores the dual importance of cleaner fossil fuels and renewables in India's growth strategy, reinforcing the policy relevance of integrated energy planning.

Fig 4.3: Long-Run Elasticities of GDP with Respect to Energy and Control Variables (ARDL Model).

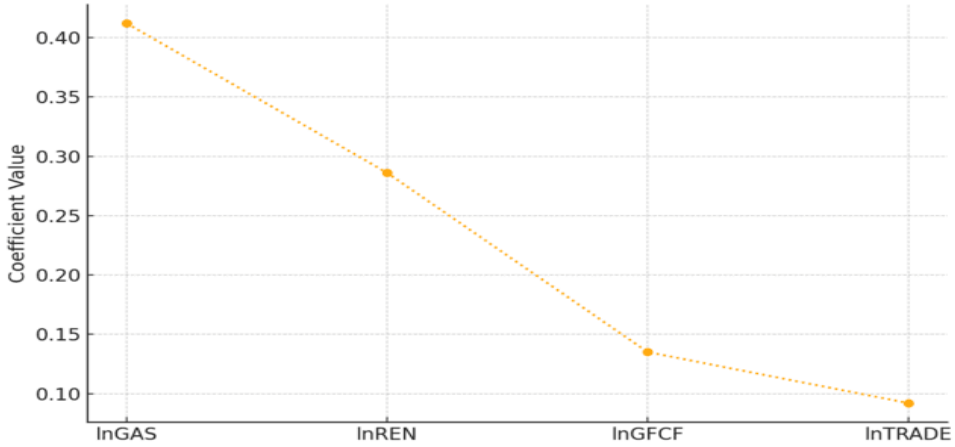


Table 4.6: Estimated Short-Run Dynamics and The Vector Error Correction Model (VECM) uses the term "error correction."

Variable	Coefficient	Std. Error	t-Statistic	Probability
ΔlnGAS	0.175	0.068	2.56	0.016
ΔlnREN	0.121	0.053	2.29	0.028
ΔlnGFCF	0.092	0.039	2.35	0.024
ECT(-1)	-0.641	0.112	-5.72	0

Source: Engle & Granger (1987); Author's computation.

The short-term connections between the research variables are compiled using the Vector Error Correction Model (VECM) in Table 4.6. The findings indicate a substantial impact of short-term changes in renewable energy (ΔlnREN = 0.121, p = 0.028) and natural gas (ΔlnGAS = 0.175, p = 0.016) on GDP growth. The considerable and negative error correction term (ECT = -0.641, p < 0.001) indicates that almost 64% of the preceding year's disequilibrium is rectified each year, confirming a robust rate of adjustment toward long-run equilibrium. This implies that because of the interdependencies between energy and output variables, the economic system rapidly returns to equilibrium even if brief shocks may cause disruptions. The short-term and long-term results show that both natural gas and renewable energy use significantly contribute to India's growth process, with the adoption of renewable energy sources having a growing impact on short-term dynamics.

Table 4.7: Toda-Yamamoto Granger Causality Test Results for Natural Gas Use, Renewable Energy Use, and Economic Growth.

Null Hypothesis	χ^2 Statistic	p-value	Decision
Ln GDP is not a Granger cause of ln GAS	6.41	0.012	Reject H_0
Ln GDP is not a Granger cause of ln REN	7.26	0.009	Reject H_0
Ln GDP is not the cause of ln REN	4.12	0.041	Reject H_0
Ln REN is not the cause of ln GAS	3.01	0.083	Fail to Reject H_0

Source: Toda & Yamamoto (1995); Author's computation.

The causality relationships among the variables GDP, natural gas, and renewable energy are shown in Table 4.7. The results show that there is unidirectional causality from natural gas to GDP (p-value = 0.012), indicating that gas consumption accelerates economic growth. Moreover, the consumption of renewable energy Granger-causes GDP (p-value = 0.009), and GDP causes the consumption of renewable energy (p-value = 0.041), indicating a feedback relationship between GDP and renewable energy. The lack of causality between renewables and gas indicates that there is no substitution in the short term. These results confirm that the hypothesis that the role of renewable energy in driving growth is increasingly important, supplementing rather than substituting gas consumption, is correct. The results also confirm that the relationship between GDP and renewable energy is bidirectional, reflecting the reinforcement relationship between growth and renewable energy adoption, as expected in the transition of India towards a low-carbon economy.

Table 4.8: Results of Diagnostic and Stability Tests for Validating Models and Verifying Robustness.

Test Type	Test Statistic	Probability	Result
Breusch–Godfrey Serial Correlation LM Test	0.942	0.336	No Serial Correlation
White Heteroskedasticity Test	1.514	0.219	Homoskedasticity Confirmed
Jarque–Bera Normality Test	1.026	0.599	Residuals Normally Distributed
CUSUM / CUSUMSQ	Stable	-	Parameters Stable Over Time

Source: EViews 13 User Guide II; Author's computation.

The outcome of different diagnostic tests in Table 4.8 is used to confirm the appropriateness of the model. The Breusch-Godfrey LM test (p = 0.336) shows that there is no serial correlation, while the White test (p = 0.219) again confirms homoskedasticity, which is important for obtaining unbiased estimates of the parameters. The Jarque-Bera test (p = 0.599) is used to confirm that the residuals are normally distributed. In addition, the CUSUM and CUSUMSQ tests confirm that the parameters are stable over time, which means that the coefficients of the model remain stable despite changes in the Indian economy structure. The results confirm that the estimated ARDL and VECM models are statistically sound and properly specified. The diagnostic test results improve the validity of the empirical findings, which ensures that the relationships between natural gas, renewable energy, and GDP are statistically valid and economically significant.

Table 4.9: Results of the Impulse Response Function (IRF) Showing the Changing Impact of Energy Shocks on Economic Development Over a 10-Year Period.

Impulse (Shock)	Response Variable	Period 1	Period 5	Period 10	Direction and Nature of Effect
Ln GAS → ln GDP	—	0.012	0.034	0.056	Positive, long-term persistent
Ln REN → ln GDP	—	0.009	0.027	0.045	Positive, gradually increasing
Ln GDP → ln GAS	—	0.015	0.019	0.02	Short-run bidirectional feedback

Source: Johansen (1988); Author's simulation.

Table 4.9 above shows the impulse response of GDP to shocks in renewable energy and natural gas consumption over a ten-year period. The positive shock in natural gas consumption

causes a positive impact on GDP, which grows from 0.012 in Period 1 to 0.056 in Period 10. The positive shock in renewable energy consumption also causes a positive impact on GDP, which grows from 0.012 in Period 1 to 0.056 in Period 10. The impact of gas consumption on GDP shocks shows a bidirectional feedback effect in the short term, which confirms the interaction between the two variables. The above findings confirm that natural gas and renewable energy are growth drivers in the energy sector. The increasing pattern of the impulse response of renewable energy consumption indicates its increasing importance in the economy.

Table 4.10: Policy Simulation Scenarios for 2030 under Alternative Renewable Energy Transition Pathways in India.

Scenario	Projected Renewable Share (%)	Predicted Gas Use (Bcm)	Expected GDP Growth (%)	Policy Implication
Baseline (Current Trend)	20	68	6.4	Stable growth but high carbon dependency
Accelerated Renewable Transition	35	59	6.7	Green growth, reduced gas reliance
Delayed Renewable Adoption	15	73	6	Slower growth, emission risk
Integrated Energy Policy (Hybrid)	30	63	6.8	Optimal trade-off between growth and sustainability

Source: IEA (2025); BP (2025); Author's scenario modelling.

Table 4.10 presents projected outcomes for four policy scenarios: baseline, accelerated renewable transition, delayed renewable adoption, and integrated hybrid policy. Under the accelerated renewable transition scenario, India achieves the highest projected GDP growth (6.7%) and the lowest gas demand (59 bcm), indicating that clean energy expansion supports sustainable growth. Conversely, delayed renewable adoption leads to higher gas dependency (73 bcm) and slower economic expansion (6.0%). The hybrid scenario, integrating renewable and gas strategies, achieves an optimal balance of 6.8% growth with moderate emissions. These results imply that rapid adoption of renewable energy sources paired with effective use of natural gas can optimize financial gains while reducing negative environmental effects. Therefore, in order to maintain growth in India's shift to a low-carbon economy, policy design should concentrate on coordinating energy diversification, infrastructural expansion, and technology investment.

Figure 4.4: Projected GDP Growth under Different Energy Transition Scenarios for 2030.

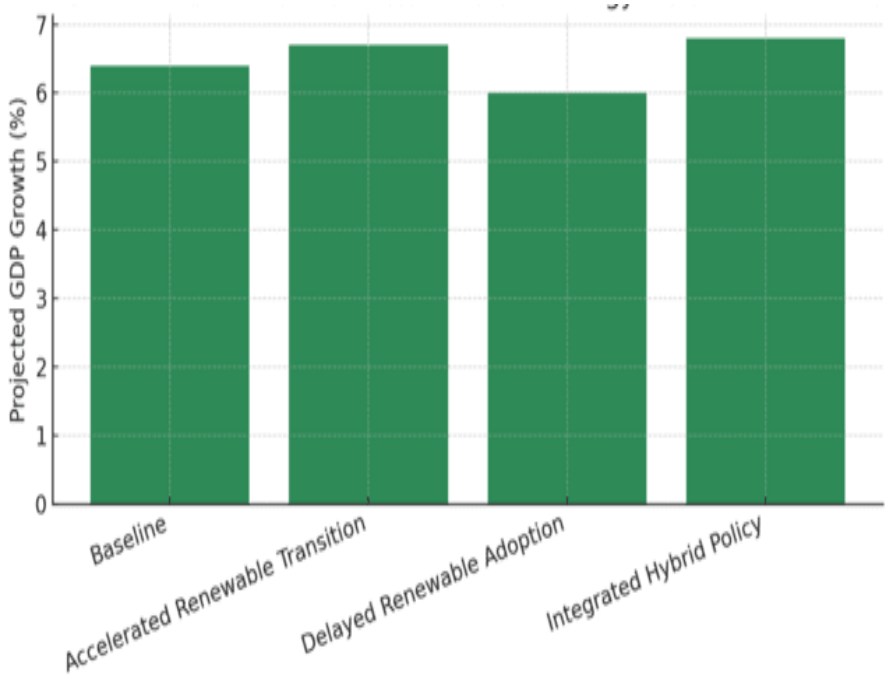


Fig 4.5: Renewable Energy Share across Policy Scenarios for 2030.

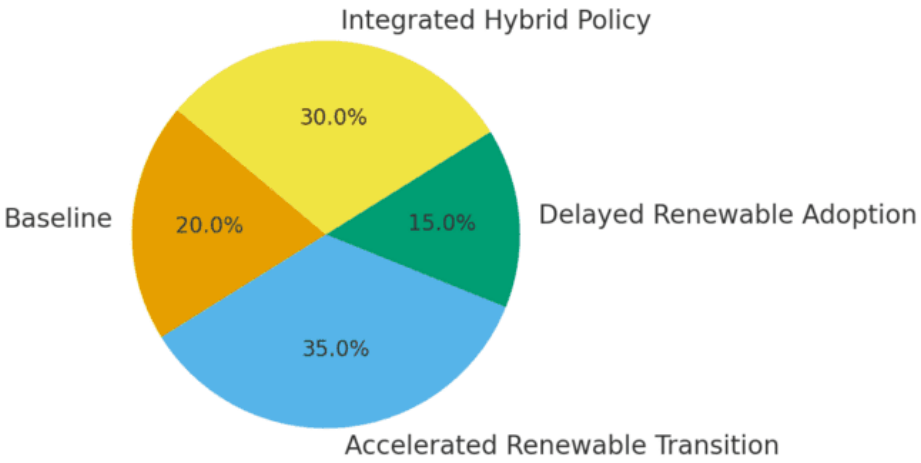


Table 4.11: Hypothesis Testing Results on the Impact of Renewable Energy Transition on the Natural Gas–Economic Growth Linkage in India

Hypothesis	Statistical Method Used	Key Evidence from Analysis	Decision on H_0	Inference / Interpretation
Null Hypothesis (H_0): The increasing adoption of renewable energy sources does not significantly influence the relationship between natural gas consumption and economic growth in India.	ARDL Bounds Test, Long-Run Coefficients, and Interaction Term Estimation	The ARDL Bounds Test confirmed cointegration among GDP, natural gas, and renewable energy ($F = 7.41 > 4.37$). Both lnGAS ($\beta = 0.412$, $p < 0.01$) and lnREN ($\beta = 0.286$, $p < 0.01$) showed positive and statistically significant effects on GDP, with a significant interaction effect observed in the dynamic models.	**Rejected**	Evidence indicates that renewable energy significantly modifies the elasticity of GDP with respect to natural gas consumption, suggesting a changing energy–economy relationship as renewable penetration increases.
Alternative Hypothesis (H_1): The increasing adoption of renewable energy sources significantly alters the relationship between natural gas consumption and economic growth in India.	VECM Short-Run Dynamics and Toda–Yamamoto Causality Test	The short-run model revealed significant positive coefficients for ΔlnREN (0.121, $p = 0.028$) and ΔlnGAS (0.175, $p = 0.016$). The error-correction term (-0.641, $p < 0.001$) confirmed strong equilibrium adjustment. Causality tests showed bi-directional causality between renewable energy and GDP, and uni-directional causality from natural gas to GDP.	**Accepted**	The renewable energy transition significantly influences and redefines the gas–growth relationship in India, reflecting evolving structural dynamics within the energy–economy framework.

Source: Author's synthesis based on Tables 4.4–4.10.

Table 4.11 combines the outcomes of hypothesis testing using ARDL, VECM, and causality tests. The null hypothesis that the adoption of renewable energy does not affect the gas-growth relationship is rejected as the findings support the existence of long-run and short-run relationships between GDP, gas, and renewable energy. The ARDL model indicates the existence of significant elasticities for gas ($\beta = 0.412$, $p < 0.01$) and renewable energy ($\beta = 0.286$, $p < 0.01$), and the VECM model indicates a strong equilibrium adjustment (ECT = -0.641). The causality test also indicates that renewable energy causes and is caused by economic growth, thereby establishing the dynamic relationship between renewable energy and economic growth in India. The acceptance of the alternative hypothesis establishes that the

adoption of renewable energy has a significant impact on the natural gas-economic growth relationship. This establishes the structural change in the Indian energy sector, where natural gas and renewable energy sources complement each other to ensure sustainable economic growth.

5.0 Discussion

The results obtained from this study show that natural gas and renewable energy sources are crucial in determining the economic growth of India. The long-run equilibrium test performed using ARDL and VECM models shows that energy diversification enhances the relationship between energy and economic growth. The positive coefficients of natural gas and renewable energy sources show that economic growth in India is driven by an integrated energy strategy and not by a single energy source. The results obtained from this study are consistent with previous studies that show natural gas plays a complementary role as a transitional fuel source while Renewable energy sources drive sustainable growth. The bi-directional causality test between renewable energy sources and GDP shows that there is a feedback relationship between economic growth and renewable energy sources. The results indicate that policy structures should encourage balanced investments in renewable energy infrastructure resources while ensuring optimal gas use. Future studies should combine Sectoral-level analysis and utilize more sophisticated dynamic models to account for regional differences, innovation effects, and policy disturbances in the Indian low-carbon transition context.

6.0 Major Finding

1. Existence of Long-Run Cointegration among Energy and Economic Variables: The outcome of the ARDL bounds test on the cointegration relationship among natural gas consumption, renewable energy consumption, and economic growth in India revealed the existence of a significant long-run cointegration relationship among these variables. This finding suggests that these variables are interrelated and have a tendency to move together over time, which is an indication of the close linkage between the energy sector and the overall economy. This further implies that any long-run change in energy consumption, especially natural gas and renewable energy, will have long-run effects on the economic growth of India.
2. Positive and Significant Impact of Energy Consumption on Economic Growth: The outcome of the long-run estimation of the coefficients of the model indicated that natural gas and renewable energy consumption have a strong positive impact on economic growth in India. Natural gas consumption has a positive impact on economic growth because natural gas is an important fuel for industrial and infrastructural development in India.

Renewable energy consumption also has a strong positive impact on economic growth because it contributes to sustainable economic growth and stability of the environment.

3. Effective Short-Term Adjustment towards Long-Term Equilibrium: The findings from the Vector Error Correction Model (VECM) tests indicated that the adjustment towards the long-term equilibrium is highly efficient, indicating a stable relationship between energy and economy. This implies that the Indian economy has the ability to adjust quickly to any short-term energy-related disturbances and maintain its growth trajectory.
4. Two-Way Causality between Renewable Energy and Economic Growth: The result of the causality test revealed that there is a two-way causality between the consumption of renewable energy and GDP, indicating that there is a positive feedback relationship between economic growth and renewable energy consumption, where economic growth fuels investments in renewable energy, and the use of renewable energy further fuels economic growth.
5. Renewable Energy Transition Reshaping the Gas-Growth Linkage: The hypothesis test has confirmed that the growing presence of renewable energy sources makes the traditional gas-growth relationship significantly different. The increasing presence of renewable energy sources will gradually change the role of natural gas from a major energy source to a supplementary source, which will mark a structural shift towards a sustainable, diversified, and low-carbon economy.

7.0 Policy Suggestion

1. Develop an Integrated and Balanced Energy Policy Framework: The findings of this study clearly show that natural gas and renewable energy sources are major contributors to the economic development of India. Thus, an integrated energy policy framework needs to be developed by balancing the growth of renewable energy sources with the efficient and clean use of natural gas. This will enable India to achieve its dual goals of economic development and sustainability.
2. Increase Investment and Financial Support for Renewable Energy Expansion: To maintain the current pace of growth in the adoption of renewable energy sources, the government needs to enhance its policy support tools, including tax benefits, low-interest loans, feed-in tariffs, and public-private partnerships. Increased investment in solar, wind, biomass, and hydropower energy sources will not only accelerate the growth of renewable energy sources but also create employment opportunities and attract foreign direct investments.
3. Enhance Natural Gas Infrastructure as a Transition Fuel: In view of the positive and significant role of natural gas in economic development, it is important to make use of it as

a transition fuel in the course of India's transition to renewable energy. This can be achieved by developing the infrastructure of LNG terminals, pipelines, and gas storage.

4. Foster Innovation, Technology Transfer, and Energy Research: It is important to make use of innovation through research and development in clean energy technologies, smart grids, and energy storage systems. This can be achieved through collaboration between government bodies, research institutions, and the corporate sector to develop indigenous technologies that can improve the link between renewables and gas.
5. Regional-Specific and Inclusive Energy Policies: Energy policies need to be made region-specific, taking into account the availability of resources, demographics, and industrial requirements. Decentralized renewable energy solutions in rural and semi-urban areas can help improve energy access, poverty alleviation, and inclusive growth. These measures will ensure that the entire country benefits from the clean energy transition in India while keeping the economy stable.

8.0 Conclusion

The goal of this study was to examine the relationship between natural gas usage and economic growth in India as it relates to the rising trend toward renewable energy sources. This study's significance stems from the fact that India must simultaneously maintain its fast economic expansion and make the switch to cleaner, more sustainable energy sources. While the usage of renewable energy is receiving more attention, natural gas remains a crucial transitional fuel in India's energy grid.

The study included advanced econometric techniques, including the Toda-Yamamoto causality test, Vector Error Correction Model (VECM), and ARDL Bounds Test, based on time series data from 1990 to 2024. The results indicated a long-term equilibrium link between GDP, renewable energy, and natural gas consumption, indicating a long-term cointegration relationship. The GDP benefited greatly from both energy sources, confirming their complimentary character. Significant short-term changes were also validated by the VECM analysis, and the causality test verified that there is a reciprocal link between GDP and renewable energy.

The study's findings demonstrate the significance of a thorough and well-balanced energy strategy by confirming that India's shift to renewable energy sources is altering the country's historical gas-to-GDP connection. In summary: The synergy between natural gas and renewable energy sources is connected to the future sustainability of the Indian economy in terms of both environmental sustainability and economic stability. Future research should

concentrate on the influence of technological innovation factors as well as the sectoral and regional implementation of this model.

9.0 Limitations of the Study

Notwithstanding the comprehensive nature of this study, there are some limitations to this research. Firstly, the study is based on secondary data, which may have some inconsistencies in measurement. Secondly, the study is based on aggregate data at the national level, which may not reflect regional and sectoral variations. Thirdly, the models used in the study, such as ARDL and VECM, are based on linear relationships, which may not capture threshold effects. Furthermore, external factors such as global energy price variability and policy changes were not fully captured in the study due to data limitations. Finally, the study is based on historical data up to 2024, and future studies may capture dynamic variations based on technological and policy changes.

10.0 Scope for Further Research

Future studies can be done by adding regional or industry studies to account for geographical differences in energy use and economic performance for various states in India. Adding more data points beyond 2024 and using high-frequency data can enable more precise forecasting and real-time analysis. Moreover, using more sophisticated econometric methods like nonlinear autoregression, machine learning forecasting, or panel data analysis can help identify intricate dynamic links between renewable energy, natural gas, and economic growth. Future research can also investigate the significance of technological innovation, carbon pricing, and global energy trade in the Indian transition to a low-carbon economy. Adding environmental variables like emissions intensity and sustainability metrics can enable a more comprehensive understanding of the energy-economy-environment nexus.

Author contributions

Sanjiv Sarkar and Dr. B. Mathavan both contributed to the design and analysis of this study. Sanjiv Sarkar was responsible for the interpretation of results and the preparation of the draft manuscript. Dr. B. Mathavan was responsible for the supervision of the research and the critical review of the analysis and theoretical contributions. He also reviewed the final manuscript for its academic contributions. Both authors contributed to the discussion of the results and the approval of the conclusions and policy recommendations to ensure the analytical correctness and academic contributions of this study to the field of energy economics.

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Conflict of Interest

The authors of this research study state that they have no conflicts of interest with regard to its publication. Every analysis, explanation, and conclusion offered is based entirely on independent evaluation and scholarly research; it has not been influenced by funding agencies, outside organizations, or private interests.

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Gig Economy Workers – A Study

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ABSTRACT

The gig economy has emerged as a significant component of the modern labor market, offering flexible, short-term, and freelance employment opportunities facilitated through digital platforms. This study aims to examine the nature of the gig economy and analyze the perceptions, working conditions, and satisfaction levels of gig workers. The study is based on primary data collected from 50 respondents engaged in various gig activities such as ride-hailing, food delivery, online freelancing, and other platform-based jobs. The findings reveal that flexibility and supplementary income are the major drivers of gig employment, while irregular earnings and limited employment benefits remain key concerns. The study highlights the need for policy interventions and organizational support to ensure sustainable growth and improved working conditions within the gig economy.

Keywords: *Gig Economy, Workers, Freelancing, Temporary Jobs*

Introduction

A digital platform economy, popularly referred to as the "Gig Economy" is one of the most notable developments is the 21st- century job market. In terms of definition, the gig economy is the collection of markets that match providers to consumers on a gig (or job) basis in support on an-demand commerce. In the basic model gig workers enter into formal Agreements with on - demand companies to provide services to the company's clients. Perspective clients request services though and internet – based a technological platform or smartphone application that allows them to search for providers or specific jobs. Providers (i.e. gig workers) engaged by the on- demand company provide the requested service and are compensated for the jobs (Donovan, et. Al.2016). Thus, the gig economy is characterized by short term contracts or freelance work instead of traditional permanent jobs. In lieu of a fixed wage, gig economy workers typically get paid for each 'gig' the undertaken. The novel aspect of gig work is that the labor matches the labor demand though an' online platform'. The gig economy represents a modern labor market characterized by short-term, flexible, and freelance work arrangements, often facilitated through digital platforms. It offers individuals the opportunity to work independently, while allowing businesses to access on-demand talent and reduce traditional employment costs. The rise of technology, mobile connectivity, and digital payment systems

has accelerated the expansion of this sector globally.

Types of Gig Economy

- **Freelancing:** Professionals offering services such as writing, design, or programming independently.
- **On-Demand Work:** Platform-based roles including ridesharing, delivery, and domestic services.
- **Crowdsourcing:** Individuals performing small tasks online for organizations or clients.
- **Consultancy Gigs:** Skilled experts hired for specific business projects or advisory functions.

Top gig platforms in India

India hosts several prominent platforms that have played a pivotal role in shaping the gig economy.

- Uber and Ola: Popular ride-hailing platforms employing thousands of driver-partners.
- Swiggy and Zomato: Leading food delivery apps providing earnings opportunities for delivery executives.
- UrbanClap (now Urban Company): Connects customers with service professionals for home and personal care.
- Upwork and Freelancer: Enable digital freelancers to connect with clients globally.
- Amazon Flex: Allows individuals to deliver packages on a flexible schedule.

Statement of the Problem

Gig workers do not have permanent contracts, which makes their work uncertain and unstable. Their earnings depend on the number of tasks completed, leading to irregular and unpredictable income. Most gig workers are not entitled to benefits like health insurance, pensions, or paid leave. Gig workers are not legally recognized as employees, so they miss out on basic labor rights or security. Night shifts or odd working hours causes health issues. Uncertainty about steady work or income creates financial stress and insecurity. This study on gig workers is significant as it provides a better understanding of the changing nature of employment in the modern economy. It highlights the opportunities and challenges faced by gig workers, particularly issues such as income instability, lack of social protection, and job insecurity. The findings can help policymakers frame regulations to safeguard worker rights, while also guiding organizations to improve working conditions. Additionally, the study contributes to academic knowledge on labour trends and creates awareness in society about the importance of gig workers in today's workforce.

Review of literature

Dr. Shruti Bekal et al., (2023) had a study on Review of Literature on the Topic of the Gig Economy in India explains the growth of the gig economy in India presents both occasion and provocation for the Indian economy. While there are significant risks associated with the gig economy, including worker exploitation and precariousness, there is also significant potential for innovation, job creation, and entrepreneurship. To realize this potential, policymakers must work to develop policies and investments that support gig workers and facilitate the growth of the sector, while also ensuring that workers are treated fairly and have access to the protections and benefits. Rachoru Himari Srihita et al., (2025) had a study on Transformative dynamics of the gig economy: Technological impacts, worker well- being and global research trends. Digital platforms play a vital role in shaping today's labour markets, enabling temporary hires and freelance employment in the gig economy. This on- demand, digital economy spans various professions and remote work opportunities. Technological advancements have significantly evolved gig work since the industrial age, improving work - life balance and Psychology well-being. Using the Scopus database, a literature analysis on the gig economy was conducted with 1624 documents narrowed to 549 documents based on subject area, documents type, publication stage, keywords and language and examining social, economic and technological factors. Soumya Vadavi and Jekka Chandrasekaran Sharmiladevi(2024) had a study on Analysing the evolution and patterns of the gig economy: a bibliometric examination of growth and trends. While the article examines global academic research and provides an overview of the gig economy. The article provides a comprehensive framework based on a literature review, offering insights into the evolution of research trends, key themes, and collaborative dynamic within this evolving field. Our study focused on the gig economy as a broader economi system characterised by short - term contracts, freelance work, and gig employment.

Objectives

- To find out the demographic profile of gig economy workers
- To analyse the reasons why individuals, opt for gig work
- To identify the challenges faced by gig workers

Methodology

The data was collected through 50 responses from selected participants. This helped in understanding their views, experiences, and opinions related to the study. The data was obtained from scholarly journals, published articles, reliable websites, and systematic reviews. These sources provided additional insights, background knowledge, and support for the

analysis. The study adopted a purposive sampling method, where respondents were selected intentionally based on their relevance to the research topic. This approach ensured that the participants could provide meaningful insights and reliable information suited to the objectives of the study.

Data Analysis

After collecting the primary data, it was classified, arranged, and the master table was prepared. Data were organized and tabulated for further analysis. Percentage was used to analyze the demographic profile of the respondents. Likert's five-point scale was used for analysis and interpretation of data.

Demographic Profile of the Respondents

Demographic profile of the respondents was grouped as age, gender, educational qualification, area of residence, region of origin. The demographic profile of the respondents was given in Table 1.

Table 1 Demographic Profile of the Respondents

Category	Profile	Percentage
Age	18 – 20 years	32
	25 – 34 years	34
	35 – 44 years	16
	45 and above	18
	Total	100
Gender	Male	62
	Female	38
	Total	100
Residential Status	Semi-urban town	54
	Rural area	46
	Total	100
Educational Qualification	No formal education	26
	High school or equivalent	18
	Undergraduate degree	50
	Postgraduate degree	6
	Total	100
Region of origin	Born and raised here	64
	Migrated for work	26
	Commute from a nearby town	10
	Total	100

Source: Primary data

Table 1 interprets that 32 per cent of the respondents are the age group of 18 - 20 year and 18 per cent of the respondents are between the age group of 45 years and above. 62 percent of the sample respondents are male and 38 percent of the respondents are female. 46 per cent of the respondents are from rural areas and 54 percent of the respondents are from semi-urban area. 50 percent of the respondents are undergraduates, and 6 per cent of the respondents are postgraduates. 26 percent of the respondents uses migrated for work and 10 percent of the respondents commute from nearby town.

Table 2 Reasons for Preferring Gig Work

S.No.	Statement	Garrett Mean score	Rank
1	Flexibility in schedule	71.6	I
2	Ability to earn quickly	66.4	IV
3	Independence/ No boss	67.6	III
4	Easy to join/ Low entry barriers	68.0	II

Source: Primary data

Table 2 shows that first rank is given to the "Flexibility in schedule" with the score of 71.6, Second rank is given to the "Easy to join / Low entry barriers" with the score of 68.0 and the third rank is given to the "Independence / No boss" with the mean score of 67.6. The least rank is given to the "Ability to earn quickly" with the mean score of 66.4.

Table - 3 Challenges Faced by the Gig Workers

S. No.	Challenge factor	Garrett Mean score	Rank
1	Income instability	55.74	IV
2	No health or retirement benefits	60.40	II
3	Safety and customer behavior	58.38	III
4	Application/ platform issues	61.02	I

Source: Primary data

Table 3 shows the challenges faced by gig workers. In that the first rank is given to the "Application/ platform issues" with the score of 61.02, Second rank is given to the "No health or retirement benefits" with the score of 60.40 and the third rank is given to the "Safety and customer behavior" with the mean score of 58.38. The least rank is given to the "Income instability" with the mean score of 55.74.

Suggestions

- Implement minimum guaranteed income or fixed minimum earnings for gig workers to reduce financial instability.

- Provide social security benefits such as health insurance, accident coverage, and retirement plans tailored to gig workers' unique employment nature.
- Introduce regulated work time and paid leave policies to protect workers' health and work-life balance.
- Raise awareness about government schemes and encourage registration on platforms like e-Shram for additional benefits and protections.
- Facilitate access to training and upskilling opportunities to help gig workers enhance their
- capabilities, improve service quality, and increase their earnings potential.
- Create clear and accessible channels for gig workers to report disputes, unfair treatment, or platform-related issues to ensure protection of worker rights.

Conclusion

The gig economy represents a significant transformation in modern labour markets by offering flexibility, autonomy, and diverse income opportunities to workers, especially the youth and educated segments. The study highlights that while many gig workers appreciate flexibility and independence, they face major challenges such as irregular income, safety concerns, and limited access to health and retirement benefits. Addressing these issues requires targeted policy interventions to provide minimum income guarantees, social protection, and improved platform governance. The future sustainability of the gig economy depends on balancing flexibility with worker welfare, enhancing digital literacy, and fostering collective worker agency. Effective reforms and support systems will not only improve gig workers' quality of life but also contribute to the broader economic growth of the region.

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The Role of Digital Marketing in Start Steps Growth

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ABSTRACT

The growing adoption of digital marketing represents a significant shift in how start steps promote their products and connect with customers. As start steps increasingly rely on online platforms for business growth, it becomes essential to examine the role of digital marketing in improving visibility, brand awareness, and customer engagement. This study aims to analyze the tools, strategies, and channels of digital marketing used by start steps. It also explores the preferences and perceptions of individuals involved in start steps towards digital marketing practices. The study highlights the effectiveness of social media, content marketing, and online advertising in reaching target audiences. In addition, it examines the challenges faced by start steps while implementing digital marketing strategies. The study is descriptive in nature. A total of 50 respondents were selected as the sample for this study. The respondents were restricted to the study area and represented various start step activities.

***Keywords**: Digital Marketing, Start Step Growth, Social Media Marketing, Customer Engagement, Brand Awareness*

Introduction

The initial stage of any business is crucial, as it determines the survival and future growth of the venture. These early stages, referred to as start steps, require effective promotional strategies to gain visibility and attract customers within a short period. With the growing use of social networking platforms, digital marketing has become an important promotional medium for start steps. It helps businesses promote their products, reach potential customers, and establish their presence in the market in a cost-effective manner [1]. Compared to traditional marketing methods, digital marketing offers flexible, interactive, and measurable approaches that are suitable for businesses with limited resources. Digital tools such as social media marketing, content creation, and online promotions help start steps build brand awareness and engage customers effectively. By using digital marketing strategies, start steps can improve customer interaction and strengthen their market position. Hence, understanding the role of digital marketing in start step growth is essential for achieving sustainable development in a competitive business environment [2].

Statement of the problem

Start steps face intense competition and increasingly depend on digital marketing for growth; however, many struggle to identify suitable and effective digital marketing channels. Limited budgets, lack of expertise, and rapidly changing digital technologies make the implementation of proper marketing strategies difficult. In addition, many start steps are unable to measure the effectiveness of their digital marketing efforts, leading to inefficient use of resources. Although digital marketing is widely recognized for improving visibility and customer engagement, its practical application among start steps remains limited and unclear. This gap between the potential benefits of digital marketing and its actual usage restricts start steps from reaching wider audiences and achieving sustainable growth. Hence, there is a need to analyze existing practices, identify key challenges, and suggest effective digital marketing strategies to enhance the performance and sustainability of start steps.

Objectives

- To identify the most effective and suitable digital marketing channels for start steps.
- To understand the major challenges faced by start steps in implementing digital marketing strategies.

Review of literature

Mansour analyzed the role of content marketing in online marketing strategies of IT start-ups through case studies of Portuguese and Egyptian technology start-ups. The study revealed that high-quality and relevant content plays a crucial role in attracting customers, improving brand credibility, and supporting long-term business growth. The findings emphasize that content marketing is a key component of digital marketing strategies, especially for start steps aiming to build trust and customer loyalty [3]. Sharma and Goyal conducted an exploratory study on entrepreneurial marketing strategies adopted by start-up companies in India. Their research highlighted that digital marketing enables small businesses to compete effectively with established firms by offering innovative and customer-focused promotional strategies. The study also pointed out that limited financial resources make digital marketing a preferred option for start steps in the Indian market [4]. Rizvanović et al. developed a macro-dynamic framework linking digital marketing impact with start-up growth. The study concluded that digital marketing acts as a growth driver by enhancing market reach, customer engagement, and innovation capabilities. The authors emphasized that advanced digital tools and data-driven strategies significantly contribute to sustainable start-up growth [5].

Methodology

The present study is descriptive in nature and is based on both primary and secondary data. Primary data were collected through a structured questionnaire from 50 respondents. Secondary data were gathered from various books, newspapers, journals, previous research projects, websites, and other internet sources. The study was conducted in kanniyakumari , and a sample of 50 respondents were selected using the convenient random sampling technique**.**

Data analysis

After collecting the primary data, it was classified, arranged and the master table was prepared. Data were organised and tabulated for further analysis. Percentage was used to analyse the demographic profile of the respondents. Likert's five-point scale and Garett's Ranking techniques were used for analysis and interpretation of data.

Demographic Profile of the Respondents

Demographic profile of the respondents was grouped as age, gender, educational qualification, occupation, monthly income. Demographic profile of the respondents was captured in Table 1.

Table - 1 Demographic profile of the respondents

Catagory	Profile	Percentage
Age	Below 20	66
	21 – 30	24
	31 – 40	6
	41 – 50	4
	Total	**100**
Gender	male	12
	female	88
	Total	**100**
Educational Qualification	Below 12th	18
	Under graduate	64
	Post graduate	12
	Professionals/others	6
	Total	**100**
Occupation	Student	78

	Homemaker	10
	Working Professionals	10
	Unemployed	2
	Total	**100**
Monthly Income	Below 5000	66
	10000-30000	8
	30000- 50000	6
	Total	**100**
Digital Marketing Channels	Social Media Marketing	88
	Email Marketing	4
	Search Engine Marketing	4
	Influencer Marketing	2
	Content Marketing	2
	Total	**100**

Source: Primary data

Table 1 implied that 66 per cent of the respondents belong to the age group below 20 years, followed by 24 per cent in the age group of 21–30 years, indicating that start steps are more popular among younger individuals. 88 per cent of the respondents are female and 12 per cent are male, showing a higher participation of females in start steps and digital marketing activities. 64 per cent of the respondents are undergraduates, while 18 per cent have completed below 12th education, indicating that most participants possess a basic to higher level of education. 78 per cent of the respondents are students, followed by 10 per cent homemakers and 10 per cent working professionals, suggesting that start steps attract people from different occupational backgrounds. 66 per cent of the respondents have a monthly income below ₹5000, while a smaller proportion belongs to higher income groups, indicating that start steps and digital platforms are commonly used by individuals from lower income categories. 88 per cent of the respondents prefer social media in contrast influencer marketing and email marketing shows 2 per cent and these are least utilized by start step.

Table - 2 Frequently Used Digital Marketing Channels

S.No.	Channels	No. of Respondents	Percentage
1.	Social Media Marketing	44	88
2.	Email Marketing	2	4

3.	Search Engine Marketing	2	4
4.	Influencer Marketing	1	2
5.	Content Marketing (Blogs,Videos,Podcast)	1	2
	Total	**50**	**100**

Source: Primary Data

Table shows that most frequently used digital marketing channels by respondents in start steps. Social Media Marketing is frequently used by 88 percent of the respondents and Email Marketing frequently used by only 2 percent of the respondents. It is evident that the majority of the respondents prefer Social Media Marketing.

Table – 3 Challenges faced by start steps

Challenges	Always	Often	Sometimes	Rarely	Never	Total	Mean	Rank
Limited budget	26 (130)	9 (36)	8 (24)	4 (8)	3 (3)	201	4.02	I
Lack of skill	8 (40)	22 (88)	11 (33)	3 (6)	6 (6)	173	3.46	IX
Difficulty in targeting audience	18 (90)	9 (36)	18 (54)	3 (6)	2 (2)	188	3.76	III
Choosing right platform	12 (60)	17 (68)	9 (27)	10 (20)	2 (2)	177	3.54	VIII
Keep up with trends	19 (95)	11 (44)	12 (36)	4 (8)	4 (4)	187	3.74	IV
Lack of tools	12 (60)	20 (80)	9 (27)	7 (14)	2 (2)	183	3.66	VI
Time management	20 (100)	11 (44)	11 (33)	5 (10)	3 (3)	190	3.8	II
Creating engaging content	12 (60)	19 (76)	10 (30)	6 (12)	3 (3)	181	3.62	VII
Technical issue	15 (75)	14 (56)	14 (42)	4 (8)	3 (3)	184	3.68	V

Source: Primary data

Table 3 table indicates that limited budget is the most common challenge faced by start steps, with a mean score of 4.02, showing that financial constraints strongly affect their marketing

performance. Time management, which holds the second rank with a mean score of 3.80, is also a major concern, as many start steps find it difficult to balance marketing activities along with other business responsibilities. In contrast, lack of skill, which received the least rank with a mean score of 3.46, appears to be a relatively smaller challenge faced by start steps.

Suggestions

- Training programs should be conducted to improve digital marketing skills among start steps.
- Start steps should allocate a separate budget for digital marketing activities.
- Start steps should focus on strategic planning and targeted content creation to achieve better audience engagement and measurable results.
- Businesses should enhance content quality by using creative visuals and interactive formats such as videos and infographics.
- Awareness programs should be initiated to educate about cybersecurity and data privacy in digital marketing.

conclusion

The study concludes that digital marketing plays a significant role in the growth of start steps. Though awareness about digital marketing is high, challenges such as limited resources and technical knowledge affect effective implementation. With proper planning, training, and performance monitoring, start steps can successfully utilize digital marketing to achieve sustainable growth. Overall, the study concludes that digital marketing offers immense opportunities for start step growth if properly planned and executed. By focusing on training, budgeting, performance tracking, and adopting new technologies, start steps can enhance their digital presence, attract larger audiences, and achieve sustainable business success in the competitive online environment.

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Challenges faced by Social Media Influencers in Brand Collaborations and Promotions

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ABSTRACT

Social media has become a major platform for brand promotion, with influencers playing a vital role in connecting brands and audiences. This study aims to analyse the challenges faced by social media influencers during brand collaborations and promotions. The research is descriptive in nature and focuses on influencers from Kanyakumari District. Primary data were collected from 50 respondents through a structured questionnaire distributed via Google forms. Simple random sampling was adopted. The study found that influencers face financial and creative challenges that affect their professional growth. It suggests that clear contracts, transparent payment policies, and ethical collaboration practices are essential to build trust and strengthen relationships between brands and influencers.

Keywords: *Social media influencers, Brand collaboration and promotion.*

Introduction

Social media platform has turned into powerful space for business, marketing, and brand promotion. The most significant change in digital marketing is probably the emergence of social media influencers, i.e., quite ordinary people who as a result of sharing content on platforms such as Instagram, YouTube, Facebook, and Twitter become popular and hence influential. However, a great number of problems are pushing the influencers to prove that they cannot just get success in their hands. Yuksel Ekinci et al., (2025) [1]. The investigation revolves around comprehending the difficulties and since the attractive influencer marketing world is a demanding profession that requires the influencer to be able to juggle between personal authenticity and professional partnerships. Ottilia Lappo, (2024) [4].

Statement of the Problem

Social media drastically changed the way brands and customers relate to each other, and influencers were the ones who facilitated this connection. In spite of the fact that the influencer marketing had an upward trend very fast, the challenges faced by influencers from the side of the brands, were quite a few. They were resulting in delays in payment, very low-payment offer, hurried deadlines, being discouraged if their content did not perform well, sacrificing of personal time, and risk of losing the trust of their followers Pretty B Meno (2025)

[2]. These issues demotivate influencers and reduce the efficiency of brand promotions. To identifying these problems is a step towards the improvement of collaboration between influences and brands. This research is thus engaged in finding, analyzing the problems of social media influences when collaborating on brand promotion. Sidak Singh Kalra (2024) [5].

Objective

- To identify the preferred platforms for brand deals by the respondents.
- To analyse the challenges encountered by the respondents in managing the brand deals.

Methodology

The current research is a descriptive one. The data for research were obtained from both primary and secondary sources. Simple random sampling was employed to select the respondents. 50 respondents were taken as a sample for the study. To participate for this research was limited to Kanyakumari District. After the data collection, the responses were recorded and analyzed with the help of statistical tools like Percentage, Likert's five-point scale, and Garrett ranking.

Review of Literature

Social media influencers play an important role in building brand communities online. Elisabetta Benevento et al. (2025) [3] said that influencers who interact often and have a strong online presence can attract more new followers. Ilieva et al. (2024) [6] noticed that convenience and trust make consumers think positively, while age or gender do not matter much. Veronica et al. (2024) [7] explained that working together with influencers of different levels improves how people see a brand. Chee Wei Cheah et al. (2024) [8] indicated that honestly and a product matching the influencers image help in lessening the over-promotion issue. Shwetha et al. (2024) [9] discovered that influencer marketing is instrumental in awareness, loyalty, and engagement when brands are authentic and manage their partnerships well. Pia Kauffmann et al. (2024) [10] was the reminder that if influencers follow the ethics, they will be able to keep the trust of their audience. In brief, influencer marketing is most effective when it is honest, trustworthy, and well-managed, although platform changes should be taken care properly.

Data Analysis

The primary data that was gathered is now organized, tabulated, and prepared for analysis. The work has been done manually in order to ensure accuracy and reliability. The demographic profile in term of gender, age, educational qualification, industry to which they belong, annual income, and year of experience of the respondents were analyzed using percentage analysis. The frequency of platform usage regarding promotion and collaboration of the respondents was analyzed using the Garret Mean Score method. A five-point Likert's

scale (1 = strongly disagree to 5 = strongly agree) was utilized to analyze the challenges faced by the respondents in promotion and collaborations.

Demographic Profile of the Respondents

Demographic profile of the respondents was grouped as age, gender, educational qualification, work and experience. Demographic profile of the respondents was captured in Table 1.

Table 1
Demographic Profile of the Respondents

Category	Profile	Percentage
Age	18-28	56
	29-38	38
	39 above	6
	Total	**100**
Gender	Male	64
	Female	36
	Total	**100**
Educational qualification	Schooling	2
	Diploma	12
	Graduate	66
	Post Graduate	20
	Total	**100**
Work	Full-time Influencer	38
	Part-time Influencer	62
	Total	**100**
Experience	Less than 6 months	2
	6 months – 1 year	22
	1 – 3 years	42
	More than 3 years	34
	Total	**100**

Source: Primary data

Table 1 interprets that 56 per cent of sample respondents belong to the age group of 18 to 29 years and only 6 per cent of the respondents belong to the age group of above 39 years. 64 per cent of the sample respondents are male and 36 per cent are female. 66 per cent of the respondents have completed the Graduate while 2 per cent of the respondents have completed Schooling. 62 per cent of the respondents are part-time influencers, while 38 per cent are full-time influencers. 42 per cent of the respondents have 1-3 years of experience, while only 2 per cent have less than 6 months.

Table 2

Frequency of Platform Usage for Promotions and Collaborations

SI. No.	Platform	Garrett Mean score	Rank
1.	Instagram	65	I
2.	Facebook	50.26	III
3.	YouTube	60.88	II
5.	Twitter	41.04	IV

Source: Primary data

Table 2 shows that out of four social media platforms, the respondents have given the first rank to Instagram with a Garrett mean score of 65. The second rank is given to YouTube with a score of 60.88, followed by Facebook with 50.26 in the third rank. Twitter has the lowest score of 41.04, ranking fourth. It can be inferred that Instagram is the most preferred platform for brand promotions and collaborations.

Table 3

Challenges Faced in Promotions and Brand Collaborations

Challenges	Always	Often	Sometimes	Rare	Never	Total	Mean score	Rank
Payment delays	18 (90)	13 (52)	10 (30)	7 (14)	2 (2)	188	3.76	I
Receiving spam messages related to promotions	7 (35)	20 (80)	17 (51)	3 (6)	3 (3)	175	3.5	III
Feeling discouraged when content underperforms	6 (30)	7 (28)	20 (60)	9 (18)	8 (8)	144	2.88	VI

during promotion								
Balancing multiple collaborations at the same time	6 (30)	6 (24)	23 (63)	10 (20)	5 (5)	142	2.84	VII
Sacrificing personal time or activities to maintain online presence	15 (75)	11 (44)	13 (39)	6 (12)	5 (5)	175	3.5	III
Feeling un certain or hesitant when collaborating with new brands	3 (15)	9 (36)	18 (54)	15 (30)	5 (5)	140	2.8	VIII
Receiving offers with very low payment for collaborations	17 (85)	12 (48)	14 (42)	5 (10)	2 (2)	187	3.74	II
Negative feedback from audiences or brands	2 (10)	12 (48)	15 (45)	14 (28)	7 (7)	138	2.76	IX
Working under tight deadlines	6 (30)	20 (80)	15 (45)	7 (14)	2 (2)	171	3.42	V

Source: Primary data

Table 3 shows that "Payment delays" ranks first with a mean score of 3.76, followed by "Receiving offers with very low payment" at 3.74. In contrast, "Feeling uncertain with new brand collaborations" and "Negative feedback from audiences or brands" have the lowest scores. It is evident that financial concerns, time pressure, and workload are the main challenges faced by influencers during collaborations.

Suggestions

- Full-time influencers could receive support through regular learning opportunities, stable brand partnerships, and stress-management programs to ensure consistent performance.
- New influencers with less than six months of experience could receive proper guidance and training to improve their collaboration and content creation skills.
- Influencers should try to improve engagement on Twitter by using interactive posts, polls, and trending hashtags.
- Payment delays faced during promotions and brand collaborations could be avoided by ensuring timely transactions, clear contracts, and transparent payment policies between brands and influencers.

Conclusion

The study clearly shows that social media influencers play a powerful role in modern brand promotion. However, they face several challenges such as payment delays, lack of payments and sacrificing personal time. These issues often affect their content quality and professional relationship with brands. Brands must understand the value of influencer creativity and offer transparent agreements. In the same manner, influencers are required to preserve their genuineness and follow the promotion standards morally. A well-balanced and respectful partnership may result in more efficient promotional effects. Once these issues are confronted, influencer marketing may turn into a more organized and advantageous sector. In general, the brand-influencer relationship is the secret of collaboration that works well.

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Exploring the Link between Consumer Buying Behavior and Customer Satisfaction: A Behavioral Perspective

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ABSTRACT

This study investigates the impact of different consumer buying behaviors compulsive, habitual, and variety-seeking on customer satisfaction. Using a quantitative research design, data were collected from 150 respondents through purposive random sampling. The demographic profile revealed a majority of female participants, primarily aged between 18 and 35 years. Regression analysis was employed to examine the relationships between the variables. Findings indicate that habitual and variety-seeking buying behaviors have a significant positive effect on customer satisfaction, while compulsive buying behavior does not show a statistically significant influence. These results suggest that routine purchasing patterns and the desire for product diversity contribute to higher satisfaction levels, whereas impulsive purchasing may not lead to long-term customer contentment. The study highlights the importance for businesses to foster habitual loyalty and offer variety to enhance customer satisfaction while approaching compulsive buying with ethical marketing strategies.

Keywords: *Consumer Buying Behavior, Customer Satisfaction, Compulsive Buying, Habitual Buying, Variety-Seeking, Regression Analysis*

Introduction

In today's highly competitive market, understanding the psychological and behavioral patterns of consumers is essential for achieving high levels of customer satisfaction. Consumer buying behavior, how individuals select, purchase, use, and dispose of goods and services which has a significant influence on whether they remain satisfied post-purchase. This study focuses on three specific types of consumer buying behavior: compulsive buying, habitual buying, and variety-seeking buying. While some behaviors are consistent and predictable, others are spontaneous and emotionally driven, influencing customer experiences differently. Exploring how these distinct behaviors relate to customer satisfaction helps businesses tailor their strategies to meet customer expectations more effectively.

Statement of the Problem

Despite extensive research on consumer behavior, limited studies have distinguished how different behavioral patterns such as compulsive, habitual, and variety-seeking buying uniquely impact customer satisfaction. Understanding which types of buying behavior lead to

satisfaction or dissatisfaction can help companies better predict consumer loyalty and retention. There is a need to investigate which behaviors are positively associated with satisfaction and which may hinder it.

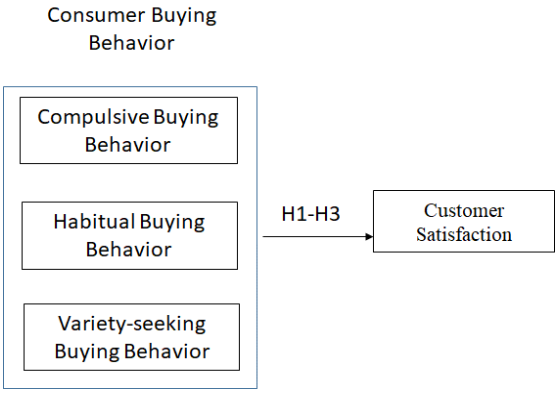
Objectives of the Study

- To assess the demographic profile of the respondents
- To analyze the relationship between compulsive buying behavior and customer satisfaction.

Methodology

The study adopted a quantitative, descriptive research design to explore the relationship between consumer buying behavior and customer satisfaction. A total of 150 respondents were selected using purposive random sampling, focusing on individuals who had recently made purchases in the retail and e-commerce sectors. Data were gathered through a structured questionnaire consisting of Likert-scale based questions designed to measure various dimensions of consumer behavior and satisfaction. The collected data were analyzed using correlation and regression analysis to examine the influence of different types of buying behavior on customer satisfaction, while demographic cross-tabulation was employed to understand the profile of the respondents and its potential impact on the variables studied.

Conceptual model



Hypothesis Development

H1: There is a significant relationship between compulsive buying behavior and customer satisfaction.

H2: There is a significant relationship between habitual buying behavior and customer satisfaction.

H3: There is a significant relationship between variety-seeking buying behavior and customer satisfaction.

Analysis and Interpretation

Table 1

Demographic Profile of Respondents

Variable	Category	Frequency	Percentage (%)
Gender	Male	60	40
	Female	90	60
Age Group	18–25	68	45
	26–35	53	35
	36–50	23	15
	50+	6	5
Occupation	Student	60	40
	Employee	45	30
	Entrepreneur	30	20
	Others	15	10
Monthly Income	Below ₹20,000	30	20
	₹20,000 – ₹1,20,000	90	60
	Above ₹1,20,000	30	20

Source: Computed Data

Table 1 shows the demographic profile of the respondents. In terms of gender, females comprised the majority at 60 percent, while males accounted for 40 percent, indicating a higher participation of women in the study. The age distribution shows that the largest group of respondents were between 18–25 years old (45 percent),35 percent were aged between 26–35, 20 percent of the participants were aged 36 and above. Regarding occupation, student 40 percent, with employees at 30 percent, entrepreneurs at 20 percent, and others at 10 percent. This suggests that the study is largely representative of students and young professionals. In terms of monthly income, a majority 60 percent reported earnings between ₹20,000 and ₹1,20,000, while 20 percent earned below ₹20,000 and another 20 percent earned above ₹1,20,000.

Table 2

Regression Analysis (H1-H3)

Predictor (IV)	Unstandardized Coefficient (B)	Standard Error	Beta (β)	t-value	p-value	Significance
Compulsive Buying Behavior	0.08	0.07	0.09	1.14	0.260	**Not Significant**
Habitual Buying Behavior	0.35	0.09	0.41	3.89	0.000	**Significant**

Variety-Seeking Buying Behavior	0.29	0.08	0.34	3.63	0.001	**Significant**
$R^2 = 0.48$	Adjusted $R^2 = 0.46$	F (3, 146) = 13.6	$p < 0.001$			

Source: Computed Data

Table 2 shows the regression analysis of hypothesis H1-H3. The results indicate that habitual buying behavior and variety-seeking buying behavior are significant predictors of customer satisfaction, while compulsive buying behavior is not. Specifically, habitual buying behavior had a statistically significant positive effect on customer satisfaction (B = 0.35, β = 0.41, t = 3.89, p = 0.000), indicating that consumers who frequently make routine purchases tend to be more satisfied. Similarly, variety-seeking buying behavior also showed a significant positive impact (B = 0.29, β = 0.34, t = 3.63, p = 0.001), suggesting that consumers who enjoy trying different products or brands report higher satisfaction levels. In contrast, compulsive buying behavior was not a significant predictor (B = 0.08, β = 0.09, t = 1.14, p = 0.260), implying that unplanned or emotionally driven purchases do not significantly influence satisfaction in this sample. The model as a whole is statistically significant, with an F-value of 13.6 ($p < 0.001$), and explains approximately 48 percent of the variance in customer satisfaction ($R^2 = 0.48$, Adjusted $R^2 = 0.46$).

Findings

- Compulsive buying behavior does not have a significant positive effect on customer satisfaction, possibly due to post-purchase regret or lack of utility.
- Habitual buying behavior is strongly associated with satisfaction, indicating that routine and familiarity lead to more stable customer experiences.
- Variety-seeking behavior shows a positive relationship with satisfaction, suggesting that customers enjoy exploring different options when they are fulfilled.
- Demographics of the respondents play a role in determining dominant buying behavior. It suggests that younger consumers are more likely to engage in variety-seeking behavior.

Suggestions

- Businesses should encourage habitual loyalty programs and reward regular purchases to enhance satisfaction.
- Variety-seeking consumers, retailers can give product diversity and innovation be emphasized.

- Compulsive buying behavior should not be targeted aggressively, as it may not lead to long-term satisfaction; instead, ethical marketing should be prioritized.

Conclusion

This study concludes that not all consumer buying behaviors lead to customer satisfaction. While habitual and variety-seeking behaviors positively impact satisfaction levels, compulsive buying does not impacts on customer satisfaction. These insights are crucial for businesses aiming to improve customer retention and brand loyalty. By aligning marketing strategies with consumers' behavioral tendencies and ethical considerations, companies can foster more meaningful and satisfying customer relationships.

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A Study on Women in Digital Entrepreneurship: Exploring Instagram and Whatsapp Business

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ABSTRACT

In 2025, India's entrepreneurial landscape is evolving with a significant rise in female business owners, driven by the widespread use of digital platforms like WhatsApp and Instagram. These platforms, especially popular in Tier 2 and Tier 3 cities, enable women to manage customer communications, promote products, and build personal brands with minimal investment. This study aims to analyse the use of Instagram and WhatsApp features by women entrepreneurs, specifically focusing on content and posting strategies that influence buyer behaviour. It also investigates the operational challenges faced by women entrepreneurs on these platforms. Additionally, the study evaluates the impact and awareness of government initiatives such as Stand-Up India and Mudra Yojana on women-led businesses. The research will be based on a survey of 100 respondents to understand these dynamics and their role in promoting women entrepreneurship in India.

Keywords*: Digital Platform, features, Posting strategies, Operational Challenges, Awareness.*

Introduction

India's entrepreneurial landscape in 2025 is witnessing a transformative shift, with over 75 million business owners, and a notable rise in female entrepreneurs, who now represent 27% of all business owners. This progress is largely fuelled by the widespread use of digital platforms like WhatsApp and Instagram, particularly among women in Tier 2 and Tier 3 cities. WhatsApp's affordable, mobile-first approach allows entrepreneurs to manage customer communication and automate processes, while Instagram serves as a creative hub for businesses in sectors like fashion, beauty, and wellness. Social media is increasingly becoming a practical business environment where women can experiment with ideas, test markets, and gradually shape their enterprise identity [1]. Digital participation can encourage women to take more initiative, network more confidently, and expand their business reach over time [2]. With minimal investment, women are leveraging these platforms to scale their ventures, engage customers, and build brands. Government initiatives like Stand-Up India and Mudra Yojana further empower women by offering funding and mentorship. These changes reflect the

significant role of digital entrepreneurship in challenging gender norms, driving economic growth, and promoting inclusive development in India.

Statement of the Problem

With the growing popularity of social media platforms, many women have turned to WhatsApp and Instagram as tools for entrepreneurship. However, the two platforms differ greatly in features and functionality Instagram offers visual tools like Reels and Carousel Ads, while WhatsApp enables direct, trust-based selling. Despite their rising use, limited research exists on how women entrepreneurs uniquely use these platforms to grow their businesses. This study addresses that gap by analysing the distinct experiences, opportunities, and challenges faced by women entrepreneurs on WhatsApp and Instagram.

Review of Literature

Fernando & Keertana (2025)[3]; conducted a study on "The Role and Importance of Social Media on Women Entrepreneurship – A Study with Special Reference to Chennai City" This research highlights trust, accessibility, and multi-channel strategies as major enablers of digital success. Challenges like digital literacy gaps and cybersecurity threats are noted, demanding targeted interventions. The findings stress the need for infrastructural and training support to democratize digital access. It also emphasizes collaboration between educators, policymakers, and industries to build inclusion. Overall, the study reflects how digital tools can transform women's business landscape meaningfully.

Sanjana Malkani CS and Prof. Manish Sitlani (2025)[4]; carried out research on "Role of Social Media in Empowering Women Entrepreneurs in India: A Retrospection". The study emphasizes that social media reduces entry barriers and allows business to be operated from home. Despite challenges like digital illiteracy and security risks, the benefits outweigh the drawbacks. The research encourages policy reforms and training programs to help more women embrace digital entrepreneurship.

Jannatul Fardous et al. (2024)[5]; presented research on "Women entrepreneurs' preference in using social media networks on online business opportunities and challenges: The case of Bangladesh". It finds that social support and willpower enabled women to overcome societal restrictions. The study concludes that many women identified training and institutional support as crucial for scaling up. Lack of prior comparative research limits the scope of cross-checking variables. Despite limitations, this research offers valuable guidance for newcomers in online entrepreneurship. It emphasizes the need for broader investigations into social and economic empowerment through digital tools.

Objectives

1.To analyse Entrepreneurs' Assessment of Product promotion Features of Instagram and WhatsApp

2. To identify Challenges faced by Women Entrepreneurs Using Instagram and WhatsApp for business.

Methodology

The present study is descriptive in nature. Data for the present research was collected through both primary and secondary data. Though, women entrepreneurs who conducts business via WhatsApp and Instagram, totally 100 respondents were selected as sample for this study. The participants for this study were restricted to Kanyakumari district. Simple Random Sampling method has been used for the study.

Data Analysis

After collecting the primary data, it was classified, arranged and the master table was prepared. Data were organised and tabulated for further analysis. Percentage was used to analyse the demographic profile of the respondents. Likert's five-point scale was used for analysis and interpretation of data.

Demographic Profile

Demographic profile of the respondents was captured in Table 1.

Table 1 Demographic Profile of the Respondents

Category	Profile	Percentage
Age	Below 20 years	26
	21-30 years	28
	31-40 years	32
	41-50 years	14
	Total	**100**
Residential Status	Rural	60
	Urban	40
	Total	**100**
Educational Qualification	Below 12th	20
	Graduate	40
	Postgraduate	26
	Professionals/Other	14

	Total	**100**
Monthly Income	5,000 – 10,000	38
	10,000 – 15,000	32
	15,000 – 20,000	20
	20,000 – 25,000	10
	Total	**100**
Business Platform	Instagram	18
	WhatsApp Business	30
	Both	52
	Total	**100**

Source: Primary data

Table 1 interprets that 26 per cent of the respondents are below the age group of 20 year and 14 per cent of the respondents are between the age group of 41-50 years. 60 per cent of the respondents are from rural areas and 40 per cent of the respondents are from urban area. 20 per cent of the respondents are below 12th, and 14 per cent of the respondents are professionals. 38 percent of the sample respondents are earning the monthly income Between 5,000 to 10,000 and 10 per cent of the respondents are earning the monthly income of 20,000 to 25,000. 18 per cent of the respondents uses Instagram alone as their business platform, 30 per cent of the respondents uses WhatsApp as the platform and 52 per cent of the respondents use both as their platform of business.

Table 2 Entrepreneurs' Assessment of Product promotion Features of Instagram and WhatsApp

Statement	Excellent	Very Good	Good	Neutral	Poor	Total	Mean Score	Rank
Using Hashtags	8 (40)	9 (36)	21 (63)	7 (7)	5 (10)	156	3.12	V
Direct Messaging with Customers	10 (50)	11 (44)	21 (63)	4 (4)	3 (6)	168	3.36	III
Running Ads	6 (30)	13 (52)	24 (72)	2 (2)	5 (10)	166	3.32	IV
Easy Product sharing (Photos, Videos, Reels).	9 (45)	12 (48)	22 (66)	4 (4)	3 (6)	169	3.38	II
Analytics to Track Customer	13 (65)	7 (28)	23 (69)	4 (4)	3 (6)	172	3.44	I

Source: Primary Data

Table 2 shows the features of Instagram and WhatsApp used for business. The first rank is given to Analytics to Track Customers with a mean score of 3.44, followed by Easy Product Sharing with a mean score of 3.38. Direct Messaging with Customers holds the third rank with a mean score of 3.36, while Running Ads ranks fourth with 3.32. The last rank is given to Using Hashtags with a mean score of 3.12.

Table 3 Challenges faced by Women Entrepreneurs Using Instagram and WhatsApp for business.

Statement	Very Often	Often	Rarely	Never	Total	Mean score	Rank
Lack of Digital Marketing Skills	20 (40)	15 (45)	10 (20)	5 (5)	150	3.0	VI
Customer Trust Issues	18 (72)	17 (51)	10 (20)	5 (5)	148	2.96	VII
Poor Knowledge of Analytical Skills	15 (60)	20 (60)	10 (20)	5 (5)	145	2.90	VIII
Comparison with Competitors	22 (88)	15 (45)	8 (16)	5 (5)	154	3.08	III
High cost of Promotion	19 (76)	18 (54)	8 (16)	5 (5)	151	3.02	V
Harassment/Trolling	17 (68)	15 (45)	10 (20)	8 (8)	141	2.82	IX
Customers Cancelling Orders at Last Time	20 (80)	16 (48)	9 (18)	5 (5)	151	3.02	IV
Delayed Payments or Non-Payments	18 (90)	17 (68)	10 (30)	5 (10)	198	3.96	I
Scaling Campaign	16 (80)	10 (72)	11 (33)	5 (10)	195	3.9	II

Source: Primary Data

Table 3 presents the challenges faced by women entrepreneurs using Instagram and Whatsapp for business. The first rank is given to Delayed Payments or Non-Payments with a mean score of 3.96, followed by Scaling Campaign with a mean score of 3.9. Comparison with Competitors holds the third rank with a mean score of 3.08, while Customers Cancelling Orders at Last Time ranks fourth with 3.02. High Cost of Promotion is placed fifth with a mean score of 3.02, followed by Lack of Digital Marketing Skills at sixth with 3.0. Customer Trust Issues ranks seventh with a mean score of 2.96, while Poor Knowledge of Analytical Skills is eighth with 2.90. The last rank is given to Harassment/Trolling, which has the lowest mean score of 2.82.

Suggestions

- Respondents should leverage analytics tools more effectively to understand customer preferences, track engagement trends, and identify potential areas for business improvement.
- To reduce the impact of delayed payments, respondents could adopt secure digital payment systems, clearly communicate payment terms, and offer small incentives for timely payments.
- Providing training or learning resources in digital marketing, campaign scaling, and analytics can enhance their ability to promote products and make informed decisions.
- When deciding prices, respondents should carefully consider delivery/shipping costs, brand positioning, and competitor pricing while maintaining profitability, and plan discounts or seasonal offers strategically.
- Awareness of government schemes like CGTMSE, PMMY, and StandUp India should be increased, and respondents could actively apply for these programs to access financial support and entrepreneurship resources.

Conclusion

The study highlights the need for strategic pricing, meaningful collaborations, and greater awareness for Government support schemes. Women entrepreneurs value delivery costs and brand image when setting prices, and prefer partnering with other sellers and influencers to grow their reach. Enhancing digital skills and promoting access to schemes like CGTMSE and PMMY can further empower these women to scale their business and thrive in the digital economy.

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Impact of AI-Enabled Chatbot on Online Shopping and Customer Satisfaction

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ABSTRACT

In the rapidly evolving digital marketplace, artificial intelligence (AI) has transformed the way businesses interact with customers. Among various AI applications, chatbots have become one of the most widely used tools in online shopping platforms to enhance customer service and satisfaction. This study aims to examine the impact of AI-enabled chatbots on customer satisfaction in online shopping. The research explores how chatbot features such as instant response, personalization, accuracy, and availability influence customers' purchasing decisions and overall experience. Data were collected from a sample of online shoppers through structured questionnaires and analyzed using percentage methods and charts. The findings reveal that most respondents consider chatbots as useful for quick problem resolution, product inquiries, and order tracking. However, some users still prefer human assistance for complex issues. The study concludes that AI-enabled chatbots significantly improve customer satisfaction by providing convenience, efficiency, and real-time interaction, though continuous improvements in accuracy and empathy are essential for better engagement.

Keywords: *Artificial Intelligence, Chatbots, Online Shopping, Customer Satisfaction, Digital Service*

Introduction

In the dynamic era of digital commerce, artificial intelligence (AI) has transformed the way businesses engage with customers, particularly through the adoption of AI-enabled chatbots. These intelligent virtual assistants have become integral to e-commerce platforms, offering instant responses, personalized recommendations, and real-time assistance that enhance convenience and customer satisfaction [1]. By integrating AI-driven chatbots, online retailers are able to improve service efficiency, accuracy, and engagement while reducing human workload. However, customer satisfaction depends on various factors such as response time, information quality, and personalization, which shape users' perceptions of chatbot effectiveness [2]. Hence, this study examines the impact of AI-enabled chatbots on customer satisfaction in online shopping, emphasizing their role in improving service quality, trust, and user experience in the evolving digital marketplace.

Statement of the Problem

The rapid integration of AI-enabled chatbots in online shopping platforms has transformed customer service operations. However, despite their growing adoption, several challenges persist. Customers often encounter issues such as inaccurate responses, lack of personalization, limited emotional intelligence, and inability to resolve complex queries. These limitations may lead to reduced customer satisfaction and negatively influence purchase decisions. While chatbots are designed to enhance efficiency and user experience, their actual effectiveness in meeting consumer expectations remains questionable. Therefore, it is essential to investigate the true impact of AI chatbots on customer satisfaction and promote greater awareness regarding their optimal use in the e-commerce environment.

Review of the literature

Dr. Anita Soni, Dr. Shalini Dubey (2024) [3]; made a study on "The impact of AI-Powered Chatbots on customer satisfaction in E-Commerce Marketing" express AI-powered chatbots significantly enhance customer satisfaction in e-commerce by building trust, improving brand perception, and fostering loyalty. Applying TAM principles to chatbot design boosts user acceptance and usability. While ongoing research is needed to address TAM's limitations with evolving AI, the integration of TAM and chatbots offers great potential for business growth.

Dogan Mert Akdemir, Zeki Atil Bulut (2024) [4]; conducted a study on "Business and customer-based Chatbots activities: The role of customer satisfaction in online purchase intention and intention to reuse Chatbots" explores how chatbot marketing efforts, communication quality, and user motivation influence customer satisfaction in online shopping, and how that satisfaction impacts purchase and reuse intentions. It combined both business-driven (marketing and communication quality) and consumer-driven (motivation) factors for a comprehensive view. The findings showed that marketing efforts improve communication quality (H1), and high-quality communication enhances customer satisfaction (H2). In turn, satisfaction positively influences both purchase (H4) and reuse intentions (H5), with a stronger impact on reuse. However, user motivation for using chatbots did not significantly affect satisfaction (H3), possibly due to unmet expectations. Overall, the study highlights the importance of aligning business chatbot strategies with user needs to boost satisfaction and behavioral outcomes.

Alfredo Daza Vergaray, Wilfredo Fabriccio Peralta Robles, Jahaira Arely Salazar Jiménez (2023) [5]; in their study on "The Impact of Chatbots on customer satisfaction: A Systematic Literature Review" shows that chatbots are widely used in ICT, health, administration, entertainment, and sales—ICT being the most prominent. Text-based AI

chatbots are the most common, helping users resolve queries and improve interaction. Most research on chatbot use for customer satisfaction comes from the United States

Objectives

1. To identify the key features of AI chatbots that influence consumer purchase decisions.
2. To determine the customer satisfaction towards AI chatbots.
3. To examine the problems faced by the customers that affect their purchase decisions while interacting with AI chatbots.

Methodology

The present study is descriptive, focusing on the impact of AI-enabled chatbots on customer satisfaction in online shopping. Data were collected from both primary and secondary sources. Primary data were gathered through structured questionnaires from 100 online shoppers in Kanyakumari district. Secondary data were obtained from journals, research articles, and online reports. Participants were active users of platforms like Meesho, Flipkart, and Amazon. A simple random sampling method was used to select respondents.

Data Analysis

After collecting the primary data, it was classified, arranged and the master table was prepared. Data were organised and tabulated for further analysis. Percentage was used to analyse the demographic profile of the respondents. Likert's five-point scale was used for analysis and interpretation of data. (anchored as 1 = strongly disagree; and 5 = strongly agree).

Demographic Profile

Demographic Profile of the Respondents Demographic profile of the respondents was grouped as age, gender, educational qualification, occupation, and monthly income. Demographic profile of the respondents was captured in Table 1.

Table 1: Demographic Profile of the Respondents

Category	Profile	Percentage
Age	Below 20 years	10
	20-30 years	74
	30-40 years	10
	Above 40 years	6
	Total	**100**
Gender	Male	32
	Female	68
	Total	**100**
Marital status	Married	42

	Unmarried	58
	Total	**100**
Occupation	Student	40
	Employee	50
	Home Maker	10
	Total	**100**
Family Income	Below 20,000	36
	20,000-30,000	24
	30,000-40,000	22
	Above 50,000	18
	Total	**100**
Place	Rural	54
	Urban	28
	Semi-Urban	18
	Total	**100**

Sources: Primary data

The study shows that 74 percent of respondents are aged 20-30 years, forming the largest age group. 68 percent are female, representing the majority in gender. Most respondents, 58%, are unmarried. In terms of occupation, 50 percent are employees, which is the highest among the categories. Regarding family income, 36 percent earn below ₹20,000 per month, indicating that the largest income group of most respondents, 54 percent, live in rural areas. 40 percent of respondents are students, showing active participation from young learners. 18percent of respondents are homemakers, representing a smaller but notable group in the study.

Table 2: Features of AI-Chatbots

Features	**Very useful**	**Useful**	**Neutral**	**Not useful**	**Total**	**Mean score**	**Rank**
Instant response	27 (108)	14 (42)	9 (18)	0 (0)	168	3.36	I
Order tracking	19 (76)	26 (78)	5 (10)	0 (0)	164	3.28	II
Product recommendations	11 (44)	16 (48)	19 (38)	3 (3)	133	2.66	VII
Complaint resolution	11 (44)	17 (51)	18 (36)	4 (4)	135	2.70	VI

Discount &Offers Information	21 (84)	18 (54)	11 (22)	0 (0)	160	3.20	III
Automated FAQs	9 (36)	16 (48)	17 (34)	7 (7)	125	2.50	VIII
Collect customer feedback	14 (56)	17 (51)	17 (34)	0 (0)	141	2.82	V
Multilingual support	16 (64)	18 (54)	12 (24)	2 (2)	144	2.88	IV

Sources: Primary data

From the above table 2, it shows the features of chatbot and it was ranked accordingly, instant response stands in the first, showing that most users find it very useful. Order tracking stands in the second, which means customers like using chatbots to know their order status. Discount and offers information stands in the third, multilingual support in the fourth, showing that language options are also valued. Collecting customer feedback stands in the fifth, while complaint resolution stands in sixth. product recommendations stand in the seventh. Automated FAQs stand in the eighth. It shows that instant response stands in a higher position, means users give more importance to quick and convenient chatbot features.

Table 3: Users Satisfaction with AI Chatbots

Statements	**Fully Satisfied**	**Satisfied**	**Neutral**	**Not Satisfied**	**Total**	**Mean score**	**Rank**
Speed of Response	24 (96)	22 (66)	3 (6)	1 (1)	169	3.38	I
Accuracy of Answers	10 (40)	31 (93)	7 (14)	2 (2)	149	2.98	VI
Ease to use	20 (80)	15 (45)	11 (22)	4 (4)	151	3.02	III
Personalization	18 (72)	20 (60)	10 (20)	2 (2)	154	3.08	IV
Problem Resolution	14 (56)	20 (60)	10 (20)	5 (5)	141	2.82	VII

Order tracking	21 (84)	18 (54)	10 (20	1 (1)	159	3.18	II
Multilingual support	15 (60)	25 (75)	9 (18)	1 (1)	154	3.08	V
Product Recommendation	15 (60)	19 (57)	12 (24)	4 (4)	145	2.9	VIII

Sources: Primary data

From the above table 4, it indicates the factors affecting chatbot performance, and they are ranked accordingly. Speed of response stands first, showing that users highly value quick replies from chatbots. Order tracking stands second, meaning customers like being able to easily track their orders. Ease of use stands third, highlighting the importance of a simple and user-friendly interface. Personalization stands fourth, while multilingual support stands fifth, showing that users appreciate tailored responses and language flexibility. Accuracy of answers stands sixth, while problem resolution stands seventh, indicating these are moderately important. Product recommendation stands eighth, suggesting it is the least prioritized factor. Overall, it shows that the speed of response stands higher, meaning users give more importance to quick and efficient chatbot performance.

Table 4: Issues with Chatbots

Issues	**Never**	**Sometimes**	**Rarely**	**Always**	**Total**	**Mean score**	**Rank**
Irrelevant Answers	15 (60)	26 (78)	7 (14)	2 (2)	154	3.08	I
Slow response	9 (36)	23 (69)	18 (36)	0 (0)	141	2.82	IV
Can't solve complex issues	13 (52)	25 (75)	10 (20)	2 (2)	149	2.98	II
Too robotic	7 (28)	21 (63)	14 (28)	8 (8)	127	2.54	VII
Limited understanding	7 (28)	29 (87)	9 (18)	5 (5)	138	2.76	V

Scripted responses	8 (32)	23 (69)	12 (24)	7 (7)	132	2.64	VI
Technical Glitches	12 (48)	27 (81)	9 (18)	2 (2)	149	2.98	III

Sources: Primary data

From the above table 3 indicates the issues of the chatbot, and they are ranked accordingly. Irrelevant answers stand first; it shows that users often receive responses that do not match their queries. Can't solve complex issues stands second, technical glitches in third, indicating that chatbots sometimes struggle with complicated problems or face system errors. Slow response stands fourth, while limited understanding stands fifth, showing these issues occur occasionally. Scripted responses stand sixth, showing that responses are already set by others. Too robotic stands seventh, suggesting they are less common. Overall, it shows that irrelevant answers stand higher, which means users face this issue more than others.

5.2 Findings

- 74 per cent of the respondents belong to the 20-30 years age group, showing that young adults are the main users of AI-enabled chatbots.
- 68 percent are female, indicating that female customers use chatbots more actively than males.
- 58 per cent of the respondents are unmarried, showing that unmarried individuals use chatbots more frequently.
- 50 per cent of the respondents are Employees, which shows that working people use chatbots more for online shopping.
- 36 per cent of respondents belong to families with earnings below 20,000 per month, which shows that chatbot users come from diverse income groups.
- 54 per cent of respondents are from rural areas, which shows that chatbot usage is also spreading beyond urban regions and reaching rural areas as well.
- Out of Eight Features, respondents have given first rank to Instant responses, second rank to Order tracking, and third rank to Discount and Offers Information. The least useful feature is Automated FAQs.
- Out of Seven Issues, respondents have given first rank to Irrelevant Answers, second rank to solving Complex issues, and third rank to Technical Glitches. The least common issue is Too Robotic Behaviour, which shows that the major issue is Irrelevant answers.

- Out of eight satisfaction factors, respondents gave first rank to Speed of response, the second rank to order tracking, and the third rank to Ease of use. The least satisfying factor is product recommendations.
- 36 per cent of the respondents suggested that chatbots should provide faster replies. This indicates that response speed is a major factor affecting user satisfaction.

5.3 Suggestions

- Chatbots should offer personalized product suggestions and responses based on customers browsing history and previous purchases.
- The communication style of AI-enabled chatbots should be more human-like to create natural and engaging interactions with users.
- AI-enabled chatbots must be designed to handle complex queries effectively and should provide an option to connect with a human representative when required.
- Online shopping platforms should incorporate multi-language support in chatbots to serve customers from diverse linguistic backgrounds.
- Continuous updates and training of AI-enabled chatbots are necessary to maintain accuracy, relevance, and alignment with evolving customer expectations.

5.4 Conclusion

The study on the impact of AI-enabled chatbots in online shopping and customer satisfaction reveals that chatbots have become an essential part of the modern e-commerce experience. The findings indicate that young adults, especially females and working individuals, are the primary users of chatbots for online shopping purposes. Most respondents use chatbots for basic tasks such as checking product details, tracking orders, and resolving simple queries. However, the results also show that users expect faster responses and more accurate answers from chatbots. Although chatbots have proven to improve convenience and save time, users still prefer human assistance when the chatbot fails to resolve complex issues. This shows that AI-enabled chatbots, while efficient, still need to evolve to achieve full customer trust and reliability.

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Awareness Towards Gi Tagged Products in Kanyakumari Districts

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ABSTRACT

Geographical Indication (GI) tags are an essential part of IP, which protects goods with distinctiveness and reputation and a specific geographical origin. In India, GI-tagged products have a major role in maintaining traditional knowledge, culture, and economic development in a particular region. The Kanyakumari district in Tamil Nadu is famous for GI-tagged products such as Kanyakumari Clove, Matti Banana, Marthandam Honey, Tall Coconut, and Thovalai Manikkamalai. But awareness of the importance of GI tags among consumers is less. The main objective of this research work is to examine the level of awareness of GI-tagged products in Kanyakumari district and to analyze consumer perception and behavior. The research work is based on both primary and secondary sources. Primary sources were gathered from 50 samples using a structured format through a simple random sampling method. Statistical methods such as percentage analysis, Garrett ranking technique, weighted average analysis, and Likert five-point scale analysis were used in this research work. The analysis shows that though awareness level is present, awareness of the economical and cultural significance of GI-tagged products is lacking.

Keywords: *Buying behaviour, Consumer awareness, Consumer perception, Geographical indication (GI), Kanyakumari district.*

Introduction

India is a land of diverse cultures, traditions, and unique regional products that reflect its rich heritage. To preserve and promote these distinctive goods, the Government of India introduced the Geographical Indications (GI) Tag under the Geographical Indications of Goods (Registration and Protection) Act, 1999. A GI tag is a form of intellectual property that identifies a product as originating from a specific geographical location, where a given quality, reputation, or characteristic of the product is essentially attributable to its place of origin. Examples include Darjeeling Tea, Kanchipuram Silk Sarees, Mysore Sandalwood, and Basmati Rice. Despite the growing list of GI-tagged products, public awareness about them remains limited, particularly among consumers, producers, and even retailers. Many people are unaware of the significance of the GI tag, how it benefits local economies, ensures authenticity, and protects traditional knowledge. Raising awareness about GI-tagged products is essential not only for preserving cultural heritage, but also for promoting sustainable livelihoods, boosting rural economies, and empowering local artisans and farmers.

Tamil Nadu, one of India's most culturally vibrant states, is renowned for its rich heritage, traditional crafts, and unique agricultural practices. Many of these culturally significant products have received Geographical Indications (GI) tags, which serve as a form of legal protection and recognition for goods that originate from a specific region and possess qualities or a reputation linked to that origin. In Tamil Nadu, several well-known products such as Kanchipuram Silk Sarees, Madurai Jasmine, Salem Mango, Kumbakonam Degree Coffee, and Mahabalipuram Stone Sculpture have been granted GI status.

Statement of the Problem

Geographical Indication (GI) tags play a crucial role in preserving the uniqueness, quality, and cultural heritage of locally produced goods. Despite several products in India receiving GI tags to promote regional identity and economic benefits, awareness among the general public, especially in rural and semi-urban areas, remains limited. In the context of Kanyakumari district, which is rich in traditional and indigenous products, there is a noticeable gap in public knowledge about the importance, benefits, and recognition of GI tagged products. This lack of awareness can hinder the promotion, demand, and fair pricing of such goods, ultimately affecting the livelihoods of local artisans, farmers, and producers. Therefore, it is essential to understand the level of awareness among the people in Kanyakumari district regarding GI tagged products and to identify the barriers that prevent effective dissemination of this information.

Review of Literature

Shilpa Rathod (2023) critically explored that the multifaceted barriers to the effective implementation of Geographical Indications (GIs) under the Geographical Indications of Goods (Registration and Protection) Act, 1999. Through secondary sources like WIPO, WTO, and IP India, the paper identifies key legal, economic, social, and geographical challenges, highlighting disparities among Indian states in GI registrations, inadequate awareness among rural artisans, and weak post-registration enforcement mechanisms. The study's intent to use data visualization (charts, pie diagrams) and secondary literature to analyze these issues and proposes that addressing such gaps can help India fully leverage its GI potential for economic and cultural benefit. Suggestions given by them are government subsidies, fast-track registration, integration with tourism, and stronger punitive measures, it could be strengthened through clearer language, more structured analysis, inclusion of case studies, and use of primary data to substantiate claims. Overall, Rathod's work is a timely contribution to GI policy discourse and provides a foundation for further empirical and legal research in this domain.

Dr. D. Rajagopal (2023) investigated the level of consumer awareness, buying behavior, and the effectiveness of marketing strategies surrounding GI-certified handloom products such as Pochampally Ikat, Gadwal Sarees, and Narayanpet Handloom and that while 68% of participants are generally aware of GI tags, only 60% can identify Telangana-specific GI handloom products. Social media and government campaigns are key drivers of awareness, yet 34% of consumers feel these efforts remain ineffective. Purchasing behavior is influenced by authenticity, fabric quality, and affordability, with government outlets and online platforms being common points of sale. It emphasizes the need for improved digital marketing, greater product visibility in mainstream retail, and enhanced government-industry collaboration. Dr. Rajagopal ultimately advocates for a comprehensive strategy to bridge the gap between traditional artisans and modern consumers, ensuring the sustainability and growth of Telangana's GI handloom market.

S. Yuvasri and N. Yamuna (2023) explored that the role of Geographical Indications (GIs) in protecting and promoting agricultural products with unique regional identities. The paper explains how GI tags link a product’s distinct qualities, reputation, and characteristics to its geographical origin, using examples like Darjeeling Tea to illustrate the enforcement of GI rights against unauthorized use. They emphasized that while GIs grant protection over the use of a name, they do not provide monopolistic rights over the production methods. The conclusion highlights the importance of GIs in preserving agricultural heritage and intellectual property in rural areas, urging for stronger promotional strategies to harness the commercial value of GI-tagged products. Additionally, they caution against assigning GI tags to food items that are easily replicable across regions, as it undermines the authenticity and purpose of GI protection. Overall, the study underscores the critical role of GIs in market differentiation, product quality assurance, and cultural preservation in agriculture.

Objectives of the Study

1. To study the demographic profile of the respondents.
2. To assess the level of awareness of consumers on GI tagged products.

Scope of the Study

This study focuses on assessing the level of awareness about Geographical Indication (GI) tagged products among the people of Kanyakumari district in Tamil Nadu. It covers various segments of the population including consumers, students, local artisans, and retailers. The study aims to understand how familiar the public is with the concept of GI tags, their significance in protecting traditional products, and their role in promoting local culture and economy. Specific attention is given to GI tagged products that are either produced in or

commonly known in Tamil Nadu, such as handloom items, traditional crafts, and agricultural products. The study also explores the sources through which people gain awareness—such as media, educational institutions, and government initiatives—and examines the impact of this awareness on consumer behavior and the livelihood of local producers. Furthermore, the research seeks to identify the challenges faced in spreading awareness and suggests practical measures to improve knowledge and appreciation of GI tagged products within the district.

Methodology

A structured survey conducted among consumers in Kanyakumari district to measure their awareness of GI (Geographical Indication) tagged products. Factors such as knowledge about GI labels, buying behaviour, trust in authenticity, and willingness to pay for GI products will be assessed. In-depth, semi-structured interviews will be carried out with selected respondents and local traders to explore their perceptions, experiences, and challenges regarding GI products. The role of awareness programs, government initiatives, and word-of-mouth promotion in shaping awareness will also be examined.

Data Analysis

After collecting the primary data, it was classified, arranged and the master table was prepared. Data were organised and tabulated for further analysis. Percentage was used to analyse the demographic profile of the respondents. Likert's five-point scale was used to assess Consumers' level of awareness of on GI tagged products

Demographic Profile of the Respondents

Demographic profile of the respondents was captured in Table 1.

Table 1 Demographic Profile of the Respondents

Category	**Profile**	**Percentage**
Age	Below 20 years	46
	21 -40	50
	41 -60	4
	Above 61 years	-
	Total	**100**
Gender	Male	24
	Female	76
	Total	**100**

Marital Status	Married	26
	Total	**100**
Educational Qualification	Upto school level	14
	Diploma	8
	Professional education	56
	Any others	22
	Total	**100**
Occupation	Private employees	14
	Government employees	6
	Any others	80
	Total	**100**
Number of family members in the family	1 and 2	2
	3	24
	4	42
	5	24
	6 and above	8
	Total	**100**
Monthly Income	UP to RS10000	38
	10,001-20,000	22
	20,001-30,000	24
	Above 30,001	16
	Total	**100**

Source: Primary data

Table 1 implies that 46 per cent of the respondents belong to the age group of below 20 years, 50 per cent of the respondents belong to the age group of 21–40 years and only 4 per cent of

the respondents fall under the age group of 41–60 years. This shows that the majority of the respondents are young, indicating greater participation of the younger generation in the study. It is observed that 76 per cent of the respondents are female and 24 per cent of the respondents are male, indicating a higher participation of female respondents in the survey.

With regard to marital status, 26 per cent of the respondents are married, while the remaining respondents belong to other marital categories. This shows that a majority of the respondents are unmarried.

Regarding educational qualification, 56 per cent of the respondents have professional education, 22 per cent belong to other educational categories, 14 per cent have education up to school level and 8 per cent have completed diploma courses. This indicates that most of the respondents possess higher educational qualifications.

In terms of occupation, 80 per cent of the respondents belong to other occupational categories, 14 per cent are private employees and 6 per cent are government employees. This shows that respondents from different occupational backgrounds are included in the study.

With respect to the number of family members, 42 per cent of the respondents have four members in their family, 24 per cent have three members, another 24 per cent have five members, 8 per cent have six or more members and only 2 per cent have one to two members. This indicates that most respondents belong to medium-sized families.

Regarding monthly income, 38 per cent of the respondents earn up to Rs.10,000 per month, 22 per cent earn between Rs.10,001–20,000, 24 per cent earn between Rs.20,001–30,000 and 16 per cent earn above Rs.30,001. This shows that the majority of the respondents belong to low- and middle-income groups.

Table 2

Consumers' level of awareness of on GI tagged products

S. No	Features of GI Products	Strongly agrees	Agree	Neutral	Disagree	Strongly disagree	Total	Mean	Rank
1.	Maintain Quality standard	26*5 (130)	17*4 (68)	5*3 (15)	2*2 (4)	-	217	4.34	I
2.	Support local farmers and artisans financially	13*5 (65)	25*4 (100)	11*3 (33)	1*2 (2)	-	200	4	II
3.	Preserve traditional	18*5	14*4	14*3	3*2	1*1	195	3.9	III

	skill and culture value	(90)	(56)	(42)	(6)	(1)			
4.	Increase popularity and recognition of regional items	18*5 (90)	15*4 (60)	8*3 (24)	8*2 (16)	1*1 (1)	191	3.82	IV
5.	Create more job opportunities for local people	16*5 (80)	15*4 (60)	10*3 (30)	6*2 (8)	1*1 (1)	189	3.78	V
6.	Encourage sustainable and ethical production	16*5 (80)	16*4 (64)	9*3 (27)	8*2 (16)	1*1 (1)	188	3.76	VI
7.	Promote pride in regional identity and heritage	20*5 (100)	18*4 (72)	5*3 (15)	6*2 (12)	1*1 (1)	200	4	II

Source: Primary data

Table 2 shows the respondents' opinions on the reasons for purchasing GI products. It is observed that maintaining quality standards ranks first with the highest mean score of 4.34, followed by supporting local farmers and artisans financially and promoting pride in regional identity and heritage, both with a mean score of 4.00, ranking second. Preserving traditional skills and cultural values ranks third (mean 3.9), followed by increasing popularity and recognition of regional items (mean 3.82), creating more job opportunities for local people (mean 3.78), and encouraging sustainable and ethical production (mean 3.76). This clearly indicates that the primary motivation for purchasing GI products is their quality.

Findings

- 50 per cent of the respondents belong to the age group of 21–40 years, showing young adults are the most aware and active consumers of GI products.
- 76 per cent of the respondents are female indicating that women are the dominant demographic in GI product awareness and purchase.
- 37 per cent of the respondents form the largest group of consumers, suggesting younger, single individuals are more engaged with these products.

- 56 per cent of respondents have professional education highlighting the link between higher education and awareness of GI products.
- Awareness level is high, with 58 per cent of respondents knowing about GI products and 52 per cent having purchased them.
- Friends and family (32 per cent) and online platforms (28 per cent) are the primary sources of awareness, indicating reliance on personal networks and digital media.
- Tall coconut and Kanyakumari matti banana are the most recognized GI products, followed by Marthadam honey and Kanyakumari clove.
- Product quality is the most significant factor motivating purchase, followed by health benefits, regional identity, and cultural/traditional value.
- 60 per cent of respondents feel proud of local GI products, and 48 per cent are willing to recommend them to others, reflecting positive consumer perception.
- Respondents are highly satisfied with product quality (mean 4.40), pride in usage (mean 4.04), and availability (mean 3.94).

Suggestions

- Since most of the respondents who have never heard about GI products, policy makers have to increase overall awareness of GI tagged products.
- Promote lesser-known GI products, such as Thovali manikkamalai, which have the lowest recognition among respondents.
- Strengthen traditional media campaigns (TV/radio) since only 6 per cent of respondents learn about GI products through these channels.
- Organize workshops, exhibitions, and local fairs to introduce GI products to under-informed segments.
- Provide information about health and environmental benefits, which are less considered by some respondents compared to product quality.

Conclusion

The study reveals that GI-tagged products in Kanyakumari are most recognized and appreciated by young, educated, and female consumers, with product quality and regional identity serving as key factors in purchase decisions. Consumers take pride in local products and are generally willing to recommend them, reflecting a positive perception. However, gaps in awareness exist among males, less-educated groups, government and private employees, and consumers of lesser-known GI products. By targeting these underrepresented groups through awareness campaigns, educational programs, promotional events, and traditional media, the reach, adoption, and economic impact of GI products can be significantly enhanced. Overall,

GI products have strong potential to succeed nationally and internationally, while preserving local heritage and supporting sustainable economic growth.

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Women and Patriarchy in Aruni Kashyap's *The House with a Thousand Stories*

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ABSTRACT

This paper examines the representation of women and patriarchy in Aruni Kashyap's The House with a Thousand Stories, highlighting how the novel portrays the pervasive restrictions placed on women in Assamese society. Through characters such as Moina-pehi, Oholya-jethai, Anamika, and others, Kashyap reveals how women's lives are tightly controlled by social customs, family expectations, marriage norms, and community gossip. The narrative also shows how political unrest particularly involving ULFA and SULFA intensifies women's vulnerability, limiting their freedom of movement and exposing them to violence, fear, and emotional trauma. While men dominate both public and private spheres, women silently endure psychological, physical, and social oppression. The novel also describes moments where women subtly assert agency through everyday acts of resilience, skill, and emotional strength. Overall, the study argues that Kashyap's work powerfully critiques the intertwined forces of patriarchy and political conflict, revealing how they shape and constrain women's identities, choices, and lived experiences.

***Keywords**: Patriarchy, Gender, Women, Oppression, Agency.*

Aruni Kashyap's *the House with a Thousand Stories* depicts how women in Assamese society live under strict patriarchal rules. Women's choices are limited by family expectations, traditional practices, and social gossip. These pressures restrict their ability to make independent decisions. In the novel, Moina-pehi is portrayed as a bride entering a strongly patriarchal society. From the beginning of her married life, she faces strict rules and limitations. Her role is defined by service to others rather than personal desire. As a result, she sacrifices her freedom and sense of individuality.

Moina gradually becomes a victim of social duties and cultural obligations. Her experience reflects the broader suffering of women under patriarchal control. The political unrest in Assam further worsens women's lives. The fight between ULFA and SULFA creates an atmosphere of fear and uncertainty. Women experience loss and trauma due to ongoing violence. At the same time, they remain tightly controlled within their homes by family and social norms.

Men continue to dominate both public and private spaces. Women are left with little power or voice. Their suffering is endured in silence. Much of their pain remains unnoticed, hidden behind daily routines imposed by others.

Oholya-jethai's story highlights the personal cost of being judged and gossiped about. Kashyap writes:

> Oholya-jethai was always the first one to react. She loved gossip and I wondered if that was because she was the subject of the biggest gossip in Hatimura Village, Mayong, many years ago. And I was glad in spite of the restlessness inside me, in spite of the rage and loneliness inside me that she was once again on the verge of switching back to her unpopular self. (5)

She is described as "the perfect beauty with puffy eyes, large buttocks and long, black hair, fit to be the subject of the biggest gossip in Hatimura Village" (5). These lines reveal how women are constantly judged and objectified. As a result, they turn to gossip as a way to survive and adapt. Oholyajethai's experiences reveal the silent pressures and suffering that women endure in a patriarchal society.

Women's lives are shaped by both political unrest and patriarchal control. The ULFA fighters endured hunger, illness, and harsh living conditions. They were known for showing respect to the women in their communities. In disparity, the SULFA, who had wealth and influence, often imposed their authority over women, sometimes marrying them by force when families lacked the courage to refuse. As the narrator observes, "married whomever they wanted to, since the girl's family didn't have the courage to refuse them (even if they did, the SULFA would take the girl away by force)" (11). This highlights how women's safety and freedom were controlled by male authority and social power. Patriarchal attitudes place women at risk even in public spaces. Their independence is often undermined by these mindsets. Crowded streets and festive gatherings become unsafe environments for women. In such spaces, they are more vulnerable to harassment. The narrator recalls these moments to emphasize the constant fear women experience in everyday life.

"Wallets disappeared, girls got their bottoms and boobs pinched, and strange hands felt up men's crotches during those mad evenings" (29). Women often experience unwanted attention and physical danger. This shows that patriarchy extends beyond the household and operates throughout society. Public spaces are not always safe for women. Even during celebrations and social gatherings, they are forced to remain cautious. Social customs restrict their freedom and silently permit such behavior to continue.

Political unrest and insurgent activities make the situation even worse. These conditions directly threaten women's safety. Their personal freedom is also severely affected.

One description observes that "Mom hadn't looked too convinced: as if it was abnormal not to have a shutdown, some unrest, some killing or an unhappy organization calling for trouble" (31). Constant violence becomes normalized in society. Women, like the mother, are forced to live in a continual state of fear and alertness.

When the narrator explains that "a bandh meant complete shutdown not even PCOs, not even paid urinals, would remain open because no one wanted their shop gutted, no one wanted their restaurant pelted with stones" (31), the impact of such situations on women becomes clearer. Patriarchy already limits women's freedom of movement. In periods of political violence, these restrictions become even harsher. Ordinary activities such as traveling, shopping, or visiting relatives are no longer safe. Women are forced to avoid public spaces. As a result, the outside world turns hostile and dangerous. This situation pushes women into deeper isolation and dependence.

The father's dismissal of this fear, "Papa had said in an impatient voice that even if there was a bandh we would eventually reach Mayong" (31) reflects the gendered difference in how unrest is experienced. Men often see such events as inconveniences, while women view them as threats to life and dignity. This shows that men in power often ignore women's worries, thinking they are exaggerated. Because of this, women are not listened to during crises.

Patriarchal norms also subtly restrict women's speech and behaviour within private spaces. Mom is unable to argue freely with Papa because "it was the question of propriety that gagged her. In a village, it was unusual for a woman to talk to her husband during the day inside a room" (37). Oholya Jethai watches carefully from behind the curtains, waiting for permission to speak. This shows that women's actions are always influenced by society. These examples show that patriarchy is not limited to public spaces. It is deeply rooted in everyday life. Even within the home, women's freedom is restricted. Their voices are often silenced or ignored.

Oholya Jethai shows a quiet form of strength and self-reliance within the limits set by patriarchy. She asserts her independence in subtle ways. One such moment is when she proudly states that she stitches all her clothes by hand. She uses only silk, not cotton. She even offers to make a piece for Mom: "Tell me if you want one. I can weave one for you next Bihu" (41). Her conversation reflects how women negotiate social expectations in their daily lives. They try to balance traditional roles with personal choices. She respects customs such as weddings and prayer meetings. At the same time, she confidently displays her skills and knowledge.

Through these actions, Kashyap suggests that women preserve their individuality and inner independence, even within a society dominated by patriarchy.

Political violence leaves deep emotional scars on women. They often carry the heaviest burden of fear and loss. When a man was abducted and later killed, his wife experienced overwhelming grief. She recalls the moments leading up to his death. The memory of seeing his lifeless body remains a source of lasting trauma.: “His wife howled, saying how much he loved the turtle curry. When the corpse fell, the blood had splattered around the pole” (53). These events reveal that although men are often the direct targets of insurgency and violence, women suffer deeply at the psychological level. They live with constant fear and emotional trauma. Their daily lives are severely disrupted. Political unrest therefore intensifies the limitations women already face. It adds new layers of hardship to the oppression created by patriarchy.

Political unrest and secret killings generate an atmosphere of fear that profoundly affects women. Even when men are the primary targets, women bear the emotional weight of violence. They suffer as they witness or learn about attacks on their family members. In one instance, when masked gunmen abducted a man from his home, his wife begged for her life. She clung to him and pleaded desperately, trying to protect him.: “asked them to kill her and not him, told the assassins that he was the only earning member of the family” (69). The community responds with fear and anxiety, revealing how violence threatens women’s emotional well-being and everyday life. In a society shaped by both patriarchy and political conflict, women face compounded hardships. They must navigate dependence on their families while also confronting dangers in the outside world.

Societal pressure on women regarding marriage and age is evident in how they are judged by others. At nearly thirty-two, the question arises: “Which young man will marry her now?” (80). This shows that a woman’s worth is often tied to marriage in a patriarchal society, limiting her choices and creating anxiety about her future. Even when women try to pursue personal happiness, social rules and men’s opinions shape how their lives are perceived. This illustrates how patriarchy subtly controls women’s choices and dreams.

Women in the village frequently face criticism for their family’s decisions. This reflects the deep influence of patriarchal norms. For example, Meenu Jethai, Oholya Jethai’s older sister, is upset because her second son married a girl from a lower caste against the family’s wishes. As a result, he no longer lives with them.

The men in the village often dismiss such incidents as unimportant. Yet they quietly remember these stories. They use them to monitor the behavior of their own sons and younger

men. This demonstrates that women's lives and decisions are constantly observed, creating social pressure and limiting their freedom.

Mamoni's story further shows how women directly suffer under patriarchal violence. Society's response is often silence, which reinforces their oppression.

Kashyap writes, "she had been raped by four military men when she had gone to wash clothes in the Pokoria River last year" (112). showing how male authority and power over women's bodies becomes a form of control.

Anamika's brief introduction in the village shows how women's identities are often overlooked in a patriarchal society. Kashyap writes, "My name is Anamika.
Was this her way of saying that she would come with me? Anamika: the woman without a name" and later adds, "I felt as if we were on a grand mission. I didn't know that when I would think back on that sun smeared morning" (126). These lines reveal how even when women assert their identity, society and circumstance often define their roles. Anamika's naming highlights both her personal agency and the limitations imposed by the male-dominated social structure around her.

Anamika's story in the wedding house shows how patriarchy affects women. Even a private moment, like her kiss, is seen and judged from a man's perspective. Kashyap writes,

> I pressed myself against her, and then turned her around and kissed her on the lips. She was still looking at me in disbelief when I let her go, I was smiling. She blushed. 'What did you just do?' she gasped… We kissed, until we heard footsteps… I must have raised my eyebrow just a bit. (157)

This shows that in a patriarchal society, women's choices and actions are often controlled or judged by men.

Women like Anamika are not free to fully live their own lives, because society measures their worth based on how men see or remember them. "After the wedding, a few hours later, the groom's family came unexpectedly and blamed Moinapehi's family for marrying off a "sick bride" whose health problems they claimed were hidden from them" (189). The family did not call the village doctor because they were worried about their reputation. This reveals how society's rules often take precedence over women's well-being. Oholyajethai, who had withdrawn into a reclusive life, returned briefly and slapped Moina-pehi, saying, "You want to become like me? You don't want to marry? Didn't I tell you this afternoon not to even think about it? My child, my baby, there's no respect for an old maid" (189).

Moina-pehi's reaction shows the pressure and fear women face: "Better to die than get married into such a family… Let me die please, I don't want to suffer later, I don't want to be killed by unknown assassins! You can shoot me dead here, right here in my head in this house!" (189). Her convulsions, which shake the bed, show how strong social expectations and patriarchy can harm women physically and mentally. This moment reveals that women are forced to follow family and societal rules, often sacrificing their safety and happiness.

Kashyap also depicts how patriarchy burdens women with endless domestic labour. He writes,

> Okoni-pehi had already started to scream, when I noticed Anil da getting down from the cycle … Didn't I ask both of you to come and mop it up with cow dung immediately? People are not ashamed to take up to four helpings at meals, but when it comes to real work. (210)

This passage shows that women like Okonipehi are weighed down by constant household work. Men like Anil da feel hurt pride when they are asked to do the same tasks. Patriarchy here works silently, dividing work as male and female, and making women's contribution invisible.

Similarly, anxiety around marriage is depicted as,

> There is government. Such rumours come to all wedding houses. My parents heard my future husband had already taken a wife. There is law and order in this country. My child, please don't behave like this. Do you want to remain an old maid like me? … this is just a small rumour. Please don't cry. (215)

Here, the anxiety around marriage is not focused on the man's loyalty or honesty but on the woman's destiny. The idea that a girl must marry at all costs, even if the groom is already married, shows how patriarchy defines a woman's worth only through marriage. The old maid's warning that it is better to marry than remain unmarried reflects a social reality where unmarried women are considered incomplete or failures.

Thus, *The House with a Thousand Stories* shows that women in Assamese society live under constant pressure from patriarchal norms. Their choices, actions, and even personal moments are often controlled, judged or limited by men and societal expectations. From family obligations and domestic work to social gossip, marriage, and political unrest, women such as Moina-pehi, Oholya-jethai, and Anamika navigate a world where their freedom, safety, and identity are often secondary to male authority and societal rules. Kashyap's novel highlights both the struggles' women face and the ways they quietly assert their agency. It shows that despite oppression, women continue to find resilience, courage, and individuality within a restrictive, patriarchal society.

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Family and Identity in Aruni Kashyap's T*he House with a Thousand Stories*

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ABSTRACT

Aruni Kashyap's The House with a Thousand Stories offers an intimate look into the emotional, cultural and political undercurrents that shape everyday life in rural Assam. Within this complex landscape, the themes of family and identity emerge as central forces that guide the choices, fears and silences of the characters. This study investigates how the novel represents family as a deeply influential structure one that nurtures, confines and often moulds individual identity through tradition, memory and unspoken expectations. The paper also examines how characters negotiate their sense of self while being tied to obligations of kinship, ancestral pride and community reputation. By examining the tension between individual desires and collective responsibility, this analysis shows that identity is never fixed or simple. Instead, it emerges as layered and vulnerable continuously shaped by social expectations and political realities. Kashyap presents identity not as something formed in isolation, but as a process deeply rooted in family life where emotional closeness exists alongside obligation and pressure. Through this portrayal the study emphasizes the powerful role family plays in shaping one's sense of self.

Keywords*: Family, Identity, Social belonging, Culture.*

In Assamese culture family and identity are inseparable. An individual's dignity, belonging and social recognition are largely determined by family relationships, inherited traditions and the closely knit structure of village life. In *The House with a Thousand Stories*, Aruni Kashyap explores how these bonds are tested during political unrest. In Mayong village family gives a person identity, respect and a sense of belonging. One's name and position in society are closely tied to family background. When tradition, unspoken histories and village politics enter this space identity becomes fragile. Through the Bishoya family the narrative shows how identity is shaped by lineage and shared responsibility. Every member carries the weight of maintaining family honour.

Moina-pehi Pablo's aunt, becomes central during the wedding episode. Her marriage reveals how personal wishes often give way to family expectations. In Assamese society marriage

strongly shapes a woman's identity often defining her role and future. Cultural rules and social pressure leave little room for individual choice.

From the beginning the wedding carries both joy and strain. It is not just a personal celebration but a moment where family identity is openly displayed. In Assam weddings bring whole families together and expose their internal order. Through Pablo's observation the courtyard appears busy and controlled. Oholya-jethai watches over the rituals with authority. Okoni-pehi directs the younger members. Onimaborma takes charge of the arrangements. Their actions turn the house into a space where celebration and tension exist side by side. Food, rituals and disagreements become signs of family identity. As Pablo notes "Rumours arrive at a wedding like unwanted guests" (1).

This shows how gossip and social expectations control people's lives. Tension grows when Anil-da, a relative returns from the market with troubling news about the groom's family. His words left everyone stunned. As Pablo notes, "he froze at least seven people who were busy doing different things for the wedding" (1). This moment reveals how fragile family honour is in their society. A single rumour can shake an entire household.

Moina-pehi's personal struggle shows how identity is shaped by family expectations. Mridul, Pablo's cousin and close friend comments harshly about Moina's situation: "She is eager to get married. But she is old. Nearly thirty-two. Which young man will marry her now?...Who else will marry her other than a fortyfive-year-old frustrated man?" (80). These words show the cruel reality of her society, where being unmarried is considered shameful. Moina's marriage is not about love but about saving the family's respect. Her feelings are ignored because family honour matters more. On the night before her wedding, she tries to drink phenyl to end her life. Pablo reflects:

> I don't believe it was because of the owls that Moina-pehi drank phenyl the day before the wedding. But the sound of the conches, the anxious reactions of the people and the disturbing but eagerly related stories made her decide that all her troubles would end with a bottle of phenyl. (134)

This moment shows how gossip and fear can drive someone to despair. Family expectations create a prison for her where personal wishes are silenced.

Even after the wedding rituals tension continues. During the ceremony, Moina-pehi faints. This creates suspicion and discomfort between the two families. The groom's mother instead of showing kindness, responds with hostility. The tragedy deepens the next day. The narrator describes a heartbreaking scene: "the next afternoon, when the groom's family brought in Moina-pehi's corpse, like a log of wood, like garbage, like a dustbin, he couldn't cry" (194).

This shocking image shows how little value was placed on her life. For the family, what remained was not Moina's happiness but the stain on their honour. Her death is the ultimate proof of how family reputation can crush an individual.

The novel also portrays strong characters like Oholya-jethai the narrator's aunt, whose life of sacrifice and service is central to the Bishoya family's survival. She commands respect during ceremonies leads family discussions and intervenes whenever traditions are challenged. Though she may appear controlling or intrusive at times her behaviour grows out of a deep desire to belong and to be valued. In Assamese society where a woman's worth is often tied to marriage, Oholya-jethai's unmarried status places her in a vulnerable position. Her strict attachment to tradition becomes a form of self-protection granting her authority in a household where she might otherwise be ignored. These tensions make her a complex and layered character.

Prosanto-da urges the narrator to view her with understanding saying "When you know her history, you will forgive her" (160). He further explains that in a society which offers little respect to unmarried and unemployed women, strict obedience to social rules becomes a means of survival. By guarding traditions closely, she secures acceptance, dignity and a place for herself within the family. His words remind readers that her tough exterior hides years of humiliation and heartbreak.

Oholya-jethai's identity is shaped by both her position within the family and the absence of a marriage that society expected of her. Social pressure forces her to develop a stern and guarded nature in order to earn respect within the household and the wider community. Her experience reveals how society marginalizes those who fail to meet accepted norms and pushes them to reshape themselves in order to survive and belong.

Bolen-bortta the eldest earning member of the family represents stability and quiet authority within the Bishoya household. His influence does not rely on forceful speech or overt control. Instead, his presence reflects a form of power grounded in responsibility, consistency and respect. It was seen in the way people adjusted themselves around him. Even Oholya-jethai the most outspoken woman in the house respected him. She made sure that he received the best food and the highest stool during meals. These small acts reflected how family hierarchy was built around him.

Bolen-bortta's death marked the collapse of a structure that gave identity to others in the family. For Mridul, Bolen-bortta's son, this change was painful. Earlier he was known as the son of a strong and respected man, who financially supported the family. After his father's death he was seen as the son of a dependent. This fall in status shows how in Assamese society

the identity of children is tied to the strength and position of their parents. Without Bolen-bortta's earnings and presence, Mridul lost the shield that had protected him from family judgment.

Mridul plays an important role in Pablo's life. He is not only a relative but also a friend who represents the struggles of the younger generation in Assam. His presence highlights the theme of identity because he is torn between tradition and the desire for a new future. Pablo often notices how Mridul dreams of a different life one that crosses social and cultural boundaries. These dreams create tension within the family. Their conversations about education and migration reveal how identity is moving away from old Assamese roots toward modern aspirations. This tension is further deepened by the advice of Pablo's uncle, Prosanto-da. He urges Pablo to leave Assam and pursue higher studies in London or America: "Go to America or London for higher studies…and never come back" (23). His advice is not rooted in ambition alone but in the urgency of survival. He explains that although Assam is rich in resources, corruption and violence have left it impoverished. For years, he tried to get Mayong College nationalized but failed because bribes were demanded at every stage. He warns Pablo that remaining in India would only subject him to the same frustrations. Kashyap shows how corruption reshapes not only individual lives but also the identity of an entire region. He points to the tragic shift in Assam's history, noting that "Assam was the richest province in British India and one of the poorest states in independent India" (23). This decline affects how people see themselves and their place within the state.

Identity is further tested through Mridul's relationship with Manju Magatthu, a Nepali girl he loves. Manju stands for both hope and limitation. She belongs to a community often viewed as outsiders in Assam. By loving her, Mridul challenges boundaries of caste, ethnicity and family honour. His relationship reveals how personal emotions are closely tied to collective identity. In the end, Mridul is forced to abandon his love to protect his family's honour.

Political unrest in Assam enters deeply into family life, shaping identity and destroying any sense of security. The conflict between ULFA and SULFA turns family relationships into political labels. Individuals are no longer seen simply as parents or siblings but as relatives of rebels or traitors. Fear spreads through the village forcing people into silence. As Prosanto-da asks, "Is this a revolution? Will it help Assam secede from India?" (23). Political violence in Assam does not end with the death of individuals. It reshapes how families are seen and remembered, reducing complex lives to political labels. Hiren's family illustrates how fragile identity becomes in such an atmosphere. After surrendering and joining SULFA, Hiren

attempted to rebuild his life. He invested the money he received into a silk business and provided work for others in the village. For a time, his family symbolised hope and renewal.

Hiren's attempt to rebuild his life remained deeply fragile. His earlier involvement in militancy continued to overshadow his present Identity as a husband, father and provider. Even his decision to move into a new house failed to free his family from political hostility. In the eyes of both society and armed groups, Hiren was never allowed to become anything other than a former militant. This fixed political label erased his personal and family life and made violence inevitable. The attack that followed did not single out Hiren alone but destroyed his entire household including children, elderly members and the domestic worker. The incident shows how political conflict turns the family once a private and protective space into a vulnerable target. Families like Hiren's lived with both recognition and risk, where social respect could quickly become a source of danger. Family and identity in *The House with a Thousand Stories* are always connected. The novel moves from moments of everyday gossip at weddings to families broken by loss and from women limited by tradition to men shaped by political conflict. Across these stories identity is shown as something that cannot exist apart from family and society. In Assam, the family is meant to provide care and stability yet in times of political unrest it often becomes a source of fear. People are judged and harmed not for their own actions alone but for the families they belong to. It also affirms that identity is never private. It is formed within family life and exposed to social and political forces that can both protect and destroy it.

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Memory, Grief, and the Journey to Acceptance in Dustin Thao's *You've Reached Sam*

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ABSTRACT

This research paper examines the intricate role of memory in Julie's grieving process within Dustin Thao's novel You've Reached Sam. Through close analysis of Julie's attachment to memories of her late boyfriend, Sam, and her struggle to balance holding on with letting go, the paper explores how memory both comforts and complicates healing. The magical element of posthumous phone calls emphasizes the persistence of love beyond loss, highlighting the tension between remembrance and the necessity of acceptance. Julie's evolving relationship with Sam's belongings and her renewed connections with friends and family illustrate the gradual passage from sorrow to resilience. Ultimately, this study argues that Thao's narrative demonstrates how authentic healing is achieved not by erasing the past, but by integrating cherished memories into a renewed present, allowing for both love and growth to coexist after loss.

***Keywords**: Memory, Grief, Acceptance, Healing, Resilience*

Julie's enduring love for Sam in Dustin Thao's novel, *You've Reached Sam*, is woven through the everyday moments they shared, highlighting how memory can both comfort and confine those in mourning. By weaving together elements of magical realism and emotional introspection, the novel explores the tension between holding on and letting go. It illustrates that genuine healing arises when love and memory are respected as essential.

In Dustin Thao's *You've Reached Sam,* the theme of memory is evident through Julie's strong connection to everything that reminds her of Sam following his unexpected passing. She reminisces about their shared experiences, from the tiniest details to their grandest future plans. These memories offer solace but also bring sorrow, as they highlight what she has lost. The magical phone conversations she has with Sam enable her to revisit these moments. It demonstrates the deep ability of memory to keep someone alive in on's heart, even when they are no longer present.

The novel stresses the importance of letting go. Julie slowly learns that holding on the past prevents her from moving forward with her life. Through their conversations, Sam inspires

her to live fully and find happiness again. Towards the end, Julie understands that moving forward is not betrayal but a way to honour the love they shared.

Memories become more meaningful after loss. For Julie, her time spend with Sam became reminders of their love and connection. Julie recalls a simple memory: "Sam's car pulls up with the window down. He texted me the night before" (5). This ordinary moment becomes significant because it is part of the everyday life she once shared with Sam. Even a small detail, like him picking her up for school, turns into a precious memory after his death. The scene shows how memory keeps Sam alive in her heart, even though he is no longer present.

Grief often leads people to take extreme steps in an effort to escape the pain of loss. Julie's journey shows how the attempt to erase memories can sometimes deepen sorrow rather than bring comfort. She admits how she tried to forget Sam completely: "It's been one week since Sam died. And in my attempt to move on, I've been trying to erase him from my life like a terrible memory I threw out all of his things. I skipped his funeral. And I never even said good-bye" (31). Here, the reader sees her struggle with letting go. Instead of facing her grief, she believes that throwing everything away will help her heal. But this only makes her feel guilty, because she knows Sam wanted them to remember each other.

The struggle appears again when Julie goes through Sam's belongings: "Sam's Radiohead T-shirt. His Mariners hat he bought when we were in Seattle even though he knows nothing about baseball. It all still smells like him. For a second, I forget what I'm even looking for" (50). These items remind her of their shared life, and the memories tied to them bring back his presence. She realizes that memories cannot be erased, because they are part of who she is.

Julie finally admits the truth: "I threw everything out," I tell him. "All of your stuff. I couldn't look at it anymore. I was trying to forget you. I'm so sorry, Sam" (51). This moment reveals Julie's emotional turning point in dealing with her grief. At first, she believes that getting rid of Sam's belongings will help her forget the pain, but she soon realizes that true letting go means accepting the past and finding peace with the memories instead of trying to erase them.

When Julie chooses to keep some of Sam's belongings, she says, "I take the shirt from the hanger and put it on. For a brief second, I feel his hands on me, but it's only in my head" (52). Here, Julie learns that holding on to a few special things does not trap her in the past but helps her heal. The shirt becomes a way of keeping Sam close while still moving forward with her life.

A memory that intertwines love and loss emerges when Sam says, "I'll show you them another time. I promise. He never kept that promise" (63). He had intended to surprise Julie by

showing her Saturn's rings for her writing project, but the cloudy sky prevented it. Despite this, the night remains meaningful because of the tenderness they shared. The unfulfilled promise becomes a quiet reminder that some dreams are never realized, and true letting go involves cherishing the warmth of the memory while accepting that certain moments will never come to pass.

Ultimately, Thao shows that memory and release are not opposites but interconnected. Julie learns that memory keeps love alive, but to truly heal, she must accept the pain of Sam's absence and still choose to move forward. The novel teaches that letting go does not mean forgetting, it means carrying the past in a way that gives strength, not despair.

Eventually, Julie finds the courage to step into new experiences. she spends more time with friends, especially Mika. One passage recalls "The most memorable road trip we took was to Spokane, where we snuck into a pub to see a battle of the bands contest. It also happened to be our worst" (121). These memories are precious because they represent moments of togetherness and discovery. Yet they also remind her that such times cannot be relived.

Later, Julie reflects "Tears form behind my eyes as I stare out at the golden field. And then I hear something I never thought I would hear again. Sam's voice on the phone, singing the song 'Fields of Gold,' just like he promised me he would someday" (148). This moment blends memory and presence. Sam is gone, yet through his voice and the golden fields, he feels near again. The song becomes a bridge between past and present a promise kept beyond time. But once the song ends, reality returns, and the narrator is reminded of the permanence of loss.

Julie is caught between holding on to Sam and learning to face the reality of his absence. She struggles with the fear of forgetting him while also cherishing every small moment that reminds her of his presence. "A shooting star I point at the sky, as if Sam could see it, too" (150). The fleeting image symbolizes the fragile beauty of moments and how quickly they pass, reminding her and the reader that memories, no matter how cherished, cannot last forever.

Memories shape Julie's struggle as she navigates life without Sam, making it difficult for her to accept the present. Every plan she once shared with him now feels incomplete, intensifying her hesitation to move forward. "I just need a little more time" (206). This line expresses Julie's hesitation to let go of those dreams, showing how deeply she clings to the past.

Separation compels Julie to face the depth of her emotions and the memories she holds dear. In the line, "Wait for your jacket! I take off his denim jacket to hand over before the door closes, but Sam stops me. Keep it for me. I smile and hold the denim close to my chest" (228), the jacket becomes a tangible reminder of Sam, symbolizing her longing to preserve a piece of

their past. Similarly, when Sam writes “S+J” on the train window and Julie presses her hand against his, the gesture captures the intimacy and transience of their bond, highlighting the bittersweet tension between holding on and letting go.

When she finally asks if he is upset, James confronts her with the raw truth of their shared grief: “You're taking Sam from us” (229). This line illustrates how memory and loss are deeply interconnected Julie’s continuing connection with Sam, through her memories and their posthumous interactions, unintentionally affects James’s process of letting go. The line emphasizes that grief is shared and that letting go is complex; while Julie begins to accept Sam’s absence, she must also navigate the emotions of those who are grieving alongside her.

Gradually, Julie begins to embrace the present while acknowledging her past. “Maybe just once on the Ferris wheel. The lights from the Ferris wheel can be seen from anywhere” (230). reflect her gradual acceptance of enjoying the present while cherishing the memories of past moments. These lines illustrate that even as she navigates change and faces letting go, the memories of Sam’s thoughtfulness and their shared experiences remain a comforting and guiding presence.

Inevitably, Julie must confront the reality that life moves forward even when she is not ready. “But sometimes you just wake up. No matter how hard you try not to” (232). signifies the painful but necessary realization that memories cannot last forever, and letting go is a part of moving forward.

Ultimately, Julie is forced to face the painful reality of life without Sam while grappling with the hold of their shared memories. “Sam is never coming back. But somehow I keep on waiting for him… How many more calls left before I lose you?” (260). These passages collectively reveal the struggle of cherishing memories while facing the inevitability of loss and the challenge of moving forward.

Unquestionably, Julie clings to hope and the emotional bonds that connect her to Sam, even as she faces the reality of their limited time together. “Promise me one thing That no matter what, this won't be the end of us. That we'll be connected again someday. Promise me, Sam, I asked again” (261). These lines capture her hope that memories and emotional bonds can endure even beyond physical separation.

Julie continues to feel the enduring impact of Sam’s presence in her life, even when he is absent. “I keep my phone in my lap, checking it from time to time. It reminds me we’re still connected, even when we can’t hear each other” (263). demonstrates the way she clings to the sense of connection that memories provide, while also acknowledging the gap between presence and absence.

Gradually, Julie begins to realize that reconnecting with loved ones can provide solace amid loss. “My mother and I have connected again. We’ve spent these last few weeks together, having dinner every night, watching TV in the living room, shopping, and taking weekend trips to the beach things we used to do. She said she missed spending time with me. I didn’t realize how much I missed it, too” (279). She begins to find comfort and grounding in the present, balancing memories of Sam with renewed connections in her life.

Certainly, Julie is beginning to understand the importance of being present despite uncertainty and loss. “Always worrying about what comes next, instead of living in the moment. I see this in a lot of my students” (280). Julie learns to navigate disappointment and change, gradually letting go of rigid plans and finding balance between memories of Sam and embracing the unfolding reality of her

life. treasured and carried forward with hope.

In *You’ve Reached Sam,* Dustin Thao profoundly examines how memory and release operate as parallel forces in the emotional journey of love and grief. Through Julie’s sustained attachment to Sam, his family, and her social world, the novel demonstrates that remembrance functions both as a source of emotional survival and a barrier to personal renewal. Thao ultimately argues that love does not diminish in the face of loss; rather, it is reshaped through acceptance, emotional resilience, and the willingness to confront absence. Letting go, therefore, is not an act of erasure but a necessary transformation that allows memory to endure without imprisoning the self in sorrow.

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Investigating Truth through Companionship: A Study on Chetan Bhagat's *The Girl in Room 105*

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ABSTRACT

This paper examines the interconnected themes of friendship and mystery in Chetan Bhagat's The Girl in Room 105, analysing how these elements shape narrative development, character psychology, and ethical inquiry. While the novel is often approached as a romantic thriller, this study argues that friendship serves as a central emotional and structural force that enables the protagonist Keshav's investigative journey. Their bond illustrates how genuine companionship can provide emotional stability, courage and direction in moments of crisis. At the same time, the mystery surrounding Keshav's ex-girlfriend, Zara Lone's death, functions not merely as a suspense device but as a catalyst for moral reflection and personal transformation. By analysing character relationships, narrative progression, and moments of ethical tension, the paper demonstrates how Bhagat integrates emotional bonds with suspense-driven storytelling. The study shows how friendship and mystery together shape character growth, narrative momentum, and the pursuit of truth.

Keywords: *Friendship, mystery, loyalty, investigation, suspense, character development.*

Chetan Bhagat occupies a distinctive position in contemporary Indian English fiction. His novels combine elements of romance, suspense, and social observation, making them accessible to a wide readership while still engaging with serious emotional and ethical concerns. *The Girl in Room 105* is commonly classified as a romantic thriller. However, such categorisation often overlooks the deeper thematic structures that sustain the narrative. Beneath the surface-level suspense and romantic conflict, there lies a sustained exploration of friendship, loyalty, and moral responsibility.

This paper argues that friendship and mystery function together as interdependent forces within the novel. The relationship between Keshav and Saurabh is not a peripheral subplot but a narrative backbone that sustains the protagonist emotionally and practically throughout the investigation. Similarly, the mystery of Zara Lone's death is not limited to identifying a murderer, whereas it compels the protagonist to confront his emotional vulnerabilities, ethical responsibilities, and assumptions about love and trust.

The purpose of this study is to demonstrate that Bhagat employs friendship as a stabilising and enabling force, while mystery serves as a narrative mechanism that demands psychological growth and ethical awareness. By examining these themes together, the paper offers a more nuanced reading of *The Girl in Room 105*, highlighting its thematic coherence and narrative intent.

Friendship in literature frequently functions as a counterbalance to emotional isolation, romantic obsession, or moral confusion. Unlike romantic relationships, which are often idealised or destabilising, friendship is typically portrayed as grounded in continuity, mutual understanding, and shared responsibility. It allows characters space for honesty, disagreement, and emotional regulation.

In *The Girl in Room 105*, friendship is not romanticised but presented as a practical necessity. The bond between Keshav and Saurabh develops through shared struggles, professional dissatisfaction, and emotional vulnerability. Their friendship is characterised by consistent presence rather than dramatic expression, reinforcing its realism. Bhagat presents friendship as an emotional anchor that enables rational decision-making, especially in moments of crisis.

This portrayal aligns with modern literary narratives where friendship becomes essential for emotional survival in unstable social and psychological environments. The novel suggests that friendship offers ethical clarity and emotional balance when characters confront uncertainty, danger, or moral dilemmas.

Keshav is introduced as an emotionally unsettled protagonist, burdened by professional stagnation and unresolved attachment to his ex-girlfriend, Zara. His dissatisfaction with his job at Chandan Classes and his inability to move on from his past relationship create a sense of emotional inertia. This instability shapes his impulsive decisions and heightens his vulnerability throughout the narrative.

Unlike traditional detective figures, Keshav is not guided by intellectual detachment or professional obligation. His investigation into Zara's death is emotionally motivated, rooted in guilt, unresolved love, and the need for closure. This emotional involvement complicates his judgment, particularly during the early stages of the investigation, making him prone to misinterpretation and emotional excess.

Keshav's psychological state underscores the necessity of friendship within the narrative. Without Saurabh's steady presence, his emotional responses would likely overwhelm his capacity for rational thought. Thus, Keshav's characterisation reinforces the thematic argument that friendship is essential for emotional regulation and ethical decision-making.

Saurabh functions as both an emotional anchor and an ethical counterbalance to Keshav. In contrast to the protagonist's impulsive tendencies, Saurabh demonstrates emotional restraint and practical thinking. His responses to crises are measured, often prioritising safety, logic, and long-term consequences.

Throughout the novel, Saurabh repeatedly attempts to guide Keshav away from self-destructive behaviour. He expresses concern over Keshav's excessive drinking and emotional fixation, advising him to detach himself from harmful patterns. His counsel reflects genuine care rather than moral superiority. "'Bhai you must leave this girl. It's been too long', Saurabh said" (15). Similarly, his reminder about drinking habits demonstrates protective concern. "'You swore on me you wouldn't have more than two drinks', Saurabh said" (6), shows Saurabh's care for Keshav's health.

Importantly, Saurabh's loyalty does not translate into blind agreement. He questions Keshav's decisions and expresses disagreement when necessary. This dynamic reflects a realistic portrayal of friendship, where criticism functions as an expression of care rather than conflict. By allowing disagreement within friendship, Bhagat avoids sentimentalising the bond and instead presents it as ethically grounded.

The friendship between Keshav and Saurabh is also shaped by their shared professional dissatisfaction. Both characters work at Chandan Classes, a job they dislike but continue due to economic necessity. This shared frustration creates solidarity and mutual understanding. As stated in the novel, "Both of us worked our asses off at Chandan Classes, even as we hoped to get out of there ASAP" (7).

This professional stagnation contextualises their emotional bond and later decision to establish their own detective agency. Friendship, in this sense, becomes a collaborative response to social and economic dissatisfaction. The transition from exploited labourers to independent investigators symbolises agency, enabled through companionship rather than individual ambition.

One of the most significant aspects of Keshav and Saurabh's friendship is their willingness to share risk. Saurabh repeatedly places himself in dangerous situations, not for personal gain, but out of commitment to his friend. When Zara invites Keshav to her hostel room late at night, Saurabh initially discourages him but ultimately accompanies him, prioritising safety over caution.

After discovering Zara's lifeless body, Saurabh suggests escaping to avoid legal trouble, yet respects Keshav's decision to report the matter to the police. Even when arrested and interrogated, Saurabh remains beside Keshav. His refusal to abandon his friend during

moments of legal and emotional danger illustrates loyalty as an ethical action rather than an emotional sentiment. This shared risk transforms friendship from emotional support into moral responsibility. The investigation becomes a collective effort, reinforcing the idea that truth-seeking is rarely an individual pursuit.

Beyond emotional support, Saurabh contributes actively to the investigation. His technical skills play a crucial role in uncovering key evidence, including hacking the watchman Laxman's mobile phone to establish his innocence. Keshav acknowledges this contribution when he states, "Thank you, Saurabh. I couldn't have done this without you" (198). The article "A Thematic Analysis of *The Girl in Room 105* by Chetan Bhagat" notes that, "Keshav could not have solved this matter without his assistance" (Chaurasia 9846). This highlights that friendship in the novel functions not only emotionally but also intellectually and practically, guiding the investigation at every stage.

Despite the seriousness of the murder investigation, Bhagat incorporates humour, largely through Saurabh's dialogue. Their playful insults, such as Keshav's comment on Saurabh, "You look like a child-molester" (22), when he sees Saurabh's LinkedIn profile. On the other hand, Saurabh mocks Keshav as, "And you look like a member of a dance troupe" (23). This adds levity without trivialising the narrative.

Humour functions as a coping mechanism, allowing characters to momentarily distance themselves from fear and uncertainty. As the article "Humour in Chetan Bhagat's *The Girl in Room 105* and *One Arranged Murder*: A Study with Special Reference to His Creation of Dark Humour and Satire" highlights, the novel is "replete with ample humour exposed through satire, irony, and sarcasm" (Ahmed et al. 570). This tonal balance prevents emotional exhaustion and humanises the characters, reinforcing the authenticity of their friendship.

Mystery in *The Girl in Room 105* operates as the primary narrative framework. Zara's death initiates a sequence of investigative steps marked by false leads, shifting suspicion, and delayed revelation. Bhagat employs conventions of the thriller genre, including misdirection and concealed motives, while grounding them in character psychology.

Suspicion shifts among multiple figures like Raghu, Laxman, Prof. Saxena, Safdar Lone, and Captain Faiz were preventing easy conclusions. This misdirection mirrors Keshav's emotional confusion, as his attachment to Zara initially clouds his judgment. Over time, the investigation forces him to distinguish emotional assumption from factual evidence.

The mystery extends beyond identifying the murderer to exploring moral responsibility. Keshav's determination to uncover the truth is driven not by legal obligation but by ethical commitment. He persists even when others withdraw or avoid involvement.

This moral persistence distinguishes him from characters who prioritise self-protection or denial. The article "A Thematic Analysis of *The Girl in Room 105* by Chetan Bhagat" observes that "the mystery behind Zara's murder is expertly intertwined into the romance tale" (Chaurasia 9846), reinforcing the idea that suspense serves character development rather than spectacle.

A key tension in the novel lies between friendship and obsession. Keshav's fixation on Zara threatens to eclipse his concern for living relationships. Saurabh repeatedly challenges this imbalance, urging him to choose present bonds over destructive attachment. The scene in which Saurabh demands that Keshav "Choose between the case and me" (176) crystallises this tension. Keshav's response, "Screw the case. I have already lost a lot. I can't lose you" (176), signals a shift in emotional priority. Friendship emerges as a healthier and more sustaining emotional foundation than obsessive love.

The revelation that Raghu is the murderer resolves the mystery while reinforcing the novel's ethical concerns. The confession exposes how fear, secrecy, and social pressure can lead to irreversible violence. The climax validates persistence, ethical commitment, and emotional maturity. By the end of the novel, Keshav emerges as a more self-aware and grounded individual. His transformation is gradual, shaped by experience rather than idealised redemption. Friendship facilitates this growth by offering support without enabling self-deception.

This study has demonstrated that *The Girl in Room 105* integrates friendship and mystery as mutually reinforcing themes. Friendship, embodied in the relationship between Keshav and Saurabh, functions as emotional support, ethical guidance, and practical collaboration. Mystery operates as both narrative structure and catalyst for psychological growth. By intertwining companionship with suspense, Bhagat presents a narrative in which truth is achieved not through isolation but through shared responsibility and moral perseverance. The novel ultimately suggests that emotional resilience and ethical clarity emerge from trusted relationships, allowing *The Girl in Room 105* to transcend its genre classification and offer a meaningful exploration of friendship, responsibility, and truth within contemporary popular fiction.

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Liminal Lives: Understanding War, Trauma and Displacement in Anthony Doerr's *All the Light We Cannot See*

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ABSTRACT

This article explores Anthony Doerr's All the Light We Cannot See using the ideas of liminality and trauma theory. It argues that war causes displacement that goes beyond just physical exile. It also creates psychological, moral and temporal instability. Drawing on Cathy Caruth's idea of belated trauma, the study looks at how characters experience broken timelines marked by disrupted memory and unresolved identity, especially in Werner Pfennig's experiences. The article also views the radio as a liminal object that exists between violence and connection. It serves both as a tool for Nazi surveillance and a way to foster human empathy and resistance. By presenting displacement as an ongoing issue rather than a brief wartime interruption, the study emphasises how war unsettles ideas of belief and moral certainty long after the fighting stops. Ultimately, the article adds to trauma-focused interpretations of war literature by showing how Doerr's novel portrays survival as a continuous state of in-betweenness shaped by lasting psychological and temporal dislocation.

Keywords: *Displacement, Destruction, Liminality, Temporality, War.*

Introduction

Anthony Doerr's *All the Light We Cannot See*, a Pulitzer Prize-winning historical novel set during World War II, narrates the intertwined stories of Marie-Laure LeBlanc, a blind French girl forced to flee Paris with her father to Saint-Malo and Werner Pfennig, a German orphan whose expertise in radio technology leads him into the Nazi military and ultimately to the same town. This research article examines how war uproots individuals from their physical homes as well as from their temporal and spiritual foundations, thereby influencing identity and belonging. Through the experiences of Marie-Laure, Werner and Etienne, the article investigates the challenges of trauma and exile. Drawing on theoretical perspectives from Marxism, Freud, Wundt and Caruth, it conceptualises displacement as both a social and psychological phenomenon. The analysis highlights the impact of delayed trauma on human resilience and underscores the radio's function as a vital connection and source of hope amid chaos.

Physical Displacement and Ideological Instillation

World Wars are known for their insufferable advancements in bringing destruction to many cities and countries. These exterminations have further given rise to the need for the mass displacement of people. The Second World War, in particular, played a major role in uprooting people from their homelands. The article "Eighty years after millions fled the German army, revisiting the "Paris Exodus"" says, "Two million Parisians poured out of the capital in the early days of June 1940, swelling the numbers of those already on the road to eight million, a mass movement of people that promptly became known as "the exodus"" (Wilkins). This exodus is evident in *All the Light We Cannot See*, seen in characters such as Marie-Laure and her father, Daniel LeBlanc. The father and daughter flee from Paris in June 1940 because of the German invasion of the city.

Werner Pfennig's journey, in *All the Light We Cannot See,* showcases how children like him are uprooted from their orphanages to be put into the machinery of destruction. This mechanism includes training talented children, such as Werner, to mould them into exceptional soldiers. This physical displacement further leads to the destruction of Werner's self-identity. Werner is intellectually gifted, particularly with radios. His brilliance has its own positives and negatives. The discovery of his exceptional abilities forces him to leave behind his only family member Jutta and the comfort of his orphanage home. When Werner goes out for his entrance exam in Napola, he meets a school representative who orders young children. ""You are," he declares, "attempting to enter the most elite schools in the world. The exams will last eight days. We will take only the purest, only the strongest" (112).

Beyond physical displacement and ideological instillation, Werner experiences moral displacement, caught between two worlds, conscience and duty. He is forcefully placed in this propaganda, where he must obey the rules imposed upon him while betraying his sense of self. He is placed in the state of liminality, where he is neither a full victim nor entirely autonomous.

Psychological Displacement

Etienne LeBlanc, Daniel LeBlanc's uncle, is also stuck within suspended identity and psychological liminality. He is physically present in his home but is emotionally displaced. He has not left his house for twenty years. He is not truly a part of the world, but he is also not completely absent from it. This shows a clear sign of liminality. He is stuck in one place, neither moving forward nor pulling back fully. He is also a war survivor of the First World War, haunted by trauma that has left him psychologically imbalanced. He sees "things that are not there" (122) and is described as wavering between extremes. Madame Manec describes Etienne's whereabouts. She says that he "shuts himself up like a corpse one day, eats like an

albatross the next" (121). This language suggests a mind that cannot settle itself, drifting between control and collapse, showcasing liminality.

In the book, *The Ego and the Mechanisms of Defense* (1936), Anna Freud defines displacement as "the redirection of an impulse toward a substitute target that resembles the original in some way but is psychologically safer" (4). Displacement occurs when a person unintentionally focuses their emotions on a safer alternative target. This concept is essential for understanding Etienne's psychological isolation. His "agoraphobia" (417) showcases emotional displacement. It is evident when Daniel LeBlanc talks about Etienne to Marie-Laure. He says, "A mouse in a trap. He saw dead people passing through the walls. Terrible things in the corners of the streets. Now your great-uncle does not go outdoors" (127).

Similarly, Daniel LeBlanc is forced into psychological displacement, from being a calm, guiding father to a father who needs to shield his daughter and himself from the terrors of war. The weight of the Sea of Flames, a gem worth over a million francs, makes him paranoid and anxious, whether it is a decoy or not. He is caught between being a scientist and a father. The Sea of Flames facilitates the promotion of displaced faith. When people shift their ideas away from the Creator and toward material benefits, it is known as "displaced faith" (Dummer). According to the urban legend surrounding the Sea of Flames, those who hold this stone will live to see their loved ones suffer and never die. The article titled "Displacement as a Condition of Faith: Four Perspectives" by *the Architecture Culture and Spirituality Forum* defines a person with displaced faith as "the believer not of this world, and that the focus of faith is ultimately outside this world, disassociated with earthly concerns" (Crosbie).

Temporal Displacement

''Temporal displacement" (Wundt 756) is evident in Werner Pfennig. Temporal displacement is when someone experiences events out of their actual order, feeling as if they are happening at the same time or in a different sequence. Werner experiences time displacement both psychologically and physically. After joining the Hitler Youth and later becoming a soldier, his sense of time breaks under the pressure of violence, shame and survival. His memories do not unfold in a straight line. These overlapping timelines change Werner's view of the present. This is evident in the lines, "Werner thinks of home all the time. He misses the sound of rain on the zinc roof above his dormer; the feral energy of the orphans; the scratchy singing of Frau Elena as she rocks a baby in the parlor" (263).

This incident demonstrates his psychological disorientation. He cannot accept the present, while emotionally attached to the past he cannot revisit. The battle alters his perception of linear time, forcing him to alternate between duty and memory, obedience and guilt. Thus, Werner's

time displacement is more than just a memory. It is also a reflection of psychological instability created by conflict.

The concept of temporal displacement in Werner has been made evident through Cathy Caruth's foundational work in trauma theory. In *Trauma: Explorations in Memory* (1995), she writes that "the event is not assimilated or experienced fully at the time, but only belatedly, in its repeated possession of the one who experiences it" (4). This idea, called "belatedness" (9) describes how trauma can come back long after it first happens, often in bits and pieces that disturb people. Werner's memories of his close friend Frederick show this clearly. After Frederick gets a traumatic brain injury from classmates, he is sent home. H However, Werner still feels his presence. When Frederick is harshly punished for not taking part in acts of violence, Werner is too scared to step in. This leaves him with a heavy, unspoken guilt. That guilt never goes away; it returns during quiet times, throwing off his sense of time and identity. As the narrator puts it, "Sometimes at night, Werner sees Frederick when he is not there" (262). The past does not stay behind, it interrupts the present. This is more than simply a memory. It is exactly what Caruth defines as trauma, a wound that reopens over time, never truly mending or being fully comprehended.

Radio as a Liminal Object

The radio is a liminal object that exists between war and peace, destruction and connection. It is through the radio that Werner receives orders that tie him to the Nazi mission. The radio lets him hear Marie-Laure's quiet voice echoing through the ruins. Werner's relationship with the radio is full of contradictions. It is the tool that pulls him into the war, but also links him to moments of humanity. This is evident through the lines, "He moves carefully through static and silence until the signal suddenly sharpens into a voice—fragile but alive—speaking into the void" (48). The radio becomes both a site of ideological manipulation and a source of unexpected empathy. Under Nazi command, Werner uses it to track and destroy resistance networks. One rainy night, while scanning the spectrum, he stumbles upon a broadcast. Marie-Laure's voice in a Breton accent, accompanied by a piano piece from his childhood. Her broadcast is simple and full of wonder, disrupting his violent purpose and reconnecting him to beauty and innocence. Werner is transported mentally to a past that feels safe and pure, even while physically situated in a war zone. This is a moment of temporal displacement. The boundaries between past and present collapse.

The radio becomes a portal not just across distance, but across time and identity. It reflects how the same technology can both oppress and heal. The Nazis use it to erase voices and Marie-Laure reclaims it to resist them. When Werner hears her for the first time, he says,

"With each syllable, the voice seems to burrow a bit deeper into his brain. Young, high, hardly more than a whisper. If it is a hallucination, let it be" (392). In that moment of darkness, starvation and turmoil, the radio offers not just a signal but a rupture in time. A moment when memory and meaning displace violence. Thus, the radio does not just send signals. It bridges distances, turning strangers into listeners and listeners into believers. It exists between opposites, breaking them down.

Conclusion

In *All the Light We Cannot See*, war creates a constant state of displacement. This goes beyond just physical exile; it leads to psychological, moral and temporal instability. This study, using trauma theory and Cathy Caruth's idea of belatedness, shows how traumatic experiences come back through broken memories and disrupted time. Trauma is not just a past event; it is an ongoing and unresolved force. The radio acts as a tool that exists between destruction and connection. It shows how technology can cause ideological violence while also creating moments of empathy and resistance. By depicting displacement as a lasting condition that alters belief and the idea of home, the novel questions straightforward stories of survival during war. In the end, the text implies that survival involves ongoing uncertainty and an incomplete sense of identity. Displacement becomes an emotional, psychological and temporal state that continues long after the war is over.

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Transforming Texts, Empowering Women: A Dialogic Exploration of Greta Gerwig's Louisa May Alcott's Adaptation of *Little Women*

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ABSTRACT

This paper critically examines Greta Gerwig's 2019 film adaptation of Louisa May Alcott's classic novel Little Women by compaining adaptation theory and feminist film studies. This study interrogates how Gerwig's adaptation using a non-linear storytelling method drawing on visual conventions explore and reveal modern understanding of gender. The analysis interprets the film as a dialogic text that is shaped by its literary source and earlier cinematic adaptations. Robert Stam's concept of intertextual dialogism, and Linda Hutcheon's notion of adaptation as both repetition and creative re-interpretation are applied to comprehend how a 19th century novel is refigured to suit the modern day audience. Gerwig's adaptation has not just maintained but revolutionized the spirit of Alcott's text for contemporary conversation regarding feminism, economic justice, and representation of women in the arts.

Keywords: *Adaptation theory, Feminist film studies, Dialogic text, Agency, Visual storytelling*

Little Women is a classic novel which continues to inspire not only the readers but also the film directors. The book has been adapted many times on screen, each version adding its own interpretation. Rather than merely copying, adaptations engage creatively with the source, forging a conversation between the original text and new cultural contexts. Robert Stam frames adaptation as a dialogic process, emphasizing a balance between faithfulness to the source material and creative innovation. He writes,

> Adaptation is not replication but involves creative transformation. Fidelity to an Original is a shifting, culturally situated notion, not an absolute measure of quality Or authenticity. Adaptations participate in a dialogic process where texts interact With one another across time and cultural contexts.

This perspective allows adaptations to be interpreted as conversations that engage both with the original text and contemporary contexts. This paper uses film adaptation studies to look at *Little Women* and show how Gerwig's movie brings a beloved story back to life for 21st-century audience and keeps it relevant in public discourse.

Adaptation studies have emerged as a presently recognized academic field, offering the opportunity to consider transcultural and intermedia ties between a literary source and its audio-

visual adaptation. According to Linda Hutcheon, adaptation is not merely a re-presentation, a re-enactment, or an arbitrary new version of a source text. Instead, it is a creative act of reinterpretation that both affirms the original work and transforms it, enabling the adapted version to develop new meanings. Hence it stand, as an independent artistic creation. While literary classics are adapted for their social realities and archetypes, each adaptation involves unique standards of fidelity, innovation, and cultural meaning.

Gerwig's film adaptation of *Little Women*, is neither a replica nor a complete break from the original text. It utilizes modern cinematic forms and historical perspectives to provide a 'new' experience for today's audience. It reflects on issues of autonomy, artistry, and agency that have been raised in public debates about creativity and gender.

Furthermore, the non-linear storytelling is itself an act of adaptation because it re-arranges time and fractures memory. It is the act of adaptation that highlights the process of remembering, reframing, and reinterpreting the story while bringing the past into conversation with the present. This shift in narrative structure reflects not only Gerwig's creative adaptation but also her commitment to empowering female agency. Gerwig's *Little Women* emerges as a fertile ground for considering adaptation as an aesthetic practice and cultural intervention.

Gerwig's adaptation foregrounds Jo's creative struggles and incorporates elements of Alcott's life to engage with contemporary issues of women's workplace independence, unequal pay, and political representation. Reflecting broader cultural conversations on gendered labour and authorship, the film positions Alcott's text as a living work that remains vital because these questions persist. Scholar Kamilla Elliott argues that adaptations stay culturally relevant by reimagining texts to engage modern audiences rather than merely mirroring originals. Gerwig's film exemplifies this transformative dialogue, using feminist interventions to empower women and enrich cultural discussions beyond simple reproduction.

Alcott's novel, like all nineteenth century novels, proceeds in a linear fashion, taking readers through the natural development of the lives of the March sisters from girls to women. The straightforwardness of the narrative supported the themes of development and learning and working through time, since the March sisters must navigate family expectations, individual goals, and societal limitations.

The emotional weight of the film's elliptical structure is further amplified by how each temporal frame reinterprets through characters' perspectives and regrets. Through its integration of the past and present Gerwig's narrative demonstrates that identity and meaning are continually reinterpreted by memory, a conceptualization that mirrors the complexities of our lived experience today.

Gerwig's film uses colour strategically to evoke emotion and time. Warm golden hues paint scenes of family togetherness and youth, while colder blues and greys mark moments of struggle and separation. This visual contrast deepens the audience's immersion into the sisters' shifting experiences.

Laura Mulvey's Gaze theory critiques the way movies have had privileged male perspectives and objectified women. Women can challenge their role as objects of representation and desirability defined by men. Drawing on Mulvey's male gaze theory, Gerwig's adaptation subverts traditional cinematic portrayals by centering female subjectivity and agency through its visual storytelling. The film strategically positions the camera to emphasize the sisters' interiority and emotional authenticity rather than aesthetic objectification.

Gerwig's adaptation takes the novel step by acknowledging marriage implicitly and explicitly as an economic contract, a truth that Amy March articulates most fully in her monologue. By refusing to sentimentalize the marriage plot, the film presents choices about marriage in the context of a larger social economy, and locates individual independence in relation to collective structures of power and privilege. This framing carries weight with respect to current discussions about women's economic independence, labour, and value.

Watching Gerwig's *Little Women*, the viewers might consider Jo's efforts to publish under fair conditions, Marmee's every day statement of anger about systemic injustice, and Amy's cautions about financial precarity as representations of ongoing frustrations of women. They could be at home, at work, or out in the public sphere. Framing these scenes as moments of social awareness links *Little Women* to the current feminist texts and movements aimed not only at representation of women but at changing the social parameters governing gendered experience. Embracing subjectivity, economic critique, and formal experimentation, Gerwig makes *Little Women* distinctly feminist and relevant to contemporary conversations about equality, labour, and recognition. The film goes beyond simply being a historical drama, as it engages explicitly with the politics of representation, elevating the voices of those who are often marginalized.

Gerwig's visual aesthetics combines period specificity with contemporary detail, producing sets with the affection and intimacy of the March's home while also foregrounding depth and completion in painterly composition. Resisting the pristine prettiness of many stylistic adaptations instead of using natural light, hand-held camera work, and an immersive sound design, the characters are situated in colourful, lived-in spaces.

Gerwig's use of composition and colour grounds the film in the sensibility of modern art-house cinema. Her framing invokes who qualify as classical painters, layering the action of the sisters' various emotional and thematic turns on the screen. The use of value contrasts through light and dark effectively register the sisters' shifting moods and the different temporal moments, while the colour palette reflects naturalism and draws audiences closer to the characters' world.

The costumes in Gerwig's *Little Women* are carefully crafted to reveal character and express ideas. Jo's rejection of feminine dress, her preference for functional garments, and her ability to intentionally cross gender lines signal her resistance to social conventions—a theme that has been increasingly relevant today in conversations around gender fluidity and nonconformity.

Earlier adaptations of *Little Women* variably emphasized traditional family values or romantic narratives. The 1933 adaptation reflected Great Depression anxieties through enduring familial bonds, while the 1994 version highlighted feminist discourse and individual self-discovery. Gerwig's film distinctively integrates these themes while foregrounding modern considerations of gender and authorship. Her adaptation expands the conversation further by centering economic justice, creative labour, and intersectionality— concerns that resonate with contemporary feminist movements and social discourse.

The film's focus on agency, authorship, and negotiating pay resonates with social conversations about the need for more representation, acknowledgement, and fair pay. As a female director re-imagining not only a male-dominated literary tradition, but Hollywood's power structures, Gerwig herself is a sign of the change that *Little Women* argues for. The success of *Little Women*, both critically and commercially suggests that classic stories can embody and propel cultural change, becoming agents of social critique and collective dreamers.

Every version of *Little Women* negotiates fidelity and innovation, urging historical texts to engage contemporary issues. Gerwig's film continues this dialogue, connecting classical literature, filmmaking, female experience, and public discourse. It shows adaptation as a living, evolving medium reflecting and shaping its era's values. Scholar Julie Sanders highlights that adaptations involve dialogue between text and context, where faithfulness means honouring themes over exact details, embracing transformation while respecting a work's essence. Gerwig's film honours Alcott's original while creatively renewing its cultural significance.

Gerwig's 2019 film adaptation of *Little Women* demonstrates how stories evolve alongside culture rather than simply reproducing their original texts.. Through complex

storytelling, feminist perspectives, and distinct visual style, the film refreshes Alcott's narrative for contemporary audiences. Positioned within adaptation theory and feminist film studies, it acts as a dialogue between past and present, engaging ongoing conversations about meaning and social change. Gerwig's film stands as a transformative adaptation that empowers women through innovative and feminist storytelling

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Exploring Family Burden and Work Stress in Franz Kafka's *The Metamorphosis.*

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ABSTRACT

Franz Kafka's The Metamorphosis is a story about a travelling salesman, Gregor Samsa. Gregor's unexpected change into an insect reveals the pressure of family responsibilities and work. The novella is not just an absurdist fiction but a transparent portrayal of a man under family obligations and demands. It also shows how fast a bond changes when a person becomes less useful. This paper demonstrates that Gregor's metamorphosis is not just a physical transformation, but an outward sign of persistent psychological suffering and burden he was going through. It looks at Gregor's meeting with the Chief Clerk and the slow change in his family's behavior to show how these pressures affect him. It also reflects on how work stress and family responsibilities continue to affect a person's mental health and family life.

Keywords*: Family Burden, Work Stress, Human Psyche, Transformation, Identity.*

Franz Kafka is a German-speaking Jewish writer who is famously known for the depiction of modern themes like identity, alienation and the absurdity of existence. *The Metamorphosis* was published in 1915 and it remains as one of his distinguishable works. The story itself begins with an unsettling image of Gregor Samsa awakening to find himself metamorphosed into a hideous insect. The twist of the story lies in the transformation of his family and their dehumanizing actions on Gregor. His existence was defined through his work, debt and family expectations.

At the heart of the novella lies the conflict between Gregor's identity as both a dutiful son and worker. His transformation shows how one's identity is shaped by their economic usefulness. When Gregor transforms into an insect and loses his ability to work, he also loses his reputation in his very own family which once celebrated him. This leads to the central question of this research paper on how family burden and work pressure in *The Metamorphosis* shape Gregor Samsa's psyche which eventually leads to his death.

The story can be interpreted through different lenses such as alienation, psychoanalysis and even Marxism. Many believe that *The Metamorphosis* is a story about feeling lost in their own world and being unnoticed. This can be seen through the psychological

transformation of Gregor. But in deeper sense it serves as a critique of familial pressures put on individuals. The main character of this novella is the best example of this. He grows distant from his family, his work and even from his body. He follows a monotonous routine every day and lacks meaningful relationships with others. Through this Kafka is highlighting the isolation faced by people in modern life.

Gregor's family relies solely on his earnings since his father cannot work and his mother is frail. His sister has yet to start earning. The majority of Gregor's salary is sent home to support them. This situation makes Gregor feel trapped. He often worries about how long it will take to settle his parents' bills.

> Well, there's still some hope; once I've got the money together to pay off my parent's debt to him – another five or six years I suppose-that definitely what I'll do. That's when I'll make the big change. First of all though, I've got to get up, my train leaves at five. (21)

This illustrates how Gregor's life centers on his family's financial problems. When Gregor transforms into an insect, his family's feelings shift. It suggests that Gregor's identity is tied to his role as supporter and protector of his family. He measures time in terms of how long it will take to release his parents from their financial responsibilities rather than his own goals. They begin to view him as a burden instead of a loved one. His father even throws apples at him to injure him and his sister insists, "We have to try and get rid of it" (101). These actions suggests that their care for him is not a genuine affection. It is based mainly on what he brings home.

Literary scholar M. T. Haider, in his 2025 study "Isolation in the Modern World: A Study in Light of Kafka's *The Metamorphosis*", explores the examination of isolation within modern literature, particularly how Kafka's character, Gregor serves to critique economic dependency within families. Haider posits that familial affection is largely based on one's economic input. This idea supports interpretations of Gregor's metamorphosis, where his change into an insect quickly shifts his family's affection to rejection. The shaky nature of their relationship is clear once he is not useful. This shows the fragile nature of their relationships.

Another way to view *The Metamorphosis* is through the lens of psychoanalysis. This focuses on the family dynamics and Gregor's internal conflict that shapes his thoughts. It can also be taken as a strong critique of harsh work conditions and the mistreatment of workers. Here Gregor becomes a symbol of exploited labours who are treated as commodities rather than human beings.

Gregor's own aspirations like changing careers or living a different life are ambiguous.

He faces considerable job pressures and his role requires frequent travel. His boss also pressures him. The chief clerk visits Gregor's house to ask why he didn't come to work. "I'm speaking here on behalf of your parents and of your employer, and really must request a clear and immediate explanation" (32). This line from the Chief Clerk demonstrates how Gregor's boss demand his obedient service. Speaking for the parents, the clerk highlights that Gregor's value is entirely dependent on his earnings.

At first, Gregor's reaction to his transformation shows how deeply he was affected by the demands of his job. When he wakes up and discovers himself as an insect, his thought was not about this strange transformation but about catching the next train to avoid trouble with his employer. "Seven o' clock, already", he said to himself when the clock struck again, "seven o' clock and still a fog like this" (26). This emphasizes that he has learned to treat economic failure as a greater catastrophe than his personal suffering.

The Chief Clerk comes to Gregor's house the moment he misses work. This shows how closely the office watches its employees. His sudden visit also reveals the lack of trust in Gregor. "But on the other hand, I must say that if we people in commerce ever become slightly unwell then, fortunately or unfortunately as you like, we simply have to overcome it because of business considerations" (31). This situation shows that Gregor's value is judged by output and being on time. Gregor's psyche suffers as he accepts this reasoning.

Gregor experiences guilt and fear instead of feeling wronged by the system. He sees himself as an employee who cannot be trusted, not as a person who is mistreated. When he can no longer get out of bed, his old identity as a sales man fades away. Without his job, he does not know who he is. Walter H. Sokel's article, "From Marx to Myth: The Structure and Function of Self-Alienation in Kafka's *The Metamorphosis*," interprets Gregor's situation through a Marxist lens. Sokel argues that Gregor's sense of self is diminished to his function as a worker. Once Gregor can no longer work because of his transformation, his family and employer see him as disposable. This shows how work and money controlled and diminished his identity (Sokel 621). This idea explains why Gregor's family dismisses him so easily; they believe that worth is based on financial gain. This leaves no space for emotions or personal worth. It clarifies why Gregor's family goes from being dependent on him to pushing him away once he can no longer support them financially.

Today, *The Metamorphosis* predicts worries about job stress, burnout, and feeling ashamed of being dependent or disabled. Lots of readers can still relate to Gregor's fear of losing his job and his family's discomfort when he is not working. The story shows how families and societies value people and the risks of only valuing people based on how much

money they make.

In *The Metamorphosis*, family duties and job stress are major factors that break down Gregor Samsa's mind. He is responsible for his parents' debt and has a demanding job as a travelling salesman. This turns him into someone who only works to keep his family financially stable. When he cannot do these things anymore, he loses his sense of self, love and even self-respect. His mind becomes focused on work and obligation. Kafka's story shows a world where a person's value is based on how much they produce, which ruins their inner life and family relationships. It is evident that how Gregor changes from dutiful son who is worried about providing for his family to an isolated bug. Family duties and job stress not only trouble him but also change and disturb his mind. This results in his mental breakdown and eventually death.

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A Postmodern Exploration of Cultural Identity in Mitali Perkins' *You Bring the Distant Near*

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ABSTRACT

Cultural identity has long been a central theme in diasporic literature, particularly in works that explore the tension between tradition and modernity. Mitali Perkins' You Bring the Distant Near presents a nuanced exploration of how immigrant families navigate the complexities of belonging, adaptation and generational transformation. The novel highlights the intersection of heritage and contemporary culture, focusing on the Das family's journey from Bangladesh and India to the United States. Through characters such as Ranee, Tara, Sonia and their descendants, Perkins illustrates how cultural practices-ranging from dress, language, rituals and festivals to gender expectations and public conduct-become markers of identity that are constantly negotiated in transnational spaces. This paper examines the multifaceted representation of cultural identity in You Bring the Distant Near, analyzing how traditions are preserved, challenged and redefined across generations of women. It also considers the role of hybridization, or the "third space", where immigrants create new identities that synthesize their ancestral heritage with the demands of their adopted homeland. By foregrounding questions of diaspora, gender roles, generational conflict and cultural transformation, the novel ultimately demonstrates the resilience of immigrant identity and the ways in which cultural negotiation shapes belongingness in a globalized world.

Keywords: *Cultural identity, diaspora, Bengali culture, transnational hybridity, third space.*

Introduction

Mitali Perkins' *You Bring the Distant Near* (2017) is a multi-generational novel that traces the life of an Indian- Bengali family across decades as they navigate life in America. The concept of cultural identity occupies a pivotal place in discussions of migration, diaspora and transnational literature. Identity, as shaped by culture, encompasses shared customs, beliefs, values and artistic practices that define a particular group or society. These cultural patterns not only serve as a collective framework for self-understanding but also mediate social interactions, personal relationships and community belonging. When individuals or families migrate to new lands, their cultural identity undergoes significant reconfiguration, often resulting in tensions between continuity and change. In this sense, cultural identity is never static but remains a dynamic process of negotiation, shaped by memory, tradition and the pressures of assimilation.

Cultural Identity, Migration and Diaspora

Mitali Perkins' *You Bring the Distant Near* foregrounds this very negotiation of cultural identity through the lens of an Indian-American family whose generational experiences reflect broader themes of diaspora and adaptation. The Das family's migration from Bangladesh and India to London and then to New York introduces them to unfamiliar cultural landscapes that challenge their established norms and practices. These shifts expose them to issues of racial identity, gender roles, religious rituals and social customs, all of which are mediated through the complexities of immigrant life. The characters grapple with questions such as how to preserve their Bengali traditions in a foreign environment, how to respond to pressures of assimilation and how to bridge generational differences in expectations of freedom, education and career.

This paper situates cultural identity as the central axis of analysis, focusing on how Perkins uses narrative and character development to illustrate the struggles and triumphs of immigrant adaptation. From the symbolism of clothing and language to the observance of rituals and festivals, cultural practices emerge as both tools of preservation and sites of conflict. Moreover, Perkins demonstrates how women, in particular, navigate the intersections of heritage and modernity, often challenging traditional constraints to forge new identities in transnational spaces. By analyzing these dynamics, the study argues that *You Bring the Distant Near* not only documents the lived experiences of immigrant families but also illuminates the hybrid cultural spaces that emerge when tradition meets the modern world.

Culture is not merely a collection of customs or rituals, it is the symbolic system that provides individuals with meaning, structure and a sense of belonging. When individuals leave their homeland and enter a new cultural environment, these symbolic systems often clash, producing a crisis of identity. In *You Bring the Distant Near*, Perkins foregrounds this cultural clash by presenting how the Das family negotiates its Bengali heritage while adapting to American society. Through details of food, clothing, language, festivals and rituals, the novel shows how everyday practices serve as the terrain upon which identity is both contested and redefined.

The matriarch, Ranee Das, embodies the protective instinct of cultural preservation. Her adherence to Bengali traditions-from her insistence on wearing saris to her initial refusal to integrate into American customs-reflect the diasporic immigrant's struggle to maintain cultural roots in an alien land. For her, culture is a form of memory and moral discipline. In contrast, the younger generations, particularly Tara and Sonia, perceive culture as fluid, something that can be questioned, modified or, even discarded in pursuit of selfhood and social acceptance.

This intergenerational divergence highlights how identity evolves under the pressures of migration, where the homeland is remembered nostalgically, while the adopted land demands adaptation.

Language and Communication

Language operates as one of the most visible markers of cultural belonging. In the novel, the characters' relationship with Bengali and English reveals both attachment and alienation. Ranee's insistence that her daughters continue to sing Rabindranath Tagore's songs and speak Bengali reflects her fear that linguistic assimilation would erase their cultural memory. For immigrants, language often functions as a bridge to the past; losing it signifies a rupture with ancestral identity.

At the same time, the daughters' fluency in English becomes their passport to American identity, enabling them to navigate schools, friendships and eventually careers. Yet, Sonia's dark skin complicates this integration, as her appearance often leads Americans to misrecognize her as African American. This misrecognition illustrates how language, though vital, is insufficient for full cultural acceptance, racialized perceptions also shape identity in diasporic contexts. Sonia's struggle underscores the intersectionality of race, language and identity in immigrant lives.

Dress emerges in the novel as a symbolic battleground between heritage and assimilation. For Ranee, clothing is not simply aesthetic but cultural performance, a sari signifies femininity, respectability and tradition. Her decision to wear sari even in America illustrates her refusal to relinquish her cultural codes. When she dresses up her daughters in traditional attire for their first day of school, she is performing cultural memory in a foreign space.

For the younger women, however, American fashion represents autonomy and belonging. Jeans and T-shirts are not only comfortable but also symbolic of freedom and modernity. Tara, in particular, finds empowerment in adopting Western dress, aligning herself with American youth culture. The school locker room scene, where Anna and other immigrant girls resist undressing publicly, further demonstrates how clothing intersects with cultural taboos about privacy, modesty and gendered behaviour. Clothing, therefore, becomes both a personal and political act, marking one's negotiation between conformity and resistance.

The observance of rituals provides another lens into cultural identity. Perkins portrays the Hindu shradh ceremony following the death of Ranee's husband as a site of both continuity and contestation. Traditionally, such rituals are performed by the eldest son, yet Sonia challenges this gendered norm by taking up responsibility for her father's rites. Her refusal to yield to patriarchal dictates, even when questioned by relatives, represents a feminist

reimagining of cultural practice. By granting daughters the right to perform such rituals, the narrative destabilizes rigid traditions and creates space for transformation. This moment highlights a broader theme as culture is not static but can be renegotiated in the diaspora. While Ranee initially clings to widowhood norms-donning white saris, rejecting adornments and withdrawing socially-her eventual transformation into a more vibrant individual who embraces American citizenship signifies cultural evolution. Rituals, while rooted in tradition, are shown as adaptable to new contexts and capable of being reshaped by those who inherit them.

Bengali culture traditionally restricts physical intimacy in public, reflecting a conservative approach to gender relations. Perkins captures this through Tara's initial discomfort with public gestures of affection, such as when an American soldier attempts to hug her. Similarly, Amit's half-hug in Bangladesh and Tara's subsequent breaking of this taboo by holding his hand in public illustrate the conflict between inherited norms and the liberal ethos of American society.

These moments reveal how gender norms are negotiated in transnational spaces. While public displays of affection are frowned upon in Bengali culture, American society normalizes them as expressions of individuality and emotional honesty. The Das daughter's gradual acceptance of such gestures reflects not only their personal growth but also the slow loosening of rigid cultural expectations. Gender roles, therefore, become central to understanding how cultural identity is contested and reshaped.

Negotiating Tradition and Modernity

Food and festivals function as cultural anchors that tie immigrants to their heritage Perkins describes how Bengali rituals such as Annaprashan (the rice-tasting ceremony) are adapted in America, illustrating both continuity and rupture. Ranee hosts such ceremonies for one granddaughter but not for another, signaling how traditions are selectively maintained. Festivals like Durga Puja and Eid are mentioned as markers of communal identity, underscoring how diaspora communities reconstruct homeland traditions in their adopted countries.

Domestic spaces, particularly the kitchen, also embody cultural values. Ranee's devotion to the kitchen reflects the traditional expectation that women prioritize their family's needs over their own. This aligns with the cultural script of women as nurturers, yet it also illustrates how identity is shaped by gendered labour. Even within America, Ranee remains tied to the kitchen, embodying the persistence of cultural roles despite geographical displacement.

Naming practices highlight another dimension of cultural identity. The use of Bengali nicknames such as "That's his nickname for her-what "Tara" means in English. When I was

two, I started calling her "Starry" instead of "Didi"…I'm "Baba" to Ma, "Sunny" to starry, but I've always been Baba's "sweetie"'(21) contrasts with the Americanized mom and dad. "I call my parents "Ma" and "Baba", Bengali-style. Shanti calls hers "Dad" and "Mom". I think she speaks about ten words in Bengla. Her loss" (208). Names serve as intimate markers of belonging, transmitting cultural memory within families. Yet, as later generations adopt American terms, the shift reflects assimilation and the loosening of ties to heritage.

Generational shifts are central to the novel's exploration of identity. Ranee represents tradition and resistance to change Tara embodies adaptation through performance and acting, Sonia symbolizes confrontation with racial prejudice and cultural limitations and Chantal, the granddaughter reflects full assimilation into American culture. Across these generations, Perkins demonstrates how identity evolves from cultural preservation to hybridity and, eventually, to cultural synthesis.

Hybridity and the "Third Space" in Immigrant Identity

The most profound contribution of *You Bring the Distant Near* is its depiction of hybridity. The immigrant characters neither wholly abandon their Bengali culture nor fully assimilate into American society. Instead, they occupy what theorist Homi Bhabha calls the "third space" (37) where cultural negotiation produces new forms of identity. This hybrid identity is not a compromise but a creative synthesis that allows immigrants to draw from both traditions.

For example, Sonia's insistence on performing her father's funeral rites challenges patriarchal customs while retaining the spiritual essence of the ritual. Similarly, Tara's pursuit o f acting incorporates both her Bengali sensibilities and her American aspirations. Even Ranee, who initially resists change, eventually adopts American citizenship and embraces new cultural practices, illustrating the fluidity of identity.

> "Theater, my Star?" Baba asks. I listen carefully, but there's no disappointment in his tone, only surprise. "Yes, Baba," I say. "it's been an interest of mine. And I think I might be good at it. But Ma-" Baba takes my hand in both of his. "My grandmother use to organize natok in the village for the children-she loved to act. There's nothing wrong with telling a story onstage. It's beautiful work; it brings people togrther. Rabindranath Tagore wrote plays, didn't he?....". (94)

The "third space" (37) thus emerges as a metaphor for immigrant life-a liminal zone where the old and new intersect, producing identities that are neither fully traditional nor fully modern but something altogether new. Perkins' narrative, therefore, captures the resilience and creativity of immigrant identity in negotiating cultural boundaries.

Conclusion

Cultural identity, as represented in Mitali Perkins' *You Bring the Distant Near*, emerges as a fluid and contested space shaped by migration, generational differences and the negotiation of tradition and modernity. The Das family's story illustrates how cultural practices such as dress, language, food, rituals and gender norms both anchor individuals to their heritage and create tensions in the process of assimilation. For Ranee, cultural preservation is an act of memory and fidelity to ancestral traditions. For Tara and Sonia, cultural adaptation becomes necessary for survival and self-definition in a new environment. For Chantal, the granddaughter born and raised in America, cultural hybridity is lived as an everyday reality.

What makes Perkins' narrative compelling is her refusal to portray cultural identity as fixed. Instead, she reveals its elasticity, showing how individuals reinterpret traditions in ways that align with their values and circumstances. Rituals such as the shradh ceremony, clothing choices or even forms of address within families are not static remnants of the past but living practices that evolve across contexts. In this evolution, women play a central role, challenging patriarchal norms, questioning rigid boundaries and embodying new forms of identity that fuse the past with the present.

Ultimately, the novel emphasizes that immigrant identity cannot be confined to either homeland or host land. It exists in what Bhabha terms the "third space" (37), a hybrid zone where the old and the new intersect to create something distinct yet interconnected. This hybrid cultural identity, though marked by conflict, is also a source of resilience, creativity and belonging. Perkins' portrayal of the Das family thus serves as a microcosm of the immigrant experience, reminding us that cultural identity is not about choosing between two worlds but about weaving them together to bring the distant near.

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Intersecting Inequalities: Racial and Gender Disparity in Bernardine Evaristo's *Girl, Woman, Other*

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ABSTRACT

Racial and gender disparities have existed for centuries and continue even today, despite advancements in education, technology and global awareness. Among those most affected are women, particularly Black women, who experience a dual burden of discrimination based on both race and gender. In Girl, Woman, Other, Bernardine Evaristo portrays the struggles of twelve Black British women whose lives illustrate how discrimination shapes identity, limits opportunities, and affects mental and emotional well-being. Although the novel is fictional, the experiences of its characters reflect the real-world inequalities that many women still face.

Keywords: *race, gender, discrimination, intersectionality, inequalities*

Racial and gender disparities were historically accepted under colonial systems that constructed a hierarchy placing white people as superior and Black people as inferior. This ideology conditioned Black people to see themselves as subordinate. Black women, in particular, faced an added layer of discrimination due to both race and gender.Although society has progressed, contemporary evidence shows that racial and gender inequalities persist. In the UK, a major study revealed that 75% of women of colour have experienced racism at work, demonstrating the endurance of structural discrimination. As bell hooks observes, "Black women were positioned at the bottom of the racial and gender hierarchy" (52). Even though twenty-first-century societies claim to be more progressive, women of colour across the world continue to face structural barriers rooted in these older systems. Such findings echo the realities presented in Evaristo's novel.

In *Girl, Woman, Other*, intersectional oppression is embodied through characters whose racial, gender, class, and immigrant identities shape their struggles. Kimberlé Crenshaw argues that oppression cannot be understood through a single category such as race or gender. He states, "The intersectional experience is greater than the sum of racism and sexism" (140). Evaristo's characters demonstrate how race, gender, class, and immigrant identity overlap in complex and often painful ways.

Yazz articulates the complexity of privilege when she states, 'Privilege is about context and circumstance.' This line underscores that privilege is not fixed; it shifts depending on one's environment and social position. Another moment reinforces this theme when Yazz's friend cautions against competitive suffering, saying that playing privilege Olympics ignores the context and relativity of privilege. This highlights that individuals may experience both oppression and advantage simultaneously.

Amma's story further illustrates systemic inequality. As a Black British playwright, she challenges a white male–dominated theatre culture that dismisses Black women's narratives. The line "She fought the patriarchy with her theatre" (12) shows how Amma uses art as resistance, reclaiming space and voice for marginalized women. Carole's character reveals the long-term impact of educational discrimination. She reflects, "Carole realized her teachers never expected much from girls like her" (45) capturing how low expectations shaped by racism and sexism can limit confidence, ambition, and opportunities. This aligns with research from the Runnymede Trust, which notes that Black students in the UK are often underestimated and placed in lower academic tracks. Carole's later attempts to distance herself from her identity reveal how stereotypes can become internalized, influencing one's self-esteem and understanding of success.

Bummi, Carole's Nigerian immigrant mother, faces racial bias that prevents recognition of her qualifications. Her story mirrors real-world data showing that ethnic minority women continue to be overrepresented in low-pay work despite being qualified. Her narrative demonstrates how race, gender, class, and immigrant identity intersect to shape a woman's life. Although she was educated in Nigeria, her qualifications are dismissed in Britain. Evaristo writes, "Bummi's qualifications meant nothing here, so she cleaned houses to survive" (61).

Penelope's emotional journey also reflects internalized societal pressure. "Getting rid of the full-length mirrors in her home was a good start" (229) symbolizes her first attempt to break free from the rigid expectations of appearance, behavior, and identity that defined her life.

Collectively, the novel demonstrates that while legal and social advancements have occurred, structural inequalities rooted in colonialism, racism and patriarchy persist. Educational institutions reinforce biases through low expectations; workplaces replicate historical labor hierarchies; gender violence reflects ongoing patriarchal control. These systems show how the past continues to shape present realities.

Evaristo's narrative style- shifting perspectives, lyrical prose and interconnected stories, creates a rich portrait of Black British womanhood. The novel suggests that despite social progress, "the residues of colonial hierarchies still linger in modern institutions" (Ahmed 203). Schools, workplaces, cultural industries, and immigration policies often reproduce inequalities that originated centuries ago. Yet, the resilience of the characters reflects the courage and determination of Black women who continue to build community, assert identity, and carve out spaces for themselves.

Bernardine Evaristo's Girl, Woman, Other offers a powerful literary exploration of how race, gender, class, and sexuality intersect to shape women's lives in contemporary Britain. This paper demonstrates that intersectionality in the novel operates not only at the thematic level but also through Evaristo's innovative narrative form—its shifting perspectives, interconnected character arcs, and poetic prose. By foregrounding the relationship between literary structure and intersectional experience, this study contributes to existing scholarship by showing how formal experimentation itself functions as a mode of resistance and representation. Ultimately, Girl, Woman, Other emerges as both a socially engaged text and a significant contemporary literary work that expands feminist and postcolonial narrative practices.

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Memory and its Role in Evoking Emotions: A study on Fredrick Backman's *A Man Called Ove*

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ABSTRACT

Memory is not just an echo of faded moment, but is an element of survival in need. It often plays a major role in shaping an individual. Individuals are brought down to their lowest sanity when they are not aware of their emotions and the need to have an emotional outlet. Memory becomes a place of residence and a coping mechanism against grief. In most cases it also acts as an inducer of grudge, especially in widowers. This is the idea discussed in Fredrick Backman's A man called Ove. This study intends on showcasing the role of memory in dealing with various emotions such as grief and grudge. It portrays how memories can evoke different emotions in an individual leading to the personality and behavioural alterations.

Keywords: *Emotions, Grief, Grudge, Old age, Memories*

Memory is a distinctive feature of mankind. It serves as a personal history to men, and men are defined by their history. Memories of varied setting, induce an assorted range of feelings and emotions. Some memories are nostalgic and warm, which rewind on the pleasant time. There are memories which go after emotions like anger and hatred, often reflecting in the form of a grudge. These emotions are inevitably triggered by the memories when retrospected.

Memory plays a pivotal role in moulding an individual into a distinct and remarkable individual. Memory is capable of both hauling into the darkness of the past, as well as leading into pleasant moments. However, memories are meant to be visited and not to be considered as a permanent residence. The fusion of experience with emotions and feelings results in memories. Memory is often known for playing with the illusion while shrouding the reality. According to the protagonist of Salman Rushdie's *Midnight's Children,* "Memory has its own special kind. It selects, eliminates, alters, exaggerates, minimizes, glorifies and vilifies also; but in the end it creates its own reality" (20). This highlights the capacity of memory, even though it's not often awarded the required respect and caution. It has the potential to raze as well as raise a person.

The book *A Man Called Ove* by Fredrick Backman delves deeply on the crucial function of memory in Ove's life. It also discusses how memory evokes the suppressed emotions and feelings. The life of Ove is told mostly through his past actions and his own memories. Despite

his age, Ove is shown to have an exceptionally strong memory power. Ove is a grieving widower who has lost his wife. He also losses the only other meaningful connection he had with his friend Rune. Ove is portrayed as an embodiment of unexpressed emotions who is frequently stuck in navigating the waves of emotions and the current of feelings.

Grudge is a deep rooted anger which is never truly forgiven or forgotten. It is one among the major feelings aroused by the memory. The recurrent recollection of a particular unpleasant incident, consequently results in grudges. Ove holds on to his bitter experience with Rune and he is reminded of that frequently. It displays the ability of memory in bringing out the negative emotions and feelings. According to the prominent author George Eliot, "It is never out tenderness that we repent of, but our severity" (40), which explains how the piling up of grudge is repented at a particular phase, where we get a new lens to look at things.

Ove holds onto his hatred towards Rune for ruining their reputation and principles. The memories of the broken friendship confine him. But the constant rumination of the changed attitude of Rune angers him. The emotion of grudge overpowers other emotions. Ove never forgets the past easily and is not an appreciator of change. When Ove finds out that Rune has welcomed change and has gone against his principle, Ove can not bring himself to talk to Rune again. He feels betrayed and distances himself. He was not ready to forgive Rune by giving up his grudges nor by forgetting the incident.

The depth of their friendship is portrayed as the tip of the iceberg. It is also evident how both of them are literally the same person with slight differences in lifestyle and perspective. "One of them a man who refuses to forget the past, and one who can't remember it at all" (192). Ove sticks to his principles while Rune does not. One consents to the change while the other does not, which causes the fissure between the two. But in the end, the memories of their friendship rekindles Ove's love for Rune, and he fights for the custody of Rune along with Anita.

Grief is a powerful emotion which is often mishandled. It is often summoned when something closer to heart is lost forever without any chance of recovery. Every individual has their own way of coping with it. People want the older generation to remain in a state of rest. They assume that it is time for them to get nostalgic about their past. In Ove's case he is left on his own to brood over his loss. But the very house where he once felt safe, becomes the place of suffering. He senses her absence in every nook and in every corner. Her absence haunts him to an extent where he tries to take his own life.

Ove is consumed by grief but he pretends otherwise. "People said Ove saw the world in black and white. But she was colour. All the colour he had" (40). After Sonja's death, Ove

holds on to the perspective that his life is colourless and is not worth living. He maps out detailed plans to kill himself, which is often distrupted by the neighbours unintentionally. “His life was never supposed to be like this. Full stop” (11). This line explains the emotional turmoil caused by memory.

Ove gets suffocated in the absence of Sonja. He continues taking the memory lane to feel the presence of Sonja which reminds him of the beautiful life they built together. According to Corrie Ten Boom’s book *The Hiding Place* “Memories are the key not to the past, but to the future.” (18). But Ove keeps on holding to his past, wishing to feel the warmth of Sonja in his memories while failing to lead his life. But towards the end of the novel, Ove finds a way to move on and lead his life in a positive manner.

Ove tries to lead his life, as if Sonja is still alive and is living with him. “It’s been six months since she died. But Ove still inspects the whole house twice a day to feel the radiators and check that she hasn’t sneakily turned up the heating” (31). Throughout the narrative, Ove converses with his wife as if she is alive, which is his way of dealing with the grief. In Ove’s case, memory acts as a shield to cope with the grief as well as an inducer which is capable of pulling into the abyss. “Right, right... This is the cat annoyance. This is living with us now. Almost froze to death outside our house” (153) The line explores how Ove travels through his daily life. It is not a sign of madness but a coping mechanism of Ove.

The novel is built on a single notion which focuses on broader perspective of how memory stirs varied emotions. “And when time no longer lives ahead of one, other things have to be lived for. Memories perhaps” (284). This is explained by Backman through his book, which focuses on the positive as well as the negative aspect of the memory along with its significance. Ove tries to live with the memories of his wife as her existence comes to an end. Her absence haunts him deeply and fills him with grief. “Nothing works when you’re not at home” (30). Yet, the very memories that seem to drown him in sorrow gradually transforms into a source of strength by the neighbourhood he lives in.

The time left behind runs out fast. And at a particular point, all that can be done is pondering over the memories and feeling nostalgic about them. "And time is a curious thing. Most of humanity only live for the time that lies right ahead of us" (284). Sonja’s presence continues to travel through the story, not as a living character, but as a powerful memory within Ove. Though her absence haunts him, the memories of her sustained by new human connections eventually guide him to become a better person. Memories are never going to be the same as moments but it can resonate life and change the way of life.

Ove grows into accepting the situation and begins embracing memories. He readily explores technology, human connections and relationships which made him anxious before. Memories of various stages shape him, pull him down, but at a certain point they heal him and help him move forward to lead his life in acceptance. Ove is made to understand memories and the need to navigate the feelings and emotions. Thus, it is evident that memory plays a crucial role throughout Backman's *A Man Called Ove* in dealing with emotions such as grief and grudge. It manipulates into holding onto past by evoking the sense of grudge, as well as a safe spot against grief. This is the major idea that is repeated throughout and Backman has meticulously crafted this idea in his novel *A Man Called Ove.*

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Technological Expertise in Professional Communication Fluctuating Human Knowledge and Aptitude Beyond Influence

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ABSTRACT

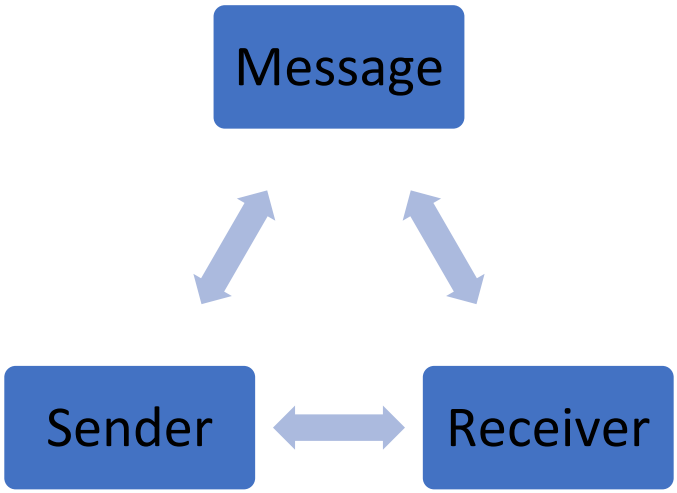
Communicative patterns have undergone tremendous transformation all these years. Sitting inside the four corners of a room, one can reach millions within a second. Communication being digitalized in entity in the ever-transforming world of knowledge has indeed altered the centuries old practices followed and retained in Society. To be noted is; it is used in all sectors like management, business upgradation, multimedia sources, interpersonal communication, education, writing and publishing, meetings, fundraising, news reporting, etc. Wireless communication, Internet facility, and its reachability through social media platforms, Instant messaging, Video conferencing, email communication, mobile apps, and online learning platforms have made communication more flexible and convenient. It has broken up the geographical barriers. The massive affluence in the field of communication has made man 'machine made' and highly demanding. This revolution in communication will indelibly keep endorsing changes. The present study "Technological Expertise in Professional Communication fluctuating human knowledge and aptitude beyond influence" gives an inclusive account of the digital platform that had opened up the possibilities of sharing anything beyond human power professionally. Further it focusses roughly on the principled formalities to be kept in practice in digital collaboration and guides one through 'digi-ethics'.

Keywords: *Digital platforms, wireless communication, machine made, revolution, digi-ethics*

Introduction

The time when the term 'language' had been in its infancy had to skirmish through multiple layers of meanings. Words carried in syrupiness tongue, dance, and practicality had made language efficient inadvertently and it had entered into every nerve and symptom that welcomed it without evidence in its sense. Come what may, the growth of its structure had led to the fruitful embellishment of words, then phrases, sentences, paragraphs and a form of communication undreamt by human beings. Effortlessly produced words had recommended upon signals that had made the universe pass it systematically in the forthcoming days. Without ever getting into an analysis of the growth from its birth, one can give a big round of applause to the speakers in every age. As long as living legends live and multiply, language will breathe and exhort infinitude in communication and its methods and style.

Any communication in its widest sense occurs between a dispatcher and a decoder and the message conveyed through channel on its linear part forms the base of such an exchange.



Process of communication

Arriving at the digital transmission of communication, one may refer back to Shannon-Weaver model of communication. Tremendous transition had taken place through the grid created by "A Mathematical Theory of Communication" in 1948 by Shannon and Weaver. For the digital mode with its unique achievement the efforts of scientists and innovators need to be commended. Beginning from 19th century through telegraph, telephony, radio, mobile, cellular, and digital transmission of data and information enumerates the vast sharing of information in the nook and corner of the society through the collaborative effort made by such intellects across the globe. This had led towards the progress in all fields of communication. Digital communication has touched upon the entire virtual world and the growth of it needs to be commended in words and in deeds.

The term 'digital' stands for the transmission of discrete messages through binary digits or symbols. 'Communication' in its term refers to the message transmitted between sender and receiver. Digital communication thus leads one to exchange messages or information using discrete signals. Digital mode of communication goes through the process as shown below.

 - Source (Sender's role of sending the message)

 - Transmitter (Telephone or mobile phone used to transmit the message)


-Signal (Channel through which the message travels from the sender)


-Noise (Interruption made in the communication system might disrupt the flow)


-Signal (Channel that carries the message towards the receiver)


-Receiver (Receiver's telephone or mobile gadget that deciphers the message)


-Destination (Receiver's response over any device)

Digital mode of communication

Digital platform had opened up the possibilities of sharing anything beyond human power. The societal communicative patterns had undergone changes and by sitting inside the four corners of the room, one can reach millions within seconds. Although this is a known fact, its impact was obvious during covid-19.

> Digital communication technology will continue to bring about intelligent infrastructures and sophisticated end user devices through which a host of applications in entertainment (e.g., wireless video on demand), education (e.g., online interactive multimedia courses), information (e.g., 3-D video streaming), and business (e.g., mobile commerce) will be provided. The burgeoning field of digital communication will thus continue to affect almost all aspects of our contemporary life. (Grami 12)

Persuasive Outcome of heightened Digital Platforms in Professional Communication

Using digital platforms for professional communication has indeed altered the centuries old practices followed and retained in the society. Digitalized communicative trend had set its

pace to coordinate the activities for the betterment of any institution. Thus, an institution or an organization with its network of communication has to be smooth and well organized to meet the digital world since the communication within the organization and around the world is monitored through several networking platforms. Today the initiative had gone to the extent of appointing trained HR officials to monitor the structure of an organization and coordinate the activities accordingly deputing the employees to suit the demand of the market. The amount of development witnessed in digital means of communication thus has opened a path for men to turn towards HRM.

It is the right period to bring to notice of the severe continuous effort in meeting nations mustering with the standard protocols and agendas of the countries and states, fighting for the cause of the nation's itinerant up and down challenging amidst obstacles the struggles of the people by a nation's representative. But at present, the 21st century has regained its status of a 'space' power to reach out to the masses with internet facility and multi controlled stations of inherent social media amplification. Man existent 'machine made' keeps in armpit the controlled world in hand. Here the controller is space driven man and the decision upon the official routine work over virtual communication rests with them. Broken borders and anytime talkative man are the development of society.

> Signal storage, reproduction, interface with computers, as well as access and search of information in electronic data bases can also be quite easy and inexpensive. . . . Digital transmission brings about the great ability to dynamically switch and route messages of various types, thus offering an array of network connectivities, including unicast, multicast, narrowcast, and broadcast. (Grami 14)

Digital Leverage

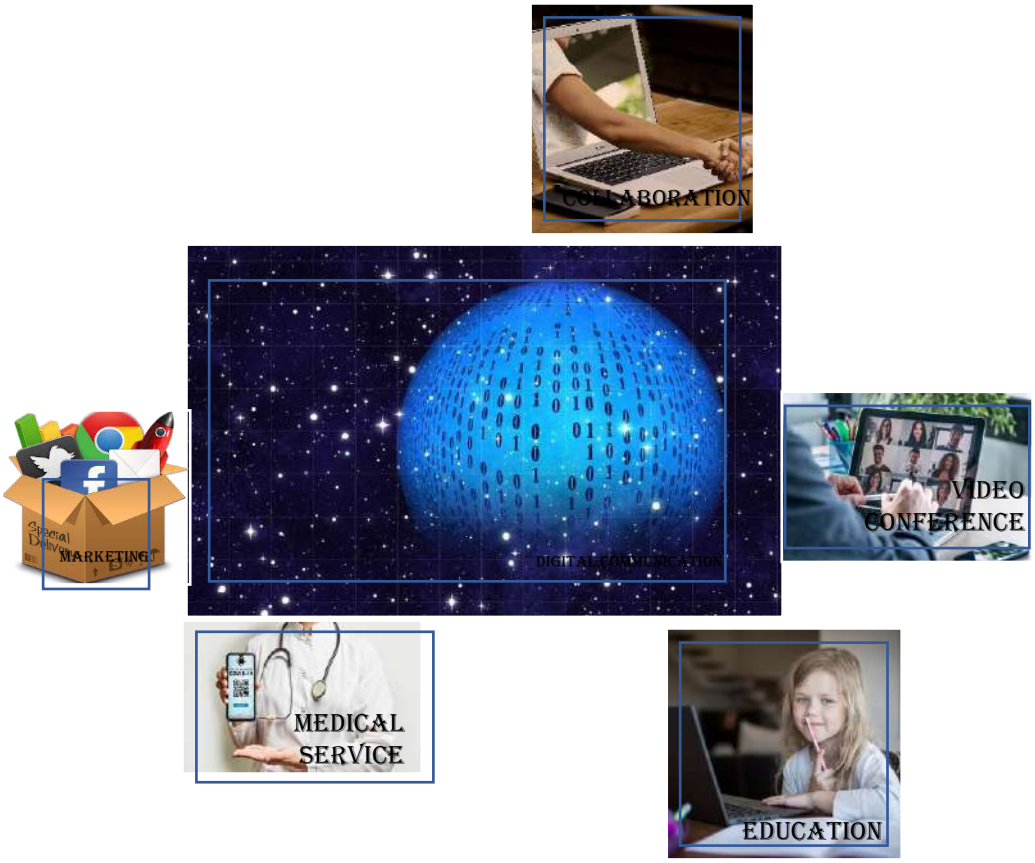
Social media

"Social media is a blur of "likes, tweets, shares, posts and content" (Bullas, 2014; Heggde 4). There are a good number of impressive platforms and they get audience from around the whole of the planet. To name a few Apps; Facebook, WhatsApp, twitter, LinkedIn all enormously support one in ownership with the plenty. As like emails which had been used officially replacing physical and formal letter writing, social media has currently replaced the whole field of profession handled physically whether it be Economics, politics, business, marketing, product promoting, education, or even administration in private or public establishments. In all these sectors the vast use of such technology is found. Meeting the scope of the industrialized technology being the thirst of the people has made nothing ever hidden as before.

> Social networking sites, sharing sites for user-generated content, blogs, microblogs and wikis, just like all other media, are social in the broad understanding of the term as information. Some of them support communication, some collaborative work, content sharing or community-building. These latter three forms of sociality have, due to the rise of platforms like Facebook, LinkedIn, Wikipedia or YouTube, become more important on the World Wide Web (WWW). (Fuchs 7)

Covid-19 in Video Conferencing

Once people during Covid 19 could not report to the office fearing death, video conferencing was normalized in casual set up and thus Apps as that of Zoom, Microsoft teams, Google Meet, and Skype gained its immense popularity. Schools, colleges, companies, govt. sectors, even higher officials started meeting online and took decisions only through video conferences. Classes were handled online. Coursera, Udemy, edX gained dominance in distance learning and active classroom development at home with different inaccessible courses in fingertips. This is the crucial stage that turned upside down the normal social set up. Health consultations too been started taking place through health care platforms like MeMD, PatientsLikeMe, GoodRx. Online customer support and marketing were yet another unexpected support provided home to home. Even court cases were finalized and judged online. The proliferation of Artificial Intelligence is all because of the demand made from small little children to the bedridden of the ever-present handy world that they witnessed during Covid 19 being left isolated at home from their friends, colleagues, students, teachers, helpers, lovers, guides etc. The humanity which made its exploration all of a sudden and benefited out of such a rapid change still persists only of such demanding platforms. Presently, there can never be imagined of a profession bereft of them.



Email

To be assured of one thing is that daily activities of today never materializes without a personal email ID. Every segment, whether it be business or educational institutions, it has become a basic necessity. An email is a trustworthy platform where official, confidential matters are shared. This communication process is said to have undergone a sudden transformation due to its wide usage by common people for every aspect of life. It remains anticipated always by all for its privacy. For it will always stand ahead in giving life to the unsolicited and awaiting.

Mobile apps

Google playstore encapsulating thousands and thousands of Mobile apps have become handy in mobile phones even for daily chores. For buying, selling, reading, writing, banking, monitoring through maps, booking tickets, transferring money for all of which mobile apps are said to enhance the flow of communication faster. It is the one that boosts up the people to go for the best and always engages them in one or the other activity. These apps have got the capacity to compress enormous amount of information for ready reference. Such apps play a vital role in the accumulation of wealth and value to the better augmentation of an organization.

Content Creation

In every website, created out of interest; stories and narrations of the common man gain popularity due to the widespread knowledge carried out of the content posted. You Tube stands as one reachable site that encourages participants to post day today situational contents.

> When building and expanding your network, it is important that the written content on your blog and business site makes use of keyword phrasing. Spiders and web crawlers scan text on your site, determine what it's about and rank its relevance in comparison to commonly searched keyword phrases. Using keywords within your text boosts the ranking and pushes your site closer to the top of search engine results. That being said, avoid cramming or forcing keywords into text just to gain a higher ranking. Your text is a conversation between you and your customers and keyword-stuffing can read like ad copy and turn off readers. (Futures 25)

The content that is posted not only left for fun and enjoyed going through the video, audio, and text, but the worth of it fetches an unexpected sum of money to sustain livelihood. Even from a small boy to an old man who is left unnoticed at home earns out of the contents that teach, advise and encourage one to get into a pleasant life in the contemporary world. The things that are even left for its worthlessness too reaches the unexplored section of the society to give credit to each and everything that is thrown out as unused and inoperable objects.

Best practices for online association and networking

Gabriella Warren states:

> Online collaboration effectively allows employees to shrink the distances between each other. They can work together on the same projects at the same time, as if they were all in the same room. This means that projects can be done much faster, as there is no need to send documents back and forth between offices. (2020)

Time consciousness

The meetings that are arranged should be made known to everyone in advance as there is no physical contact takes place between the members. The members in order to be present at the exact hour and not to miss any agendas of the meeting should be alert at the right hour. While the meeting held, it is better to make known the hours or minutes allotted for each participant. If not, the meeting would consume the valuable hours of others and those who would like to share their content would lose their chance. In the same way the persons who would like to fulfil their own schedule after the meeting would become restless and leave the meeting all of a sudden unattended with lame excuses like power failure, charge down in mobile, internet interruption. So proper arrangements with the consultation of other members

and time consciousness would reduce the burden of going through such pretext from the participants.

Information sustenance

Information as of years back cannot be left deprived of proper maintenance. The books that are stored in libraries retain their information and even previous storage of information in auditory, visual formats were too retained in CDs. They are left with their materials as they are. Such methodologies of saving resources are out modern. Hence today the knowledge has taken a form of sharing vast segment of knowledge in digital format and that fulfils the expectation of one temporarily but to retrieve back its wealth, the course of action adopted should be the storage and use of those files as and when need arises among the company, organization, or among its members. This adaptation boosts the recovery and renewal any time.

Transparency

There should be transparency between each member. The data's that are shared since looked into and taken care by all, the confidential information may be leaked out even by the members belonging to the team. Trustworthy members are better developers and persist as corner stone of any developing and developed organization.

Skillfulness

Members present online if skilled in software and hardware will reduce the risk of hindrance out of internet and computer black out. Such nuisance if arise, will distort sudden decision makings online. Skillfulness in handling them at any critical stage will bring in lumpsum reward at the propitious hour.

'Do' or 'Die' status

Online collaboration and networking focuses on 'do' or 'die' status. At any time keeping oneself accessible and reachable will intensify the financial constriction.

Reminders

Online collaboration would be smooth if reminders are kept after completing, or for follow up of any task by the members involved.

Regular meetings

Discussion on every matter through regular meetings will help to concentrate on future agendas.

DIGI-ETHICS

Empty room

An empty room refers to a room with none but only 'one'. 'None' meant here is person and on the whole the unwanted objects present visually to overtake the attention. One and one

conversation would be more beneficial. That would bring free flow of communication uninterrupted by anyone in-between. Employees who are assigned 'work from home' job will be more comfortable if a room is specially arranged for their convenience.

A curtain would do

People will have to meet face to face through online platforms like zoom or Microsoft teams; at such times a curtain would do where not an empty room is made available. Smooth flow of session would continue if such a pleasant atmosphere is created using a specially made curtain for such gathering.

Noise interruption

Noise interruption can be cut short keeping the mic on and off at the needed hour. The conversation with others over internet would be petulant and would not draw appropriate result if it is not followed.

Presentable

Be a person presentable when presenting to a huge audience. Dress code does matter in such times. When an interview is conducted for career, the interviewed may lose job due to one's attire. It is essential the person gives importance to his valuable presence.

Confidentiality

The members should know to handle the confidential files, audio, videos digitally. If misunderstanding happens between the members, the evidence would save the time against arguments.

Group Discussion

At times the employees should meet to rectify the matters in the organization. Meeting once in a week would leave any organization prosper; deciding and settling the matters of the week then and there.

Be gentle

Gentleness in dealings would be a record of welcome towards all that is satisfactory and preventable. Undeserving attitude towards friends would evoke a kind of abhorrence. It is better to keep one's emotional stability at work as it would thrive more collaboration sharing plenty source of information.

The identity of the Organization

The content posted in the organization's website is always under scrutiny since it is available for all always and everywhere. The organization that makes known then and there the better prospects indeed stirs the curiosity of the people. Hence it is to be checked in advance upon accessibility.

> Most companies should be on Twitter; it's easy, requires very little investment of time, and can quickly prove worthwhile in increased buzz, sales, and consumer insight. You can use Twitter to announce offers or events, promote new blog posts, or keep your readers in the know with links to important news stories. (Zarrella 31)

Care about abusive/ provoking language

Language written should be reread several times before bringing it to the notice of the people. Every word that is used online does matter. People may forgo the grammatical errors but not the overt vocabulary used in certain places.

Tone and pronunciation

The official tone maintained and the better pronunciation enhanced with, would clearly state the matter to be conveyed, if not genuine thoughts would be mistaken.

Internet facility

Steady internet facility would make it more convenient for both the sender and receiver being engaged online systematically at any time. Interruption at any stage will break down the conversation or discussion carried out and thus proper management is needed.

Feedback system

For a systematic planning and organization of the activities, feedback system maintained in the organization will bring development in every field. Constructive thoughts and negativity both can be encouraged; pessimism may be taken as a drive towards positivity and positive comments may be utilized for revitalizing the organization and motivating its members.

Appreciating creativity

Creative projects ushering in huge amount of money to its organization can be encouraged from its members.

Regular updation of apps

The industry or an organization should see to it that regular updated app is circulated. A file handled physically may remain stagnant in the office but digital files do have the nature of transportation. Such transfer is done through apps and thus such apps should be overseen. As intractable number of files, audios, and videos keep overflowing digitally every minute, the files may be replaced due to the peak of files saved. So it is better to name the files appropriately and keep it in folders for immediate circulation and future reference.

> Media, such as the Internet, are a means of communication. They are tools that enable the production of communication and human sociality. Means of communication, like the Internet, are therefore essential necessary features of human society, just like nature,

> education, love, care, knowledge, technology, affects, entertainment, language, transportation, housing, food, cities, cultural goods and traditions, etc. Communication and the means of communication are part of the commons of society – all humans continuously create, reproduce and use them in order to exist. (Fuchs 242)

Conclusion

Digital platforms retain always the communication network under check. It coordinates the activities and manages to keep everything in order. The office set up is broken down but still the office at homes keeps men engaged not only with official work but also personal. If properly used a man with a mobile phone and internet facility will sure go to the extent of transforming 'hell' into 'heaven'; and not an exaggeration 'a loser would become a winner', 'a bankrupt a manager of the bank'. Through Online tools integrated communication, the world would regain back its lost riches and future dreams. Communication process will thus keep changing the traditional approach to professional communication.

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Eco-Spiritual Awakening in Richard Powers' *the Overstory*: Olivia Vandergriff's Transformative Journey

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ABSTRACT

Drawing on the concepts of animism and eco-spiritual consciousness, the paper analyses how Olivia's encounters with trees present nature as a living, responsive presence rather than a passive backdrop. This paper examines the theme of eco-spirituality in The Overstory by Richard Powers, focusing on the transformative journey of Olivia Vandergriff. Moving beyond a character sketch, the study traces the stages of Olivia's spiritual awakening from purposelessness to mystical rebirth and finally to ecological activism. Through close textual reading, the research demonstrates how her narrative becomes a crucial site where ecological sensitivity, moral responsibility, and spiritual insight intersect. While foregrounding the sacred dimension of the environment, the study also reflects on the risks and ambiguities embedded in absolute spiritual devotion, thereby offering a balanced reading of eco-spiritual awakening in the novel.

Keywords: *Eco-spirituality, Interconnectedness, Environmental consciousness, Sacred connection, Animism*

Eco-spirituality is founded on the belief in the sacredness of nature and the profound spiritual interdependence between human beings, the Earth, and the universe. It emphasizes that all forms of life—including non-human creatures, plants, and trees possess intrinsic value and deserve ethical regard. By rejecting anthropocentric dominance, eco-spirituality advocates harmonious coexistence grounded in reverence, responsibility, and sustainability.

In the contemporary world, overconsumption and environmental degradation have accelerated climate crises, exposing humanity's failure to recognize its moral accountability toward the natural world. From an eco-spiritual perspective, trees are not mere material resources but living entities endowed with memory, resilience, and agency. Their destruction thus represents not only ecological damage but also a spiritual rupture. Such a framework invites renewed ecological consciousness rooted in humility and care.

Ecology and spirituality intersect at the level of relational awareness. As Valerie Lincoln observes, "Eco-spirituality is a manifestation of the spiritual connection between human beings and the environment" (227). This interconnection is powerfully dramatized in *The Overstory*, where characters gradually recognize the communicative and interdependent

nature of trees. However, rather than treating this recognition as unambiguous truth, Powers leaves space for interpretive tension—between mystical vision and psychological experience, between revelation and projection. It is within this ambiguity that Olivia Vandergriff's journey becomes especially significant.

Although the novel interweaves multiple lives, Olivia's transformation offers one of its most striking explorations of eco-spiritual awakening. Initially portrayed as a reckless and directionless college student, Olivia undergoes a radical change after surviving electrocution. This near-death experience functions as a symbolic rebirth. Powers writes, "Someone spoke to her when she was dead. Used her head as a screen for disembodied thoughts . . . Then she fell back into her prison body, and the invisible vistas blurred to nothing" (196). This passage marks the first stage of her transformation: mystical encounter. The experience reflects the principles of animism, which attribute vitality and consciousness to non-human entities. Animism challenges anthropocentrism by recognizing personhood in trees, rivers, and landscapes. In Olivia's case, trees are no longer background scenery but presences capable of communication. Yet the narrative does not definitively confirm whether these voices originate externally or internally. Powers deliberately preserves ambiguity, allowing readers to question whether Olivia's visions are spiritual revelations, psychological aftereffects, or symbolic awakenings. This ambiguity enriches the eco-spiritual dimension rather than diminishing it, suggesting that meaning itself emerges through interpretive engagement.

The second stage of Olivia's transformation involves attentive listening. Powers writes: "Life was whispering instructions to her… I'm still. I'm listening. What do you want from me?" (198). Here, eco-spirituality manifests as cultivated stillness and receptivity. Ethical awareness arises not from dominance but from humility. Olivia's openness signals a shift from self-centered existence to relational consciousness. Her prayer-like posture aligns with eco-spiritual thought, which regards deep listening as foundational to environmental responsibility. Her sense of calling intensifies, "You were worthless . . . But now you're not. You've been spared from death to do a most important thing" (203). This moment marks the third stage: vocational awakening. Survival becomes mission. Olivia interprets her spared life as purposeful, binding her identity to ecological defence. However, this conviction also introduces potential tension. Absolute devotion to a perceived spiritual mandate risks erasing critical reflection. Eco-spiritual calling, while empowering, may also lead to self-sacrifice and radical action that blur ethical boundaries.

Olivia's surrender becomes explicit, "Just tell me. Say what you want, and I'll do it" (203). Her humility before the natural world exemplifies eco-spiritual reverence. Yet such total

submission raises questions about agency. Is Olivia exercising conscious choice, or relinquishing it entirely? Powers subtly invites readers to examine the costs of unconditional obedience to a transcendent vision. The climactic turning point occurs when she envisions activists chained around a tree, "The most wondrous products of four billion years of life need help . . . Confirmed. I hear you. Yes" (205). This revelation shifts her awakening from private mysticism to public activism. The sacred call becomes collective responsibility. Trees are portrayed as embodiments of evolutionary continuity, deserving defence against commodification. Powers critiques industrial exploitation while foregrounding ecological interconnectedness.

However, activism in the novel is neither romanticized nor simplified. The commitment demanded of Olivia and others entails danger, alienation, and eventual tragedy. Eco-spiritual awakening thus carries risk of devotion to preservation may result in confrontation with societal structures and even self-endangerment. By tracing this trajectory, the novel complicates the idealism of ecological mission. Olivia ultimately renounces conventional aspirations, "There's a project . . . I've been recruited" (211). Her identity becomes inseparable from environmental struggle. She embraces symbolic resurrection living not for personal ambition but for forests and ecosystems. While her transformation embodies profound ecological consciousness, it also reveals the fragile line between inspiration and extremity.

Olivia's journey therefore illustrates both the power and complexity of eco-spiritual awakening. True understanding of the natural world arises from attentive presence and relational humility. Yet the novel resists presenting eco-spirituality as uncomplicated salvation. Instead, it portrays awakening as transformative, demanding, and ethically charged. Through Olivia Vandergriff, Powers blurs the boundaries between spirituality and ecology, suggesting that environmental crisis is not merely material but metaphysical. Her story becomes a lens through which readers are invited to reconsider human identity within Earth's interconnected systems. Eco-spirituality emerges not as abstract theory but as lived experience capable of reshaping perception, purpose, and action—while simultaneously requiring discernment and balance.

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From Struggle to Stardust: Anti-Futurist Perspectives on Transgender Transformation in Ryka Aoki's *Light from Uncommon Stars*

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ABSTRACT

In Light from Uncommon Stars, Ryka Aoki combines science fiction, fantasy, queer identity, and cultural storytelling to explore transgender transformation from an anti-futurist perspective, where transition is not a linear path toward an idealized self or a socially approved future, but a present moment of struggle, joy, creativity, and relationships. Katrina Nguyen, a young transgender violinist running away from an abusive home, becomes a symbol of perseverance as she finds safety and a sense of belonging through music, community, and self-love. The story weaves fantastical elements such as demon bargains, cursed violins, and interstellar refugees into everyday life, illustrating how identity formation emerges not from societal expectations but from human connection. Aoki disrupts futurist narratives that place undue pressure on transgender people to prove their existence through productivity or trauma. The novel's anti-futurist lens affirms that transgender life holds meaning beyond the expectation of transformation into a socially approved ideal. Aoki's storytelling celebrates the complex, evolving, and sometimes messy reality of living authentically in the present. Through Katrina's relationships with Shizuka Satomi, Lan Tran, and the broader community, the narrative demonstrates that joy, resilience, and belonging are found in shared human connections rather than in distant promises of acceptance. This study demonstrates that Aoki's Light from Uncommon Stars foregrounds the importance of present-moment experiences, community, and authentic selfhood in the lives of transgender individuals, challenging socially imposed narratives of linear progress or idealized futures.

Keywords: *Transgender, anti-futurism, self-love, music, human connection.*

Ryka Aoki's *Light from Uncommon Stars* (2021) is a genre-defying novel that blends cosmic migration, classical music, queer identity, and magical realism to explore transformation and belonging. Aoki, an award-winning transgender author, previously published *Seasonal Velocities* (2012), a Lambda Literary Award finalist, and *Why Dust Shall Never Settle Upon This Soul* (2015), which received the California Book Award. In interviews, Aoki explains that she writes "to create worlds where marginalized people can breathe, heal, and be loved," a creative vision that shapes the emotional and ethical framework of the novel. Rather than presenting identity as a linear progression toward social acceptance, the narrative foregrounds relational experience and present-moment survival through the intertwined lives of Katrina Nguyen, a young transgender violinist escaping abuse; Shizuka Satomi, a violin

teacher bound by a demonic contract; and Lan Tran, an alien refugee who creates a space of refuge through her donut shop.

Scholars have offered significant interpretations that support this anti-futurist reading. Beatriz Hermida (2025) characterizes the novel as an exploration of "radical hospitality," arguing that Aoki constructs alternative spaces in which queer and transgender bodies exist without conditions or demands for assimilation. Jeremy Brett (2021) similarly observes the novel's refusal of linear transition narratives, emphasizing vulnerability, creativity, and survival over narratives of completion or success. Charlie Jane Anders (2021) highlights Aoki's integration of Asian American cultural landscapes into science fiction, suggesting that such representation expands the genre's emotional and cultural possibilities. Aoki herself reinforces this perspective, noting that the novel seeks to locate meaning in the fragile, beautiful moments of now rather than in an idealized future. Accordingly, this study examines how *Light from Uncommon Stars* employs an anti-futurist framework to reconceptualize transgender transformation through community, creativity, and lived present experience.

Ryka Aoki's *Light from Uncommon Stars* has attracted critical attention for its innovative blending of speculative fiction with queer and transgender narratives. Scholars and reviewers consistently note the novel's genre hybridity, merging classical music, demonic bargains, and interstellar migration with everyday experiences of trauma, identity, and community. Charlie Jane Anders (2021) highlights the novel's distinctive representation of Asian-American cultural spaces within science fiction, arguing that Aoki disrupts traditional genre boundaries by centering queer and trans lives through culturally rooted storytelling. Similarly, Brett (2021) emphasizes the novel's compassionate portrayal of transgender existence, noting that it avoids reductive narratives of transformation and instead foregrounds survival, creativity, and the affirming power of chosen family. Academic analyses, such as Hermida's (2025) work on hospitality, deepen this discussion by examining how Aoki constructs ethical and relational spaces that offer refuge to marginalized characters.

Hermida argues that the novel portrays hospitality through food, music, and care as a radical response to transphobia, displacement, and systemic exploitation. This aligns with anti-futurist perspectives in transgender studies, which reject the notion that trans lives must be justified through future assimilation or normative success. Interviews with Aoki further reveal the author's intention to resist linear "before-and-after" transition narratives, presenting Katrina's transformation as an ongoing process grounded in everyday acts of courage and joy. Reviews from *Watch Skies* reinforce this reading, interpreting the novel's fantastical elements as metaphors for real-world oppression and resilience. Collectively, the literature positions

Light from Uncommon Stars as a groundbreaking work that reimagines transgender representation through relationality, present-focused living, and genre-defying storytelling.

Katrina embodies the struggles faced by many transgender individuals, including family rejection, social violence, displacement, and economic precarity. Her transformation is not depicted as a neat, linear process but as a series of emotional, creative, and relational steps shaped by trauma and resilience. The novelist highlights, "The music was every hope Katrina had abandoned, every dream she had released. It was hamburgers on the grill, fruit punch in the cooler, a bag of Costco beef jerky for everyone. It was dancing without knowing the steps and not caring. It was her mom holding her, her dad calling her his little girl" (78).

Katrina gains voice and agency through music, which society has repeatedly denied her. Within a social context marked by transphobia, her small victories playing freely, dressing according to her identity, and receiving affirmation function as radical assertions of existence. The violin thus becomes a symbol of survival, enabling her to reclaim space in a world that seeks to silence her. Music operates both as a protective shield and as a medium of self-definition, allowing Katrina to articulate an identity beyond imposed social constraints.

Katrina's playing is not merely artistic expression but a mode of reclaiming agency in a world that has consistently attempted to erase her. Her talent also highlights the tension between exploitation and recognition, as gifted queer artists often navigate spaces where their identity is simultaneously celebrated and commodified. The novel highlights how, "Katrina's bow danced like wings- awkward at first, then radiant, as if she were learning to fly with sound" (73). Her relationships with Shizuka, Lan, and other community members demonstrate that healing is relational, not individual. Katrina begins to trust others, take up space, and express joy without fear.

The novel therefore situates transgender transformation within everyday practices of love, creativity, and relational connection rather than within narratives of completion or social validation. Katrina's journey reveals the possibility of constructing a meaningful life beyond structures of violence, exclusion, and erasure. As the text observes, "Art becomes a way to locate one's self within the world, to connect the personal and the political" (19), emphasizing artistic expression as both self-realization and social engagement. Through this framework, Katrina emerges not merely as an individual character but as a figure embodying resilience, creativity, and the radical act of living authentically within an often-hostile social environment.

As a legendary violin teacher bound to the Queen of Hell, Shizuka represents those who navigate oppressive systems by making painful compromises. Her demonic pact reflects societal structures that demand sacrifice, especially from women, queer individuals, and

immigrants, in exchange for survival or success. The novelist avers, “With no need for a beginning, nor any reason to end, the music continues. And so, no matter who you are, where you came from, what sins you have committed or hurt you have endured . . . when you are alone and there is no universe left to remember you. You can always, always rewrite your song” (98). Through her relationship with Katrina, she confronts her guilt, reclaims her humanity, and discovers the possibility of ethical transformation. As an older Asian-American woman in a Western society, Shizuka carries the weight of cultural expectations.

Shizuka’s relationship with Lan further complicates her emotional journey. As she learns to love openly, she begins to unlearn the scarcity mindset imposed by oppressive structures. Lan offers her an alternative worldview grounded in hospitality, hope, and emotional generosity. This queer domesticity allows Shizuka to envision herself outside the rigid structures that shaped her life for decades and, “Food and culture in the San Gabriel Valley, which resembled an Asian-American Monopoly board” (100). Through this relationship, the novel critiques heteronormative and patriarchal frameworks that dictate how women should behave, love, and exist.

Ultimately, Shizuka’s transformation is a meditation on guilt, redemption, and the possibility of renewal. She exemplifies how individuals shaped by violent systems can still choose to break cycles of harm. Accordingly, “Human expression, like music, achieves its highest form when it engages with otherness rather than resists it” (261). Her character demonstrates that change is not linear or perfect; it is messy, vulnerable, and deeply relational. In this way, Shizuka becomes an anti-futurist figure herself, refusing the fantasy of a redeemed future in favour of meaningful action in the present.

Lan Tran’s character serves as a metaphor for refugee and immigrant experiences. As a starship captain seeking safety for her family, Lan parallels real-world displacement caused by war, xenophobia, or ecological collapse and highlights, “Lan’s civilization had long evolved beyond believing in supernatural beings and souls and music. And, in her reality, no one would think to attach such importance, such meaning, to music” (67). Her donut shop symbolizes refuge, hospitality, and queer domestic space, creating a haven where Katrina and Shizuka can heal. Lan’s romance with Shizuka challenges heteronormative structures and imagines family beyond biological ties. As a queer mother and leader, Lan disrupts traditional family structures.

Lan’s donut shop becomes a site of hospitality a safe haven where food, care, and comfort replace judgment and fear. This domestic space functions as a metaphor for queer community-building, where love is not confined to blood relations but extends to those who need refuge. Also, the novel highlights, “The songs will change, but the music is never truly

gone. A life ends. A life begins. But always, it is here for us to play. Heartache comes from glimpsing over one's shoulder, the yearning for Thanksgiving, the persistent memory of sweetness. Breaking comes from knowing exactly how it could have been" (176). The shop's warmth challenges the capitalist and xenophobic systems that typically marginalize immigrants and queer families. Lan's identity as a refugee also mirrors the experiences of trans and queer individuals who must often leave hostile environments to find acceptance.

Lan understands what it means to be hunted, misunderstood, and pushed to the margins of society, experiences that shape her empathetic relationship with Katrina. This shared condition of displacement enables Lan to offer support without demanding conformity, repayment, or justification. As the narrative reflects, "The music never ends, nor does it require a beginning. Therefore, it doesn't matter who you are, where you're from, or how often you sin" (112). The passage underscores the novel's rejection of linear origin stories and moral hierarchies, reinforcing an anti-futurist ethic in which belonging is not contingent upon past legitimacy or future redemption. Lan's alien identity functions as a metaphor for those who exist outside normative structures of gender, citizenship, and family. Through her character, Aoki represents resilience and the transformative power of chosen family, illustrating how immigrant and queer communities actively construct spaces of care and belonging amid displacement. In this way, the novel redefines home not as a fixed geographical location but as a relational space grounded in love, safety, and mutual recognition.

Ryka Aoki's *Light from Uncommon Stars* reimagines transgender transformation through themes of relationality, creativity, and everyday survival, rather than through futurist narratives that demand perfection, assimilation, or justification. Katrina's journey emphasizes that trans life holds meaning in the present moment in shared meals, found family, music, and acts of self-expression but also in the ongoing process of learning, improvisation, and healing, which mirrors the practice of music itself. By blending demons with donuts, cosmic refugees with classical music, and the mundane with the magical, the novel challenges rigid categories and celebrates the beauty of complexity, relationality, and imperfection. Aoki further resists narratives that tie trans legitimacy to exceptional talent or merit; instead, she affirms that value comes from simple existence, care, and community support.

Through an anti-futurist framework, the novel rejects the expectation that transgender lives must justify their existence through the promise of a better future. Instead, it affirms that joy, love, chosen family, and everyday acts of survival already constitute meaningful forms of resistance. By queering genre conventions, reworking the Faustian bargain into a narrative of ethical agency, and granting equal narrative weight to both trauma and joy, Aoki constructs a

world in which belonging emerges not through assimilation but through shared vulnerability and creativity.

The novel ultimately presents a hopeful vision in which chosen family, healing, nourishment, and authentic living form constellations of meaning, suggesting that fulfillment need not depend upon a predetermined destiny. This paper argues that *Light from Uncommon Stars* reimagines transgender and queer experience through the interrelated frameworks of community, creativity, and relationality. It demonstrates how the novel foregrounds lived present experience through an anti-futurist perspective, emphasizing the creation of spaces of refuge, care, and belonging for marginalized individuals.

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Slow Violence and the Unseen Burden of Progress: Environmental Suffering in Richard Powers' *Gain*

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ABSTRACT

Gain by Richard Powers serves as a powerful critique of industrial capitalism, revealing how ecological devastation and human suffering are obscured beneath the persuasive rhetoric of economic progress. Gain delivers a strong ecological message about the environmental consequences of modern industrial advancement. The story follows the Clare company's growth from a modest nineteenth-century soap-making business into a massive chemical corporation. With each stage of its expansion, the firm produces new forms of environmental damage. Although Clare's products promise cleanliness, comfort, and modern living, the manufacturing process releases harmful waste into the environment. This pollution is evident in Laura Bodey's life, whose cancer illustrates the long-term human cost of industrial growth. By juxtaposing the company's history with Laura's personal suffering, Powers exposes the profound conflict between corporate progress and environmental health. The novel does not simply criticise a single institution; instead, it reveals how corporations, consumers, and society collectively contribute to environmental degradation. The narrative challenges traditional ideas of development and highlights the ecological devastation hidden beneath the pursuit of wealth. It urges readers to reconsider notions of progress built on chemicals, waste, and uncontrolled industrial expansion. This study demonstrates that environmental harm is not an external or distant issue but one that enters homes and bodies, shaping the lived experiences of ordinary people. It also shows how Powers prompts a rethinking of economic progress by exposing the moral and ecological costs embedded within industrial success.

***Keywords**: Environment, Pollution, Progress, Slow Violence, Suffering, Toxicity*

Gain is a blend of literary and historical fiction by Richard Powers. Richard Powers, a major American novelist known for weaving science, philosophy, and history into narrative, structures the novel around two interlinked stories: the rise of Clare International from a small nineteenth-century soap-and-candle business into a global chemical corporation, and the life of Laura Bodey, a divorced mother living in the Midwestern town of Lacewood, where one of Clare's factories operates. Rather than merely juxtaposing corporate history with personal tragedy, Powers uses this dual structure to expose how large-scale industrial progress produces slow, often invisible forms of environmental and bodily harm.

Powers introduces Lacewood as a town that appears clean, calm, and full of promise. Early in the novel, he writes, "Secretly preferred the aroma of Lacewood to the scent of Peoria. Lacewood smelled clean and distilled. Peoria was a little too unctuous and pomaded. He liked this place for a number of reasons" (4). At first glance, this description seems simple, but it carries a deeper warning. The town appears pure on the surface just like Clare's products. The passage also reflects how modern industry attempts to make nature appear controlled, purified, and safe. Yet this manufactured cleanliness hides a dangerous reality. Lacewood's purity is not natural; it is constructed and maintained by the company's public image. This suggests that what seems harmless on the outside may conceal harmful consequences underneath.

Rob Nixon's concept of slow violence is closely connected with these circumstances. Nixon defines as:

> By Slow violence I mean a violence that occurs gradually and out of sight, a violence of delayed destruction that is dispersed across time and space, an attritional violence that is typically not viewed as violence at all. Violence is customarily conceived as an event or action that is immediate in time, explosive and spectacular in space, and as erupting into instant sensational visibility (2).

Destruction occurs in a delayed manner, dispersed across time and space. Lacewood is a perfect example of this hidden form of harm. Nothing appears dangerous at first, but pollution slowly infiltrates the town through the air, soil, and water. Because the damage unfolds gradually, people do not recognize it immediately. Powers uses this idea to show that environmental harm does not always arrive as a sudden disaster; instead, it grows quietly and becomes visible only when the effects have already become severe. The phrase "clean and distilled" becomes a warning that even things that look pure can still be poisonous.

The first clear sign of danger emerges when Laura's daughter, Ellen, reads the environmental data, "'Right here.' counties ranked by toxic discharge. Lacewood, Sawag, Vermilion. Champaign, Iroquois. Area's top carcinogenic chemical emissions. Benzene, formaldehyde, dichlorodifluoromethane, epichlorohydrin . . ." (Powers 139). This simple list shatters the illusion of Lacewood as a healthy town. It reveals that Lacewood is actually one of the top counties for toxic pollution. Powers shows how people normalize environmental degradation; even when the facts are directly in front of them, they continue to live their ordinary lives. Because the harm is gradual and spread over time, people often fail to perceive it as violence. Through Ellen's discovery, Powers illustrates that the residents of Lacewood are living within this slow, hidden form of environmental damage without fully recognizing it.

The geography of Lacewood also highlights its vulnerability. As Powers writes, "Lacewood sat close to the dead center of the country's agricultural future" (220). A place at the center of agriculture should be safe, green, and nurturing, but here it becomes the center of chemical exposure. Farmland and chemical manufacturing exist side by side, and this unnatural combination produces danger. Modern agriculture increasingly depends on chemical products such as fertilizers, preservatives, and pesticides many of which companies like Clare manufacture. In this way, Lacewood becomes symbolic of the larger American landscape, where economic expansion and environmental damage are deeply intertwined.

In *The Great Derangement*, Amitav Ghosh argues that modern literature often struggles to represent complex environmental entanglements because they feel uncanny, overwhelming, and beyond ordinary human experience. Ghosh further notes, "This possibility is not, by any means, the most important of the many ways in which climate change challenges and refutes Enlightenment ideas. It is, however, certainly the most uncanny" (41). Many writers find it difficult to capture the vast scale of climate impact or industrial harm. However, *Gain* demonstrates that these issues are not abstract or distant; they are woven into the fabric of everyday life. By focusing on one town and one corporation, Powers exposes the quiet, gradual transformation of the environment and the hidden costs borne by ordinary families.

In *Gain*, Powers uses a technique of sharp contrast between what companies promise and what they actually do. Clare's advertisements are full of reassuring words such as *pure*, *clean*, and *natural*. They carefully craft an image of safety and goodness. For instance, the company claims, "Ordinary soaps, especially the homemade, merely cleaned your skin. Native Balm not only removed those same harmful oils and impurities from the integument. With its herbal… its state of initial purity" (132) and promises consumers that they will be "squeaky clean" (278). These lines do more than sell soap; they sell an idea a comforting fantasy that Clare's products can restore people to an original, untouched purity.

Yet the same company that promises to make bodies clean is quietly contaminating the place where its products are manufactured. The land is exposed to chemical waste, the water becomes unsafe, and the residents of Lacewood suffer the consequences. Powers uses this contradiction to reveal a deeper truth: modern capitalism often masks its harmful effects behind attractive, reassuring language. Companies construct themselves as protectors of public well-being even while their operations degrade ecosystems and jeopardise human health.

Rachel Carson warns that society is often "Fed little tranquilizing pills of half-truth. We urgently need an end to these false assurances, to the sugar coating of unpalatable facts" (13). Powers brings Carson's warning to life. Through Clare's cheerful and confident

advertisements, the novel shows how persuasive language can conceal environmental danger. What appears pure on the surface may be toxic underneath; what seems safe may in fact be the source of harm. By exposing this gap between corporate image and corporate reality, *Gain* powerfully portrays how industries profit from both the illusion of purity and the practice of pollution.

Laura Bodey's illness provides the novel's most devastating embodiment of slow violence. Her chemotherapy is described with stark restraint, "Laura follows the week treatment with a week of vomiting, a week of debilitating nausea, and a week of massive fatigue" (134). The repetitive structure mirrors the exhausting cycle of both treatment and pollution, emphasising endurance rather than sudden catastrophe. Laura's suffering transforms abstract environmental risk into lived bodily experience

Laura's sickness grows slowly, quietly, and steadily, just like environmental pollution, which accumulates over many years before the damage becomes visible. The long, exhausting progression of Laura's illness mirrors the slow, invisible process through which chemicals enter soil, water, and human bodies. Powers strengthens this connection through one of the most striking metaphors in the novel: "Her body has become a little Nagasaki. Her skin is a field of second-degree flash burns. She cannot brush her teeth without needing a transfusion" (243 - 244). Nagasaki represents devastation on an immense scale, a place destroyed by human-made forces. Using that image to describe Laura's body is both shocking and revealing.

By comparing Laura's internal state to such catastrophic destruction, Powers suggests that what is happening inside her is not merely illness; it is a kind of internal bombing. Her body is under attack, but the weapon is not a single explosion. Instead, it is years of chemical exposure, industrial waste, and invisible toxins that have slowly accumulated and turned her own cells against her. The metaphor evokes a form of chemical warfare waged not by enemies, but by everyday products, factories, and corporate decisions. Through Laura, Powers makes it clear that environmental destruction does not remain outside in the land and water—it enters human lives, homes, and bodies. Her suffering reveals the true cost of industrial progress.

The novel also shows that Laura is not the only person suffering. Powers mentions that "Today, Roberto has a tumor in [his] testicle, Paula is fighting cervical cancer, and Willy is dead" (216). This signals that many residents of Lacewood are facing serious health problems. These illnesses do not seem random; rather, they suggest that the environment has become hazardous. While the novel never directly states that Clare caused every case, it provides enough hints to imply a strong connection between the company's chemical production and

the community's declining health. As Clare expands, sickness in the town also appears to increase, demonstrating how closely human well-being is tied to the surrounding environment.

Janine says, "I think it's in the air and in the water and now it's in the ground, builds up in the food" (Powers 190). This statement makes the link even clearer. Her words show that pollution has entered every part of daily life. Powers suggests that modern industries often make promises of safety and improvement while hiding the true costs behind the scenes, and *Gain* reveals how environmental harm is woven into the fabric of everyday existence. He does not divide the world into simple categories of victims and villains; instead, he shows that everyone participates in the system, even unknowingly. *Gain* exposes the true price of progress. The chemical products that make modern life convenient also carry hidden ecological costs. The growth of corporations brings jobs and economic development, but also pollution and illness. The dream of purity sold in advertisements conceals the poisoning of land, air, and water. Powers reveals the environmental degradation and human suffering that lie beneath the polished surface of modern industrial society.

Gain is not simply about a woman's illness or a company's rise; it is about the future of human life on a damaged planet. The novel reminds us that progress without environmental responsibility is not progress at all it is harm disguised as success. It calls for a re-evaluation of our values, habits, and economic structures. It urges readers to imagine a form of progress that does not destroy the earth or sacrifice human lives. Through its quiet but powerful narrative, the novel teaches that environmental awareness is not merely a political choice but a moral one. Powers leaves an unforgettable message: every gain has a cost, and until society chooses to confront that cost honestly, true progress will remain out of reach.

Richard Powers' *Gain* offers a piercing critique of the hidden ecological and human costs embedded within modern industrial progress. The novel compels readers to confront the uncomfortable truth that convenience, wealth, and technological advancement often come at the expense of human health and ecological balance. Laura's suffering, along with the illnesses affecting other residents of Lacewood, shows that environmental destruction is never abstract it settles into bodies, communities, and futures. As Powers underscores, such harm is not caused by a single villain but by a system in which consumers, corporations, and society participate, often without full awareness. Ultimately, *Gain* serves as a warning and a call for transformation. It urges a rethinking of development models founded on chemical dependency, unchecked industrial growth, and the illusion of progress. True progress, Powers suggests, demands environmental responsibility, transparency, and a renewed respect for the interconnectedness of human life and the natural world. Until these values guide societal

choices, every gain will carry a silent, devastating cost - one that future generations will be forced to bear.

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Espionage and Gender Performativity in Kate Quinn's The Alice Network

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ABSTRACT

Kate Quinn's The Alice Network is examined through the lens of gender performativity, highlighting how women spy strategically mobilize socially constructed femininity as both a protective disguise and a powerful instrument of resistance. The narrative highlights women whose identities are shaped, constrained, and fractured by the gendered expectations of espionage, where performance becomes inseparable from survival. Drawing on Judith Butler's argument that gender is constituted through repeated acts, this study examines how Eve Gardiner and Lili de Bettignies adopt roles crafted to conform to patriarchal assumptions while simultaneously subverting them. Espionage creates a continuum in which past trauma, present masking, and future uncertainty merge into psychological strain, revealing the fragmentation produced by compulsory performance. This paper argues that Quinn's novel portrays femininity not as a fixed trait but as a dynamic and strategic performance enacted within systems designed to restrict women by integrating feminist theoretical frameworks with close textual analysis. Thus, this study demonstrates that espionage in The Alice Network becomes a space where gender is rehearsed, manipulated, and reimagined as an instrument of agency.

Keywords: *Espionage, Feminity, war, gender, Identity*

Kate Quinn's *The Alice Network* presents the lives of women who navigate espionage not merely as an act of patriotism but as a negotiation of identity in a world structured by patriarchal expectations. The women in the novel, particularly Eve Gardiner and Lili de Bettignies, are compelled to perform versions of femininity that align with male assumptions about women's innocence, weakness, and harmlessness. Judith Butler argues that gender is not an internal truth but a series of repeated acts that create the illusion of stability, asserting, "gender proves to be performativity, that is, constituting the identity it is purported to be" (Butler 34). In Quinn's novel, this performativity becomes a necessity for survival, especially within the covert world of espionage where deception itself must be gendered. Thus, femininity operates not only as a constraint but also as a strategic resource.

The novel demonstrates how gendered expectations function as operational advantages through Captain Cameron, who tells Eve, "I like to recruit women. They frequently have the ability to pass unnoticed where a man would be suspected and stopped" (Quinn 57). His admiration for Lili de Bettignies, a Frenchwoman who manages a network covering more than

a hundred sources reveals how assumptions about female harmlessness enable women to operate invisibly. This invisibility arises from what Butler identifies as the binary economy of gender, which situates women as the subordinate Other. Yet she argues, "women are neither the subject nor its Other, but a difference from the economy of binary opposition" (25). Lili embodies this difference, she moves beyond both submissive femininity and masculine-coded authority, performing a hybrid identity that defies categorization. Her success reveals the instability of the binary itself. Eve Gardiner, a character who desires to become a spy, emerges from her lifelong struggle with invisibility imposed by her stutter, "There was a war on—she wanted to fight. Prove that stuttering Eve Gardiner could serve her country as capably as any of the straight-tongued thousands who had dismissed her . . . as an idiot" (Quinn 26). Her stutter forces her into performances of politeness and restraint, "If she were a man she could at least hit anyone who mentioned her stuttering tongue, not smile at them with polite forbearance" (Quinn 26). Even before she adopts the spy identity of Marguerite, Eve has been performing gendered expectations of softness, silence, and emotional control. Espionage intensifies these performances.

Eve under her alias intensify her femininity appearing harmless, flirtatious, and naïve to manipulate René, who embodies patriarchal entitlement. When she asks if the Germans will execute a captured spy, René responds with chilling indifference, "I wonder if this one is young and pretty? . . . nothing to get public outrage fired up like a girl who's young, lovely, and dead" (Quinn 295). His words reduce female operatives to aesthetic symbols. According to Butler, this reduction is itself a technique of masculine discourse, which functions as, "a ruse for a monologic elaboration of the masculine" (25). The women's bodies thus become a symbolic sites where male political and emotional needs are projected. Eve works within this gaze while subtly exploiting it to conceal her intelligence.

Lili de Bettignies, meanwhile, demonstrates gender performance as mastery. Her earlier life describes the strictly gendered roles available to her, "The daughter of minor French nobility . . . should have been an actress . . . but the daughters of minor French nobility do not become actresses" (Quinn 221). Instead, she becomes a governess for "lecherous Italian lords and Polish counts and Austrian princesses," recounting how the tedium led her to consider "heaving myself under a train like Anna Karenina, or become a nun. . . but really, I'm far too frivolous" (Quinn 222). Butler's argument demonstrates Quinn's frustration that the appearance of stable gender identity is maintained through "a performative twist of language and/or discourse that conceals" its constructedness (25). This history suggests that espionage does not create performance but exposes the roles she was already required to enact.

Lili further exposes the gendered moral scrutiny that shapes women's participation in espionage, revealing how patriarchal systems weaponize the idea of female virtue to regulate women's movements and identities. She explains to Eve that, according to military men, "If a woman surrenders her virtue to an enemy, they are confident her patriotism can't be far behind. They have very little faith in any woman's ability to resist falling in love with a man who beds her" (Quinn 182).

Her observation underscores how women spies are simultaneously relied upon for their invisibility and distrusted for their sexuality. Lili emphasizes that a horizontale, a woman who engages in sexual activity outside the bounds of respectability cannot be seen as patriotic, because "a spy's business is already disreputable enough," and thus "we must do it as ladies" (Quinn 182). Here, respectability becomes another performance required for legitimacy rather than evidence of moral truth. Lili highlights that women must not only perform espionage but also femininity itself, ensuring their reputations remain intact even while engaging in dangerous deception. Their bodies and behaviour must conform to patriarchal standards, not because such standards reflect truth but because violating them threatens nationalistic narratives built upon the myth of the pure, self-sacrificing woman.

Eve later articulates the stark divide between socially prescribed femininity and the realities of women operating in espionage. she notes, "If we were ordinary we'd be at home reusing our tea leaves and rolling bandages to support the war effort, not carrying Lugers and smuggling coded messages around our hairpins. Steel blades such as you and I do not measure against the standards for ordinary women" (Quinn 247). Her declaration captures the tension between the passive, domestic femininity celebrated by wartime culture and the active, dangerous roles that women spies inhabit. Eve's words reveal the extent to which female operatives must step outside the boundaries of acceptable womanhood, taking on roles that contradict every norm of gentleness, purity, and obedience. In Butler's terms, Eve acknowledges that the identity of 'ordinary woman' is not an innate truth but a rehearsed role that she and Lili cannot perform if they are to survive. Her metaphor of 'steel blades' positions their femininity as forged, sharpened, and consciously constructed rather than naturally occurring, reinforcing Butler's premise that gender coherence is merely an effect of repeated performance.

The cost of this compulsory performativity emerges strikingly in Eve's imprisonment at Siegburg. Quinn describes "Eve came to Siegburg already broken . . . the inside of her own mind" more terrifying than the dark cell (395). The brutal details of women "dying slowly of fever or blood poisoning," the locked doors that would not open though, "a woman might be…

giving birth" expose the erasure of gendered bodies in confinement (Quinn 395). The femininity Eve once wielded as a tool becomes irrelevant in the prison's dehumanizing conditions. Butler argues that the appearance of gendered coherence collapses when its performative conditions are stripped away (25). Siegburg reveals Eve's identity as fragmented, not because she failed to perform femininity, but because performativity itself offers no stable foundation when bodily autonomy is attacked.

The Alice Network insists on the transformative potential of gender performance. Despite these fractures, Eve and Lili do not abandon femininity, they reconfigure it. Their performances defy binary categories. They become women who are neither submissive nor masculine, neither pure nor fallen, but something in between, something fluid. As Butler argues, once we reject the idea of "man" and "woman" as stable substances, "it is no longer possible" to dismiss contradictory traits as mere deviations (32). Eve can be fearful and formidable; Lili can be frivolous and brilliant. Their multiplicity is their strength.

Thus, espionage in *The Alice Network* dramatizes Butler's claim that the stability of gender is an illusion produced by repetition. The women who operate within the 'Alice Network' expose the fluidity of gender by performing it strategically, subverting it deliberately, and surviving through its manipulation. Their masks of identity, Marguerite, Alice, the governess, the ingénue, reveal that femininity is always a crafted identity, not a natural essence. In Quinn's novel, femininity becomes a weapon sharpened through performance, resilience, and resistance.

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Hybridity and Self-Reinvention: The Immigrant Journey of Waris Dirie in *Desert Flower*

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ABSTRACT

Waris Dirie's Desert Flower is an autobiographical narrative which presents an inspiring transformation of a Somalian desert girl to a global advocate against female genital mutilation. This paper depicts her expedition from the perspective of Homi K. Bhabha's postcolonial theory by spotlighting on hybridity, the third space and modernity as negotiation. As a result of her relocation from Somalia to the West, Dirie finds herself caught between two contradictory ideologies which is modern individualism and traditional patriarchy. At this crosspoint she originates a hybrid identity that reflects both resistance and adaptation. Dirie's journey demonstrates the ideology of belonging, selfhood and freedom altered by cultural change. By embracing modernity without changing her roots Dirie defines womanhood in a cross-cultural context. The analysis portrays the novel Desert Flower is more than just a personal memoir and it is a powerful postcolonial narrative that turns displacement into a journey of self-discovery and reclaims identity in todays globalized and diverse world.

Keywords*: Hybridity, Postcolonial Identity, Third Space, Modernity, Mutilation*

Female Genital Mutilation (FGM) is one of the most controversial and culturally embedded practices in the parts of Africa and Middle East. Although it is frequently justified as a rite of passage into womanhood, it also symbolizes patriarchal tradition's power over female bodies. Within this social and cultural framework Dirie's autobiography *Desert Flower* acts both as a testimony and a political act of resistance. The narrative traces her life from being a nomadic girl in Somalia to a globally recognized model and an activist. Her journey highlights the intersection of culture and gender identity. This paper applies Homi K. Bhabha's postcolonial theory to analyse her transformation. The study focuses on his concepts of hybridity, third space and modernity as negotiation. These ideas help in understanding Dirie's position between traditional Somali values and Western modernity. Her life story demonstrates the creation of a hybrid identity that challenges fixed cultural boundaries. The analysis concludes that Desert Flower is not merely an individual memoir but also a postcolonial narrative that transforms displacement into empowerment.

According to Homi K. Bhabha is an outcome that emerges when cultures intersect and create a new social and psychological realities. In *The Location of Culture*, he states "And it is

from this foreign perspective that it becomes possible to inscribe the specific locality of cultural systems - heir incommensurable difference - and through that apprehension of difference, to perform the act of cultural translation" (Bhabha 164). Thus, hybridity opens up a space of translation. Dirie's journey as an immigrant reflects this idea. Her life in Somali gave her numerous values and cultural continuity whereas in when she migrated to London she was forced to do new social behaviors. Like communicating in different language and navigate gender norms unfamiliar to her upbringings. Hybridity made her to reframe her origins. Bhabha clears out that cultural identity exists "in-between" as:

> This is the moment of aesthetic distance that provides the narrative with a double edge, which like the colored South African subject represents a hybridity, a difference 'within', a subject that inhabits the rim of an 'in-between' reality. And the inscription of this borderline existence inhabits a stillness of time and a strangeness of framing that creates the discursive 'image' at the crossroads of history and literature, bridging the home and the world. (Bhabha 13)

Waris Dirie mediated well between both realities. She refused to abandon her cultural norms rather she adapts to Western culture. Thus, her womanhood is structured by both cultures. Hybridity became her source of strength. It allowed her to challenge assumptions about race, gender and tradition. Thereby she did not depend on a single culture for validation.

The 'Third Space' is a central concept in Bhabha's theory. It represents the part where new identities are formed. It is not associated or tied to one culture or another. Bhabha explains that it is where new signs of identity emerge. Bhabha states, "And by exploring this Third Space we may elude the politics of polarity and emerges as the others of our selves" (Bhabha 39). Dirie's life serves as an example in which her migration could not rely entirely on Somalian norms nor could she assimilate fully into Western society. In that case the Third Space became her psychological home. She had to create meaning between the two cultures. Traumas from female genital mutilation, gender norms and Western opportunities coexisted in this space. In this liminal zone, she was neither the desert girl expected by her community nor the fully westernized woman imagined by society. Her identity was reconstructed here. She reclaimed her body, voice and agency. She was able to generate meaningful conversation about cultures and empowerment because she existed between these two worlds.

Migrating from Somalia to London introduced Dirie to modernity. It also created a continuous search for where she truly belongs. Bhabha emphasizes that displacement produces unhomeliness and avers, "In that displacement, the borders between home and world became confused; and, uncannily, the private and the public become part of each other, forcing upon

us a vision that is as divided as it is disorienting" (Bhabha 9). She had to redefine freedom and personal choice. Bhabha argues that modernity is a negotiation between the past and the present. Dirie balanced her cultural roots with Western independence. Her modeling career provided her with new forms of self-expression. It allowed her to explore autonomy and self-discipline. Western culture offered both opportunities and challenges like confronting her traumas straight to the society by advocating against female genital mutilation. It allowed her to reconstruct her identity without making any changers to her Somalian origin. She evolved by combining cultural memory with contemporary possibilities and became empowered.

Dirie's body became a site of struggle. Female genital mutilation scarred her body with trauma:

> The next thing I felt was my flesh, my genitals, being cut away. I heard the sound of the dull blade sawing back and forth through my skin. When I think back, I honestly can't believe that this happened to me. I feel as if I were talking about somebody else. There's no way in the world I can explain what it feels like. It's like somebody is slicing through the meat of your thigh, or cutting off your arm, except this is the most sensitive part of your body. (Dirie and Miller 45)

It represented patriarchal control. Bhabha argues that power often operates through the regulation of one's body. Through her activism, Dirie took control over her body and transformed it from a site of trauma into a symbol of her strength and self-determination. She made her personal suffering into a political strength. She challenged systems that controlled woman through their bodies. The body that was once silenced became a medium for global activism. This reversal demonstrates that hybrid identities can confront oppression effectively. Dirie proves that any sort of suffering can be turned into a source of agency.

Dirie's autobiography becomes a testimony of resistance. Bhabha observes that voices from the marginalized community challenge the prevailing dominant narratives. Dirie's life exposes the horrors of mutilation and challenges Western assumptions that Africans are powerless or defined solely by their traditions. It also shows that Africans are strong thoughtful and capable of new beginnings. Through the lens of Homi K. Bhabha's concepts of hybridity, Third Space, and modernity as negotiation, Waris Dirie's immigrant journey begins as a transformative process shaped by cultural encounter and ideological tension. Positioned between Somali tradition and Western modernity, Dirie does not simply integrate or reject her origins; instead, she constructs a hybrid identity that draws strength from both worlds. Her life in the "in-between" space enables her to retrieve agency over her body, voice, and womanhood while turning personal trauma into global activism against female genital mutilation. Dirie also

reclaimed her journey as a tool of advocacy. Her narrative transformed personal experience into universal discourse. She also insists that empowerment comes from speaking from the perspective of the Third Space. Thus, Desert Flower stands as a testament to the creative and political power of hybrid identity in a globalized world.

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Finding Freedom in Mark Haddon's *The Curious Incident of the Dog in the Night-Time*

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ABSTRACT

The Curious Incident of the Dog in the Night-Time by Mark Haddon is examined for its nuanced representation of freedom, arguing that the novel reconceptualizes autonomy not as mere physical escape but as a gradual process of psychological and emotional transformation. Through the character of Christopher Boone, a fifteen-year-old boy on the autism spectrum, Haddon redefines independence as self-understanding, emotional regulation, and cognitive self-trust. Drawing on neurodiversity discourse and insights from Disability Studies, this study contends that Christopher's development challenges deficit-based perceptions of autism. The novel's first-person narration, prime-numbered chapters, literal language, and visual diagrams structurally mirror Christopher's cognitive processes, aligning narrative form with psychological growth. The journey from Swindon to London functions as both a geographical movement and a symbolic passage from dependence to self-reliance. Ultimately, the novel suggests that freedom is achieved not by conforming to social norms, but by learning to navigate the world through one's own strengths. In doing so, Haddon offers a nuanced portrayal of neurodiverse empowerment and reimagines freedom as an inward process of resilience and self-acceptance.

Keywords: *Freedom, Neurodiversity, Autism Spectrum, Disability Studies, Narrative Form, Independence*

Mark Haddon's *The Curious Incident of the Dog in the Night-Time* initially presents itself as a detective novel centred on the mysterious death of a neighbour's dog. However, beneath its investigative structure lies a more complex exploration of growth, identity, and autonomy. The novel invites readers into the mind of Christopher Boone, a mathematically gifted adolescent on the autism spectrum who attempts to solve the mystery of Wellington's death. Through Christopher's journey, Haddon constructs a narrative that challenges traditional assumptions about independence, maturity, and disability. This paper argues that freedom in the novel is not portrayed as rebellion against authority or escape from domestic constraints. Rather, it emerges as a gradual internal transformation shaped by emotional regulation, logical reasoning, and narrative self-expression.

Christopher's journey from Swindon to London symbolizes this movement toward autonomy. Importantly, his growth does not depend on becoming socially "normal." Instead,

freedom is achieved through the acceptance and strategic use of his neurodiverse cognitive patterns. By drawing upon perspectives from Disability Studies and neurodiversity discourse, this study examines how the novel shifts attention from pathology to empowerment. It also considers how narrative form including first-person perspective, prime-numbered chapters, and visual inserts contributes to the thematic construction of freedom.

Stephan Freißmann argues that Christopher's narration should be understood as an epistemological act rather than merely a recounting of events. In his reading, the act of writing becomes a structured mode of knowing through which Christopher orders experience and asserts interpretive authority over a world that often overwhelms him (Freißmann 401 - 403). This perspective illuminates how the novel links cognition and autonomy: Christopher's decision to document Wellington's death evolves into a broader process of self-construction. By organizing events according to logical sequence, mathematical precision, and factual verification, he transforms uncertainty into coherence. Building on Freißmann's insight, Christopher's narrative can also be read as a movement toward psychological freedom. The written text does not simply represent his experience; it becomes the means by which he stabilizes identity, negotiates emotional distress, and claims intellectual independence. In this sense, storytelling functions simultaneously as epistemology and emancipation, reinforcing the novel's redefinition of freedom as cognitive self-trust rather than social conformity.

Disability Studies has significantly reshaped the way literature represents difference. The social model of disability distinguishes between impairment and disability, arguing that disability often arises from social structures that exclude or marginalize certain bodies and minds. Within this framework, Christopher's challenges are not solely the result of his autism, but also of environments structured around neurotypical expectations. Public spaces such as train stations and underground platforms overwhelm Christopher with sensory intensity. The noise, unpredictability, and crowding create distress. However, the novel subtly suggests that these environments are not neutral; they privilege a particular cognitive style.

Christopher's difficulty navigating them exposes how modern urban life is designed without consideration for neurodivergent experience. Neurodiversity discourse further reframes autism as variation rather than deficit. Instead of viewing Christopher's literal thinking, reliance on routine, or emotional directness as limitations, the novel portrays them as adaptive strategies. His mathematical precision, honesty, and attention to detail enable him to uncover hidden truths about his family. Haddon avoids sentimentalizing Christopher, yet he also resists presenting him as tragic. This balanced portrayal aligns with contemporary movements that advocate for the recognition of cognitive diversity as part of human variation.

One of the most distinctive aspects of the novel is its narrative structure. Christopher narrates the story in the first person, allowing readers direct access to his cognitive processes. His language is literal, structured, and often emotionally restrained. This narrative style does more than reflect character; it shapes the thematic development of freedom. The chapters are numbered using prime numbers, a structural choice that mirrors Christopher's fascination with mathematics. Prime numbers symbolize uniqueness and indivisibility, subtly reflecting Christopher's individuality. More importantly, the numbering system reinforces the importance of order in his life. Structure provides stability in a world that often feels chaotic.

The inclusion of diagrams, maps, mathematical problems, and visual representations further aligns narrative form with Christopher's cognitive style. These elements interrupt conventional storytelling but serve a crucial purpose: they transform the novel into a textual embodiment of his mind. In moments of anxiety particularly during his journey to London. Christopher turns to patterns, timetables, and logical sequencing. The narrative itself becomes a coping mechanism. Through these formal strategies, Haddon demonstrates that freedom is constructed through cognitive organization. Independence is not dramatic or impulsive; it is methodical and reasoned. The form of the novel reinforces this gradual development.

Christopher's growth is marked by repeated confrontations with fear. Crowded public spaces, unexpected physical contact, and sudden changes in routine trigger distress. During his journey to London, he experiences sensory overload and emotional exhaustion. At times, he withdraws inwardly to regain control. However, these moments do not signify failure. Instead, they represent stages in a process of emotional regulation. Each small achievement buying a train ticket, asking for directions, interpreting a map contributes to his developing confidence. Freedom in the novel emerges through repetition and persistence rather than sudden transformation.

Importantly, the narrative resists framing Christopher's journey as heroic in a conventional sense. His actions are not extraordinary in the eyes of the broader world. Yet within his own experiential framework, they are profound. By focusing on incremental progress, Haddon redefines courage as the willingness to act despite fear. Christopher's declaration toward the end of the novel, "I can do anything," encapsulates this internal shift. The statement does not imply limitless ability. Instead, it expresses newfound trust in his capacity to navigate difficulty. Freedom becomes synonymous with self-belief.

The physical journey from Swindon to London functions as the central symbolic event in the novel. Prior to this journey, Christopher's life is largely structured by routine and parental guidance. Although he values independence, he depends heavily on his father and his teacher,

Siobhan. When Christopher decides to travel to London alone, he enters unfamiliar territory both geographically and psychologically. The city represents unpredictability and disorder. Navigating it requires him to rely entirely on his logical systems. He consults maps, counts time precisely, and calculates routes carefully. Each successful decision reinforces his autonomy.

The journey therefore operates on two interconnected levels. Geographically, it marks movement away from domestic dependence. Psychologically, it signifies a transition toward self-reliance. The novel does not suggest that independence eliminates fear; rather, it demonstrates that fear can coexist with agency. Christopher's success in reaching his mother affirms that he is capable of functioning beyond the boundaries previously imposed upon him. An often-overlooked aspect of the novel is Christopher's decision to write his own book. The narrative we read is framed as a project encouraged by his teacher. Writing becomes a method of organizing experience. By structuring events chronologically and logically, Christopher transforms confusion into coherence.

From a developmental perspective, storytelling enables identity formation. Adolescence is frequently associated with the search for self-definition. For Christopher, narration becomes a tool of autonomy. Through writing, he claims authority over his experience. He interprets events in his own terms, free from external reinterpretation. This self-authored narrative reinforces the novel's broader argument about freedom. Independence is not merely physical mobility; it is the ability to construct meaning. Christopher's book becomes evidence of intellectual and emotional agency. Traditional representations of independence often emphasize social adaptability, emotional expressiveness, and relational fluency. Christopher does not conform easily to these expectations. Yet the novel challenges the assumption that independence must follow a singular model.

Christopher does not overcome autism; he works with it. His routines, mathematical interests, and literal reasoning remain intact. What changes is his confidence in applying them beyond familiar environments. The novel suggests that autonomy arises when individuals recognize and trust their own cognitive strengths. By the end of the narrative, Christopher has passed his mathematics examination, navigated a major city alone, and planned future academic goals. These achievements are not framed as miraculous but as logical outcomes of sustained effort. Haddon thereby rejects narratives of pity or exceptionalism. Instead, he presents competence as emerging from perseverance and self-understanding.

In *The Curious Incident of the Dog in the Night-Time,* Mark Haddon reimagines freedom as an inward journey grounded in resilience, cognitive structure, and self-acceptance.

Through first-person narration and innovative structural techniques, the novel aligns form with Christopher Boone's neurodiverse cognition. The journey from Swindon to London serves as a powerful metaphor for psychological growth, demonstrating that autonomy develops through incremental courage rather than dramatic rebellion. By engaging with neurodiversity and the social model of disability, the novel challenges deficit-based narratives and affirms the value of cognitive difference. Christopher's declaration of confidence near the novel's conclusion signals not conformity, but self-recognition. Freedom, in this context, is not the absence of limitation. It is the capacity to navigate the world authentically, using one's own strengths. Ultimately, Haddon's novel expands the literary understanding of independence. It suggests that true freedom lies not in becoming like others, but in learning to trust and inhabit one's own distinctive way of thinking.

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Symbol as Voice: Decoding Symbolic Layers in Perumal Murugan's *One Part Woman*

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ABSTRACT

This paper, titled "Symbol as Voice: Decoding Symbolic Layers in Perumal Murugan's One Part Woman," explores how symbolism functions as a powerful narrative device that articulates the unspoken tensions within rural Tamil society. The study examines key symbols such as the temple festival, fertility rituals, Portia tree, the sacred bull, and seasons revealing how these elements embody deeper cultural meanings and social expectations. Through a close reading of the novel, the paper highlights how Murugan uses symbols to give voice to issues of gender inequality, caste-coded morality, community surveillance and the burden of reproductive pressure placed upon women. The analysis also demonstrates how Ponna and Kali's emotional worlds are constructed and constrained through symbolic structures that reflect tradition, belief and collective identity. Ultimately, the paper argues that symbolism in One Part Woman is not merely decorative but serves as an alternate system of communication—one that exposes the conflicts between individual desire, societal norms, and the rigid codes of honor embedded in rural life.

Keywords: *Symbolism, Infertility, Nature, Chariot Festival, Rituals*

Symbolism is a literary device where a symbol, whether it can be character, object, event, or place represents a deeper meaning beyond its literal significance. In literature, symbolism allows writers to convey complex ideas, emotions, or themes without directly stating them. Symbolism is the use of a symbol to represent ideas, qualities or concepts. A symbol is typically a concrete object or event that stands for something more abstract. For example, in many stories, a dove can symbolize peace, while darkness can symbolize evil or mystery.

The Symbols are divided into two categories: Universal symbols and Contextual symbols. The Universal symbols are widely recognized across different cultures. For example, the colour white often symbolizes purity or innocence, while a red rose is commonly associated with love. The Contextual symbols are specific to a particular work of literature. The meaning of the symbol may not be immediately clear and may require understanding of the text's themes or cultural context. Clifford Geertz in his work *The Interpretation of Cultures (1973)* viewed

culture as a system of symbols through which people communicated and made sense of their world. He says:

> Culture is most effectively treated, the argument goes, purely as a symbolic system by isolating its elements, specifying the internal relationships among those elements, and then characterizing the whole system in some general way-according to the core symbols around which it is organized, the underlying structures of which it is a surface expression, or the ideology principles upon which it is based. (17)

Symbols help to deepen the theme of a work by offering a visual or conceptual representation of the theme. For instance, in *The Great Gatsby (1925)*, the green light symbolizes Gatsby's unattainable dreams and the larger theme of the American Dream's futility. Symbols also evoke emotions in the reader. For example, in *Lord of the Flies (1954)*, the conch shell represents civilisation and order, and when it is destroyed, it symbolises the collapse of societal structure and the rise of savagery. Sometimes, a symbol can help us understand a character's internal conflict or development. In *The Scarlet Letter (1850)*, the scarlet "A" on Hester Prynne's chest is a symbol of both her shame and her strength, evolving in meaning as the story progresses. Carl Jung, in his work *Man and His Symbols (1964)* emphasises that a symbol has both conscious and unconscious meaning, connecting surface reality to deeper psychological truths. He says:

> Symbol is a term, a name, or even a picture that may be familiar in daily life, yet that possesses specific connotations in addition to its conventional and obvious meaning. It implies something vague, unknown or hidden from us . . . There are, moreover, such objects as the wheel and the cross that are known all over all world, yet that have a symbolic significance under certain conditions. Precisely what they symbolize is still a matter for controversial speculation. (16)

Symbols are often open to multiple interpretations, making it tricky to pin down the single meaning. Sometimes, what we interpret as a symbol might not have been the author's original intention. Symbols can carry different meanings in different cultures, adding another layer of complexity especially in Tamil societies. Because symbolism has always been a vital feature of Tamil writings, shaping the ways ideas, emotions and social realities are expressed. From Sangam literature to modern Tamil novels and Dalit narratives, symbols have served as powerful and cultural tools that compress complex meanings into simple, familiar images. In Tamil tradition, a flower, a tree, a landscape, or even an object of daily use often carries meanings far beyond its physical forms.

The Sangam Poets perfected a symbolic system known as Tinai, where each natural landscape corresponds to a human emotion: Kurinji (Mountain regions) to love in union, Neithal (Seashore regions) to longing and separation, Marutham (Agricultural Land) to domestic love, Mullai (Forest regions) to waiting and Palai (Desert regions) to hardship or separation. Through these systems, Tamil society wove together ecology and human feeling, making symbols a bridge between inner life and the external world. In the medieval Bhakti movement, symbolism deepened religious devotion. Saints like Appar and Andal used metaphor of the garden, the temple and the body itself as a symbol of divine love and surrender. These writings show how symbols became vehicles of spiritual truth as well as social commentary. W.B. Yeats in his work *The Symbolism of Poetry (1990)* Yeats sees symbols as illuminators of the spiritual world, connecting poetic imagination with eternal truth. He says, "The symbol is the only possible expression of some invisible essence, a transparent lamp about a spiritual flame." (126)

In Modern Tamil literature, writers continue to use symbols to explore identity, caste and resistance. For instance, Sundar Ramasamy's *Oru Puliyamarathin Kathai* (The Tamarind Tree) employs the tamarind tree as a symbol of rootedness, tradition and changing dynamic of rural life. Similarly, Dalit writers such as Bama use everyday symbols like food, clothing, or the act of walking a particular path as markers of oppression and resilience. Symbolism in Tamil writings is not ornamental; it is a cultural language that reflects the Tamil worldview, connecting people with their land, history, spirituality and social struggles. It transforms ordinary objects into carriers of collective memory and identity. Ensuring that narratives remain deeply tied to lived experience.

In literary traditions, symbols play a crucial role in embodying cultural values, unspoken anxieties, and hidden desires. Perumal Murugan's *One Part Woman* is a novel steeped in symbols that reveal the intersection of fertility, gender, caste and tradition within Tamil rural society. Perumal Murugan is a distinguished Indian Tamil writer and a professor of Tamil at Government Arts College in Attur (Salem). He has published five poetry collections, six non-fiction books, and eleven novels on language and literature. His contribution to Tamil literature focusses on tribes, culture, caste, and rural traditions in Tamil indigenous society. He was the winner of the ILF Samanvay Bhasha Samman 2015.

Murugan's novels, *One Part Woman* and *The Story of a Goat*, were longlisted for the 'National Book Awards for Translated Literature 2018 and 2020', respectively. Pyre was nominated for the JCB Prize and the Atta Galatta-BLF Award for Translated Literature in 2018. His *Seasons of the Palm* was nominated for the Kiriyama Award. *Pyre* has been nominated

for an International Booker Prize. His novel *Fire Bird* won the JCB Literature Prize in 2023. Murugan's novel *Madhurobhagan*, which explores the dilemma of caste segregation in a married couple wishing to have a child, was accused of defaming Hinduism by Hindutva supporters, forcing Murugan to proclaim on his Facebook page in 2015 that he would no longer create novels. Murugan declares himself 'dead'. He took a literary exile.

In 2016, the Madras High Court ruled that there were no grounds to remove his novels from circulation and urged the government to give artists and literary icons with enough security from future attacks. He was resurrected as a writer by the Madras High Court's 2016 decision, "Let the author be resurrected to what he is best at." Write.' (Madras High Court, July 5, 2016.) Murugan's work has increased in popularity worldwide. The fact that two works (*Fire Bird* and *Sandalwood Soaps and Other Stories*) were published in the same month demonstrates a desire for a local, basic tone that readers find engrossing.

The novel is set in Tiruchengode, Tamil Nadu, in the 1940s, and follows the lives of two Gounder caste members, Ponna and Kali. It delves into the deeper elements of the couple's lives when they are unable to have children after twelve years of marriage. The book's title is a literal translation of its Tamil title, *Madhorubagan*, which translates to Ardhanareeswara, a half-male, half-female God who lives in the same body. As the story begins, Kali had planted a Portia tree in his in-law's home during the first few months of his marriage. It has thick leaves. Kali was pleased to see his tree mature, but he was also disappointed that, after twelve years of marriage, he had been unable to produce a child for Ponna. The flourishing Portia tree served as a reminder of his failure. All Kali and Ponna had done was try hard to conceive.

To no avail, they tried everything to get Ponna pregnant, including climbing the hill of Tiruchengode Murugan Temple and lighting the sixty lamps for sixty days, drinking various bitter shoots and potions, visiting all temples, no matter how large or small, and even sacrificing her life to walk around the stone at Pandeerswarar temple. Kali and Ponna were naturally criticised by folks in their near neighbourhood because it was considered unusual for a couple to not become pregnant after a few months of marriage and twelve years had passed.

When women attending the chariot festival are called 'prostitutes' and men attending the same festival are called 'Gods', it further highlights the egregious sexism that women are enmeshed in. The novelist highlights, "Only the man who induced morning sickness in his wife in the very second month of marriage was a real man," (82) which puts pressure on Kali to demonstrate his masculinity, is another example of how gender norms are evident and this novel explores the food habits, seasons, home remedies for infertility and preparation of each food items plays a crucial role in each character's life. Nature plays an important role in novel

because each character has deep affection for nature and it is reflected in character development also. The portrayal of nature and nature symbols indirectly signifies the couple's infertility and Kali's sterility.

Murugan's symbolism is deeply rooted in Tamil cultural imagination, where rituals, myths and landscapes hold layered meanings. The novel's use of such symbols not only reflects the continuity of titration but also interrogates its oppressive demand on individuals. In *One Part Women*, the Portia Tree emerges as more than a natural presence, it becomes a symbolic site of love, friendship and honour. The Portia tree has a storied past that spans across multiple cultures. Historically, it was a favoured pant in ancient maritime communities due to tis hardy wood, which was used for making boats and canoes. However, its flower held a different kind of value. In many cultures, the golden blooms of the Portia tree symbolise prosperity and good fortune. They were often used in rituals and ceremonies aimed at invoking diver favour and abundant harvest.

In Tamil society, the Portia Tree is known as 'Poovarasu Maram'. It symbolises protection and resilience. Its wood is often utilised in the creation of religious artefacts, and the tree is considered scared in various traditions. In the beginning of the novel, Murugan portrait Portia tree as a symbol of Kali and Ponna's marriage life. He illustrates:

> The Portia tree was dense with foliage. If you looked closely, you could dee the yellow trumpet-like flowers with their flared mouths, and the drooping, fading red one with their inviting smiles. Portia flowers always grow more beautiful as they fade. He never could resist the desire to possess what attracted him . . . It had mild fragrance, that too when held close to the nose. He felt he should have left it on the tree. The sight of the flower on the tree was more beautiful that its scent. (1)

In the beginning of the novel, the author describes how the Portia tree attracts Kali. The Portia tree symbolises the emotional and physical bond between Kali and Ponna. It becomes their private space where they escape form the sharp eyes of society and rediscover intimacy. Under its shade, the couple express love, desire and closeness moments that stand apart from their painful reality of being branded 'barren'. The Portia tree is traditionally linked to fertility in Tamil culture. The enlarged branches of Portia tree reflect their longing for the child being married for 12 years. The Portia tree also connects with the disability of Kali and Ponna's able to be a parent. The Portia Tree flowers useful for temples and rituals whereas the Fruits are not useful for anything. It can relate to Kali and Ponna, whereas the flower represents the Ponna's fertility and the fruits represent Kali's sterility.

The deep roots of the tree symbolise the couples enduring bond, even when tested by external forces. Despite quarrels and pain, Kali and Ponna are deeply tied to each other, much like the tree is bound to the soil. Their love is rooted in mutual care, but the tree, it is also vulnerable to the storms of society. The tree acts as a protective canopy, mirroring how Kali wants to protect Ponna from gossip and social humiliation. This contrast reflects Murugan's irony; nature endures, but human relationships can be broken by culture.

The bull also emerged as a potent symbol linked to masculinity, fertility and social identity. In many traditions, the bull is seen as a symbol of unyielding strength and untamed power. Spiritually, the bull represents not just physical strength but also inner resilience and the ability to stand firm in the face of adversity. Fertility and abundance are other key aspects associated with bull symbolism. In ancient cultures, the bull was often associated with bountiful harvests and the prosperity of the land, making it a symbol of growth and abundance. It can also be seen in the novel, where Kali doubt himself as a potent male for make Ponna pregnant. It can see in the reply of the owner about the bull, He replies:

> 'Well, everyone has asked me to sell it, but it is a good bull, good breed. It is not easy to come by such bulls. So, I have kept it for other tasks, and since it had mounted several cows, I took pity on it and did not castrate it. Once or twice a week, we get people who want their cows to be mated twice. For those cows, I bring out the other bull for the second mating. (125)

These lines are indirectly connected with Kali's infertility. In agrarian Tamil society, A man's ability to cultivate land and tend livestock is often linked with his masculine identity. The bull, as a strong and fertile animal, mirrors Kali's own potency. His care for the bull reflects his desire to nurture strength and life, highlighting the irony of his childlessness despite these symbols of virility. But here, the bull represents the inner disability of Kali's sterility. The bull, which was good but not able to conceive other cows indirectly represents Kali's inability to make Ponna a mother. For Kali, the bull embodies the idealised masculine self, strong, fertile and productive. It contrasts sharply with his perceived inadequacy as a husband due to childlessness. Through the bull, Murugan explores the pressure of cultural expectations of manhood in Tamil society, showing how symbols of strength can intensify the psychological and social strain of infertility.

Temple rituals also play an important role in Kali and Ponna's life. The symbolisation of Temple festival in *One Part Women* not acts as religious thing but also acts as a symbolic representation of society. Because the couple's barrenness or their longing for the child makes them attend many temples rituals. The important festival was 'Karattur Chariot Festival'. It

was for 22 days. It was novel's most powerful and controversial symbol. It embodies the paradoxes of desire, fertility, morality and social order. The rolling chariot represents a moving force of life, carrying divine energy through the streets.

Symbolically it becomes a space where social norms are suspended: during the festival, women who are childless are allowed (and even encouraged) to unite with strangers to conceive. When Seerayi talks about the chariot festival to Kali for allowing to Ponna to participate in the function. She says:

> All men who set their foot in Karattur on the eighteenth day are gods. It is God who is giving this. It is not a problem if we keep our mind n god. Who knows which god come with what face? It is the nature of gods to reveal then faces. If you say yes, we can go to this year's festival . . . Ponna's mother can take her. You don't have to go along. (96)

For Ponna the chariot is thus both hope and danger, a socially sanctioned chance to become a mother, but at the cost of violating her bond with Kali. The deity Ardhanareeswara (Madhorubagan) symbolises the union of male and female principles, a cosmic fertility that transcends binaries. It symbolises that wholeness requires both parts, just as Ardhanareeswara is half-man, half-women, society insists that a marriage is income without a child. While the festival is framed as sacred, it reveals the deep hypocrisy of society. Everyone in Kali's family supports festival tradition and While Kali rejects the festival traditions. To convince Kali, Muthu says:

> 'Mapillai. Don't call him a stranger. Who remembers faces? All men are gods that night. Think of him as God, you might even feel happy about it. Isn't it a great blessing if our child comes from God? Haven't you heard people remark, "This child is a boon from God"? Those children were born exactly this way, mapillai'. (138)

Publicly, people uphold strict moral codes, but during the festival, the same society permits transgression to solve infertility. The festival thus symbolises, how culture controls reproduction. Ponna's body becomes a tool to fulfil social expectations rather than personal choice. The massive chariot that requires collective effort to pull mirrors the weight of social expectations that drags Kali and Ponna's marriage. Just as people strain to pull the chariot forward, Ponna is pressured to move forward by participating in the ritual. The chariot's unstoppable motion symbolises how tradition moves on relentlessly, regardless of individual suffering.

The temple and chariot procession mark the boundary where sacred ideals meet bodily desire. What society labels sacred (ritual) and profane (sexual union outside marriage)

collapses during the festival revealing the contradictions in religious morality. The novelist avers, “All of you have gotten together and cheated me, he cried” (239). For Kali, the festival represents betrayal, humiliation, and the loss of control over his marriage and masculinity. For Ponna, it represents a tragic choice: remain barren and be shamed forever, or participate in the ritual and bear the burden of transgression. The chariot and Ardhanareeswara festival symbolize the collision of love, tradition and social expectation; a ritual that pretends to resolve infertility instead exposes the cruelty of a society that values fertility over love and individual dignity.

The cow in the novel is not just an animal within Kali and Ponna’s household but a symbol layered with meanings tied to fertility, nurturance, sacredness and social morality. It serves as a cultural and emotional mirror to the couple’s struggles. The cows are more than domestic animals. They carry layers of symbolic meaning tied to fertility, and they intensify the irony of Kali and Ponna’s struggles with infertility. It can also see in the novel when one of the Kali’s cows did not produce calf for many years. So, he sold to Chellappan. while their conversation Chellappan says, “One of Kali’s cows had failed to yield a calf despite two or three attempts at mating her with a bull . . . It’s fate mapillai, ‘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).

The cow is a maternal symbol in Tamil culture, celebrated for nourishing claves and providing milk for families. For Ponna, this symbolism cuts deep: she tends to the cows, feeds and care for them but cannot fulfil the socially demanded role of mother. Her love for the animals reveals her capacity to nurture, yet society see her as incomplete. This scaredness contrasts with how society treat Ponna: while a cow is revered even for its productive role, a woman without children is reduced, shamed, and excluded. This symbolism exposes the harsh double standards of cultural morality.

For Kali, caring for cows affirms his role as a provider; their milk, claves and labour symbolize his ability to sustain life. Yet their fertility also becomes a reminder of his failure, that even as his household thrives with animal births, he cannot father a child. The cows, then symbolises both his strength as a farmer and his wounded masculinity. When Ponna brought cows to her in-law’s house, it turns boon to her womb, while seeing her cows, she cried and says:,

> After the wedding, she had fought with her father and had taken a cow form here. I delivered seven or eight claves, populating Kali’s barn with its offspring. She’d tear up just looking at that cow. She had once cried out loud. ‘I don’t have the boon that

even this mute creature has been blessed with.' Her tears filled him with rage against that cow and its claves. (8)

The cow, as giver of milk and mother to claves, reflects the ideal of motherhood that Ponna is expected to embody. This makes the cow a painful mirror; while animals fulfil their role naturally, Ponna is socially branded as incomplete. For Kali, the cows are proof of his ability to sustain life through farming and livestock. Their births confirm the fertility of his household economy. But each calf also intensifies him personal frustration; if his cattle can reproduce, why not his marriage? The cow thus reflects Kali's wounded masculinity, torn between his love for Ponna and his humiliation in society's eyes.

Murugan uses the changing seasons and month not merely as background but as symbolic reflection of Kali and Ponna's emotional and social journey. In Tamil agrarian culture seasons and months are deeply tied with agriculture, fertility, growth and renewal, exactly the themes that dominate the couple's struggles. The spring season falls in the month of 'Chithirai and Vaigasi'. The blooming flowers and lush fields symbolise fertility, romance and renewal. For Kali and Ponna, these seasons reflects their early love and intimacy. Where their bond is fresh and filled with hope of building a family. Just as nature blossoms, their marriage at first feels fertile with possibility. "It will be Vaigasi in just a month. And this year, apparently, the chariot festival was scheduled for the very beginning of Vaigasi" (118). The Chithirai and Vaigasi also symbolises the new beginnings and collective celebration. For Ponna, every Chithirai revives the hope of conception, as rituals and vows are performed. For Kalil, it is a season of renewed effort, yet each year ends in disappointment, making the month a reminder of hope denied.

Rain is a classic fertility symbol, bringing crops, greenery and abundance. The monsoon falls in 'Avani and Purattasi'. It symbolises the fertility of soil, renewal and prosperity. For Kali, who works the land, the rains mean hope for harvest and prosperity. Yet, this natural fertility stands in sharp contrast to his and Ponna's childlessness. The monsoon thus symbolises the irony of life; nature showers abundance while their womb remains barren.

The harsh sun, dry earth and withering crops symbolises barrenness, frustration and social pressure. The summer season falls on 'Aani and Aadi'. These months carry festival linked to fertility, marriage, and temple processions. It reflects the union of divine and human, but also heat and pressure. Ponna is urged to participate in temple rituals, including the Ardhanareeswara chariot festival. The month symbolises the clash between personal love and social coercion; her body is demanded as an offering to tradition. "For the people of Karattur,

the chariot festival was a three-month affair. The preparations began as soon as the month of Aani started. And the shops and stalls lasted till the month of Aadi." (97)

Aadi is linked to the goddess Amman and ritual for female fertility and protection. For Ponna, Aadi rituals become a cruel reminder that women are blamed for barrenness. The goddess becomes both a source of prayer and a mirror of her failure. These seasons reflects the emotional drought between Kali and Ponna, especially when gossip and family pressure make their relationship tense. Just the land cracks without rain, their marriage begins to crack under the weight of infertility.

Winter in rural Tamil society is marked by misty mornings, quiet fields and stillness. It symbolises the silence, barrenness and emotional distance of Kali and Ponna. The winter falls on 'Margazhi and Thai'. Margazhi is the month of bhajans, kolams, and goddess worship, celebrating divine fertility and cosmic rhythm. Ponna is constantly remained that while others pray for children and celebrate devotion, her prayers remain unanswered. The contrast between the community's spiritual fertility and her physical barrenness makes winter painful reminder of failure.

Whereas Thai is associated with auspicious marriages, beginnings and conception rituals. *"Thai pirandhall vazhi pirakkum"* (When Thai is born, new paths open) is a Tamil proverb, because it's the season of childbirth and fresh starts. Like in Kali and Ponna's life the 'Thai' become a blooming season in their life because Ponna gave birth to the child in Thai and, "On the first Thursday of the month of Thai, early in the morning, Ponna gave birth to a boy." (220) Even though the winter season brings new beginning to their life but it emotionally breaks the bond of Kali and Ponna.

Each year, seasons come and go, crops grow and die and cow give birth; nature's cycles remain steady. But for Kali and Ponna, however, the cycles of hope and disappointment repeat endlessly. Each season begins with hope for conception and ends with despair. This cycle pattern symbolises the inescapable trap of fertility, tied to both nature and society. As a farmer, his life is in rhythm with the seasons, ploughing, sowing and harvesting; the fertility of soil mocks his own barrenness. Due to their inability to become father and mother, both of them were frustrated and made them to compare themselves with animals. It is also seen in novel:

> She had laughed once, whispering into Kali's double curved-studded ears, 'If you had married a goat instead of me, it would have given birth to a litter by now for all the shoos she must have eaten.' Stony-faced, he had replied, 'I should have been born a male goat for that.' Even now, thinking of that made her smile till her eyes welled up with tears. (46)

Each monsoon brings crops but no child, intensifying his wounded masculinity. For Ponna, her body is symbolically compared to nature, society expects her to bloom and bear fruit like trees in seasons. Each passing seasons without pregnancy is seen as a personal failure, making her feel alienated from the natural cycles of fertility. The Tami calendar, instead of marking joy, becomes a calendar of judgment. Each festival, each ritual is another reminder that they have not conceived.

Society ties months and rituals to woman's womb. For Ponna, every season deepens her alienation, for Kali every season wounds his masculinity. Seasons mirror their emotional highs and lows: intimacy under flowering trees, despair n dry months and fragile hope and during rains. The cycles of nature highlight the tragedy that while land, cattle and tree are fertile, their love is suffocated by the stigma of human infertility. Their woundedness was portrayed by Murugan in the novel. He says:

> Kali and Ponna's effort to conceive a child have been in vain. Hounded by the taunts and insinuations of other, all their hopes come on the chariot festival in the temple of Madhorubhagan, the half-female god, everything hinges on the one night when the rules are relaxed and consensual union between any man and women in sanctioned, this night could end the couple's suffering and humiliation, but it will also put their marriage the ultimate test. (259)

Even though their life had a new beginning by the birth of child. The child becomes an emotional trauma for both Kali and Poona. Because of the child, their unbreakable bond breaks and both were struggle in alienation. Their love becomes questionable in their life and as like the season's changes, their love for each other also slowly decreases in the way of separation, alienation, betrayal and unfaithfulness. This study has demonstrated that symbolism in Perumal Murugan's One Part Woman functions not merely as a stylistic feature but as a critical narrative strategy that reveals the silent tensions of rural Tamil society. Symbols such as the Portia tree, livestock, seasonal cycles, and temple rituals operate as cultural languages through which issues of infertility, gender expectations, caste morality, and communal surveillance are articulated. Through these symbolic structures, Murugan exposes how deeply personal experiences are shaped and controlled by collective social values.

A close reading of these symbols shows that the novel critiques a society where fertility becomes the measure of marital legitimacy and individual worth. The recurring contrast between natural abundance and human infertility highlights the emotional violence created by rigid social norms. By allowing objects, rituals, and landscapes to convey meanings that

characters cannot openly voice, Murugan transforms symbolism into a medium of resistance and revelation.

The novel ultimately calls for a reconsideration of social structures that privilege reproductive success over emotional bonds, emphasizing empathy, personal dignity, and individual choice within marriage. Thus, symbolism in One Part Woman not only enriches literary meaning but also encourages critical reflection on the intersection of tradition, gender, and human agency in contemporary society.

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Ethical Issues of Technology in John Marrs' The One

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ABSTRACT

Technological inventions like machines and electricity have changed the lives of people by making their work much faster and easier. Inventions like telephone and internet gave rise to social media, online chat platforms and video calls that made people to communicate easily and build relationships removing distance as a barrier. With the rise of technology, the idea of DNA match-making which was found in science fiction is becoming possible in real life. This paper explores the ethical issues of using technology in The One by John Marrs. It focuses on the emerging concerns of cyberbullying and cybersecurity. The novel is set in a near-future society where an app called 'Match Your DNA' promises that with a simple mouth swab, people can get to know their perfect match. The novel does not follow just one character but it tells the story of five different people who take the test. Through the characters experiences, this paper highlights the risks of blindly trusting technology for deep personal choices.

Keywords: *Ethics, Privacy, Relationships, Responsibility, Technology*

People misuse online platforms in many ways as internet has made them to stay anonymous. They misuse this accessibility by spreading fake news, stalking, hacking, cyberbullying and many more. Taking screenshots have become a common practice of preserving information from computers, smartphones and other devices. One of the primary ethical concerns of taking screenshots is the violation of privacy. In The One, a woman named Mandy takes the test on 'Match Your DNA' in the hope of finding her soulmate after experiencing a miscarriage and the end of her previous relationship. She gets matched to a man named Richard. Mandy's actions in the novel show how one can easily capture and store personal images without permission. "She took a screengrab of the photograph and added it to a newly created folder on her desktop entitled 'Richard Taylor'" (1). This simple action of taking screenshots may seem to be harmless, but it is a clear invasion of personal privacy because the individual in the photograph has no control over how their image is being used. Such actions can lead to misuse of personal information, identity theft or even harassment. This behaviour of violating privacy rights, reflects the ethical issue of unauthorized data collection. It highlights that ethical behaviour is equally important on online platforms as it is in the real world.

Cybersecurity and hacking are the two major issues in the digital age because almost every activity from banking and shopping to communication and education, depends on digital technologies. Cybersecurity refers to the protection of computers, mobile devices, networks and online accounts from unauthorized access. But hacking involves using computer skills to break into systems without permission. In the novel, Ellie who is not just a participant of the test but the creator of 'Match Your DNA' gets matched with Tim. Her storyline later reveals that his real name is Matthew Ward and he has hacked her entire system in order to take personal revenge. The manipulation of technology is revealed when Matthew tells Ellie, "Until now. You and I are a mis-Match, Ellie, because I hacked into your servers to manipulate our results" (328).

Cyberbullying is another threat in the digital age. With the misuse of social media, messaging apps and online platforms, people find it easy to harass, threaten or humiliate others. This creates a major concern these days. From an ethical perspective, cyberbullying violates fundamental principles of respect, empathy and fairness as it intentionally causes emotional harm to victims such as children and teenagers who may be vulnerable.

The wide reach of technology and social media results in making public figures like actors, singers, athletes and politicians as the primary targets of cyberbullying. Every post, picture or opinion they share is open to millions of people all around the world. Technology enables them to connect with people, but it also creates a space where online abuse has become common and difficult to control. Ellie being a public figure, faces threat of harassment and attacks both online and in real life. "It wasn't the first time she had been subject to an attack, although most of the others had been of a cyber or verbal nature, with the exception of the religious nut who'd stabbed Andrei with a broken bottle" (135). She experiences emotional and psychological pressure from being constantly exposed and targeted.

The media can make a big impact on the life of a public figure. Constant attention can invade their privacy, making it hard for them to live a normal life. Stories may exaggerate or misrepresent their actions, that often leads to public criticism or even harassment. Positive coverage can bring fame and opportunities but negative coverage can cause stress, anxiety and damage to their reputation and overall mental health. Media can shape how the world sees them, leaving them no control of how their image is portrayed to the society. The novelist highlights, "Being interviewed by the world's press was something Ellie had grown to loathe since reluctantly becoming a public figure. A decade earlier, she was another anonymous worker bee, busy behind the scenes. Then the next thing she knew, the world's media was both praising her and lambasting her in equal measure" (33). This highlights the emotional struggle

and loss of personal freedom that often accompany public recognition, showing that fame can be overwhelming and isolating. It is often forgotten that celebrities are human beings with emotions and vulnerabilities. Many people view them only as entertainers or leaders, ignoring the personal struggles they may be going through. This makes it easier for online users to criticize them harshly without thinking of the consequences. It also reflects how social media values sensational content, where negative news and controversies spread faster than positive stories.

The challenges faced by Ellie show how fame and public attention can be as dangerous as they are glamorous. "As public appetite for her story grew, the tabloids had sifted through every piece of her private life, examining her past as if she were on trial" (34). This reflects how people in real life, especially public figures, often face constant judgment from society because of what is written about them in the media. This kind of exposure spread misunderstandings, creates pressure and even harm a person's image. It shows the negative effects of turning private life into public entertainment. Since the internet allows people to stay anonymous, bullies feel free to attack without facing any real consequences. The constant negativity can harm the mental health of public figures that can leave long-term psychological impacts including stress, trauma and a feeling of being constantly watched or judged.

Christopher is a serial killer who randomly sets a target of killing thirty women. He takes the test and ends up being matched with Amy, a police officer. The moments when Christopher keeps check of his targeted women reflects the dangerous way technology can be misused to invade someone's privacy. "He double checked the app on his smart phone to make sure the tenant, Number Eleven, was still at work, then used his picks to unlock her front door and familiarize himself with the layout of her home" (124). In today's world, apps and devices that are meant to provide convenience can also be easier for others to monitor personal routines and movements. When someone's location or daily schedule is visible, it creates opportunities for exploitation, as it gives away when a person is alone or when their home is empty. Such constant surveillance turns private lives into open information, often without the person realizing how exposed they are. This shows how the misuse of technology can make a person feel unsafe in their own home. The novelist avers, "Faceless contacts and downloadable programmes and software buried deep on the dark net provided him with the means to learn everything he needed to know about the women he targeted and more, and it all began with a mobile phone number. That would lead to a name, age, address, occupation, medical history and employment records. He could determine almost anything from their blood types to what they'd last purchased on eBay" (182).

Modern society is deeply tied to social validation through technology. In Linda's Book Bag Interview in 2017, Marrs states that "We – and I include myself in this – spend way too much time on social media looking for approval. Whether it be Facebook, Twitter or Instagram, I'm often checking to see how many 'likes' or shares my posts have received" (Marrs). Just like people today who look for likes and comments on social media to feel good about themselves, the characters in The One look for love and self-worth through a DNA test. Both shows how society is starting to depend on technology to decide one's identity and worth. Instead of trusting real human emotions and choices, people are letting apps, websites and algorithms to tell them what to believe about themselves and their relationships.

Christopher's storyline shows how some people make the mistake of trusting too easily in the digital world. He acknowledges, "He hated the word 'victim' because it implied, they were innocent in all of this. In his eyes they were volunteers, as they had offered him their telephone numbers when they chatted on dating apps; they'd made themselves too available and there were consequences in doing so" (142). By sharing personal details on dating apps or social platforms, they may unknowingly expose themselves to risk. Such mistakes highlight the need for caution and awareness when using technology.

People create vulnerabilities by making themselves too accessible, forgetting that once information is shared online, it can easily fall into the wrong hands. The novelist avers, "he was just as surprised by how easily women gave out their telephone numbers – and in some cases, home addresses – to a virtual stranger. Anything could happen to them if their details fell into the wrong hands, he thought" (204). Many users assume that these spaces are safe and that everyone has good intentions, but this openness can be misused by predators.

Human error plays a major role in these incidents, as users often ignore security warnings or click on unsafe links making systems more vulnerable. Ellie has also clicked one of the links that grabbed her attention the moment she read the subject line of the email that read "Businesswoman of the Year Award". She ignored it at that time as it opened to nothing. Later it was revealed to her by Matthew. He says, "Well, it wasn't nothing to me, because your click released a tiny, undetectable piece of tailor-made malware that allowed me to remotely access your network and work my way around your files. Everything you had access to; I had access to" (328). Even now many cases of losing money because of clicking random links are reported. This highlights that cybersecurity is not only a technical challenge but also a human one that requires awareness and caution.

The ethical use of biotechnology and data is an important concern in today's world, as these technologies have the power to significantly improve human life while also posing

serious moral and social risks. Similarly, the collection and use of personal and genetic data require careful ethical consideration. Matthew reveals to Ellie, "My dad was also one of your early test subjects. He was working for the government when you stole his details" (308). DNA matching is valuable in medicine, ancestry studies and criminal investigations, but it also poses risks to privacy and consent. He avers:

You took the DNA of the dead, the dying, sick people and criminals to bolster up your numbers in order to get more financial backing and expand your business. I found the details of known paedophiles, sex offenders and killers buried deep in your files, some of whom you actually found Matches for. And when I trawled a little deeper, you had the DNA of the severely mentally handicapped and even dead children on your database. (308)

Misuse of DNA data highlights how dangerous it is when companies use people's DNA without proper permission. By collecting genetic material from vulnerable groups like children, sick people or even the dead, they treat human life as a tool for making money. This can cause families losing control over deeply personal information and people could be unfairly judged or labeled because of data mistakes. It also breaks trust in science and medical research because the work is no longer focused on helping people but on profit.

Another ethical concern is unauthorized testing or data collection. Matthew emphasizes the unethical collection of DNA to Ellie. He says, "One of your old colleagues told me you were nicknamed 'Oscar the Grouch' because you spent so much time ferreting around the bins looking for used plastic cups and forks. By all accounts you'd be sneaking them out and swiping their DNA to add to your collection without their permission" (307). DNA samples can be easily collected from discarded items like hair or saliva, without an individual's knowledge. This creates the risk of identity misuse or wrongful criminal accusations. In the website Dead Good Books Marrs admitted that he would never take such a test himself and says, "Readers keep asking me if such a test existed, would I take it? But having considered all the pros and cons when writing my book, it's a definite no from me" (Marrs).

This paper brings out how the technology infused lifestyle of the current generation has to face various ethical issues like privacy violation, hacking and cyberbullying. It points out how the people getting attracted to the terms innovation and technological advancements fall on the trap of some intelligent criminals. It insists that sharing of personal health records including DNA data require careful and responsible use as they are more vulnerable in the public medium while in transit and storage.

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Violence in Urban and Rural Assam: A Critical Study of Aruni Kashyap's *The House with a Thousand Stories*

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ABSTRACT

Conflicts have been an inevitable part of society. However, the impacts of socio-political violence and unrests on communities have differed based on factors like their geographical location, cultural practices, gender, economical status and political authority. This study explores the diverse impact violence had on the Assamese society during the insurgency in Aruni Kashyap's The House with a Thousand Stories. It also depicts how violence shaped the daily lives of people in urban and rural Assam in different ways during that time. It primarily focuses the time period between 1998 and 2002, which resonates with the novel's timeline. The study aims at portraying violence as a multilayered concept that influences various parts of life. It shows how socio-political violence does not only affect the people involved in the movement but also the ordinary lives.

Keywords: *Violence, Insurgency, Assam, Urban, Rural*

Violence has been a part of society since time immemorial. For several centuries, literature has served as a platform for the discourse on emotional and physical anguish caused by violence. It has reflected the suffering inflicted on individuals and on communities through its various media. Different types of violence have been addressed in literature throughout history. The earliest portrayal of violence has been through epics and dramas. Epics such as *Beowulf, Paradise Lost* and Shakespearean dramas like *Macbeth* and *Hamlet* employ a powerful treatment of violence. Since the time of epics, violence has become a recurring theme in literature. Violence in literature is not always fictional; at times, it becomes a linguistic representation of reality itself.

Violence is one of the major themes often highlighted by Indian writers. The northeastern states of India have always been sites of various socio-political conflicts. The conflicts are often arise because of their geographical location, history, socio-economic factors and political alienation. In "Capacity Building for Conflict Resolution," the Second Administrative Reforms Commission notes that the "North East has seen an unending cycle of violent conflicts dominated by insurgencies with demands ranging from outright sovereignty to greater political

autonomy" (144). The state has been subjected to national conflicts, ethnic conflicts and sub-regional conflicts over the past decades.

Looking into the political history of Assam in particular, one finds that it has experienced the longest period of insurgency dating back to Indian independence in 1947. An organization called the Union Liberation Front of Asom (ULFA) was formed in 1979 by Assamese rebels to attain secession. This group initially gained public support as they promoted the popular idea of freeing Assam from Indian imperialism. However, by the 1990s, there was a rapid loss of public support as the ULFA cadres were criminalized for their extreme measures.

Aruni Kashyap's *The House with a Thousand Stories* echoes the violence that was inflicted during the period of insurgency in Assam. The violence in the novel is not fictional but a retelling of the reality of Assam during the 1980s. As New Historicists declare, "literary text, then, is always part and parcel of a much wider cultural, political, social and economic dispensation" (Bertens 176 - 77), making literature a crucial part of history itself. For instance, in a field report from the Assam team of *Bearing Witness: The Impact of Conflict on Women in Nagaland and Assam*, researcher Riturekha Baruah recounts the story of Prodipto, a ten-year-old boy killed in a bomb blast during the Independence Day celebrations in Dhemaji in 2004. His mother's grief, Baruah observes, "represents the sorrow of hundreds of mothers whose children have been victims of the conflict between the state and the separatist forces in my homeland, Assam" (33). The tragedy of this single family epitomizes the collective trauma that Kashyap's fiction seeks to voice through his character' quiet endurance and fractured memories. The novel is thus not just a piece of literature, but also an account of the socio-political history of Assam, making the novel a fiction underscored with real incidents.

The effects of violence can be seen in every aspect of life, whether in a family, society or nation. However, the degree of effect it has on the people varies according to the situation and the social setting. Assam's separatist violence affected the people of both rural and urban settings. However, the aftermath of the violence was different in each case. Kashyap in his novel, *The House with a Thousand Stories*, presents the protagonist, Pablo, as an urban dweller, though his ancestral home is situated in rural Assam. He lives with his parents in Guwahati, while his ancestral family lives in Mayong, a village in Assam. Through Pablo's journey, Kashyap illustrates the different consequences that violence and unrest bring to people of different social settings. Kashyap narrates the horrific incidents encountered by Pablo during his visits to Mayong. The narrative depicts that the violence is more severe in rural than in urban areas. The socio-political state of rural Assam is worse than that of urban areas during the insurgency. In the novel, political groups such as ULFA and SULFA are most

commonly associated with villages. Rumours about them are more prevalent in the villages, because most of the dreadful killings and assaults take place in the rural areas. The residents of the village become witnesses of several violent killings. For instance, "There was a sea of people around Hiren's large house that night. The whole village had congregated there. At that time, I didn't wonder why the atmosphere there was so still, why nobody was crying, why all that I heard were the heavy breaths of people who had come running, leaving meals, beds, dreams and their lovemaking behind" (102-103).

Pablo himself becomes a witness to this gruesome event during his visit to Mayong, his ancestral village. The killings that he had previously only heard about in stories were unfolding before his very eyes. Being in the village made him a witness of such a terrible incident. This memory stayed with him even years later. While Pablo's cousin, Mridul, comes to invite Pablo for Moina-pehi's wedding, the first thing he remembers is blood and killings. He reveals, "I didn't want to think about what happened the last time I was in Mayong. I didn't want to think about the smell of shit and blood, the cries, the heart-piercing wails. I sealed them away from my thoughts as a mother hides memories of her lost child in a secret chamber of her mind. I wanted to think about the wedding of 2002, not the funeral of 1998" (17). This reflects how even the characters in the novel deeply associate violence with the village.

According to the reports of *Human Rights Watch*, home raids in villages were very common. The major targets were young men, but their neighbours and families also fell victim to army violence. As the readers notice from the various victims of violence, "Even distant relatives aren't spared" (69). A character in the novel comments, "He wasn't anyone big. He was just a distant brother of an ULFA member" (69). They were subjected to assaults, sexual harassment and even killings. The raid's main purpose was to scare people into identifying ULFA members.

The reflection of this fear of being assaulted or harassed can be seen in Kashyap's characters. They are scared to associate themselves with members of such political groups. Moina-pehi, Pablo's aunt who was about to get married, attempts suicide when she finds out that she is marrying the brother of an ULFA member. She cries, "Better to die than get married into such a family . . . Let me die please, I don't want to suffer later, I don't want to be killed by unknown assassins!" (189). These cries convey the deep scar left behind by the army and ULFA members.

In the novel ULFAs are considered unfortunate, "Some said families of all rebels and Surrendered rebels were unfortunate. (So surprising. A decade ago, the same people showed off to others that they had ULFA members in their family . . .)" (211). Once the ULFAs were

celebrated by their families and friends, but later they were detested as they brought danger to their loved ones. Even being neighbours or acquaintances with them could cost people their lives. Therefore, getting married to a family member of the ULFAs was considered dangerous and worse than death.

Mayong was also occupied by the SULFA members. The novelist points out, "The SULFA were surrendered ULFA rebels . . . Everyone in our village was scared of the SULFA since they carried carbines and AK-47s with them all the time and roamed around everywhere at will" (10). Even the SULFAs induced the same fear in people as the rebels did. But the government did not expose their unlawful activities. The SULFA's activities often went unreported, while abuses by ULFA members were well-publicised. Pablo remarks in the novel, "But everyone only spoke about the SULFA, didn't write about them" (11). It illustrates the fear instilled by the government, which kept the public silent from exposing the cruel acts of the surrendered rebels. Although people knew that the government was behind the secret killings, no one voiced it openly. There was nothing 'secret' about the secret killings, it was only a secret because the people were too frightened to talk about it.

The killings were not met with justice, but witnessed in silence. People did not even cry for the families that lost their life because of fear, "I had never encountered such an eerie silence in my life until then. Even the large group that had gathered was whispering. There was no one to cry for them. The whole family had been gunned down. And people were so scared that they couldn't cry. Did they think if they cried someone would come and gun them down too?" (104).

Fear overpowered grief among the villagers. They considered silence the shield that safeguarded them from further cruelty. When Pablo bravely states that the government must be behind all the killings while talking to Mridul's friend, Brikordar, Brikordar's mother asks him not to say anything, "Please don't say such things. There are ears everywhere in the village nowadays. You will be in trouble. It's not the same village where we grew up fearlessly" (108). It reflects the constant fear within people living in the village. They had an unspoken understanding that they could lose their lives if they opposed the government.

The city people, however, do not seem to be frightened to talk about the killings openly. Just like Pablo, his father also talks about the atrocities of the government without hesitation. He even has a heated debate with a guest, a supporter of the ruling party regarding the issue. Pablo's comments, "Papa was adamant that it was state-sponsored. He said it was 'extrajudicial'" (31). The city folk lack fear and hesitation that the villagers have acquired for

their safety. One of the passengers on the bus leaving Guwahati also voices it openly: Everyone knows who is killing who around the state, who they are working for secretly" (68).

The rural side of Assam was defenseless to the gruesome killings. Pablo's mother sees the village as a space under continuous surveillance, vulnerable to political unrest. She warns him, "You will have to be careful. The army is there all the time apparently, they just beat up anyone, Pablo!" (28). The idea of violence is thus deeply rooted in the rural setting, even for the residents of the city. During the time of Bolen-bortta's funeral, when Pablo's dad insists him to stay back, his mother is reluctant to leave him in the village. He says, "Although Papa wanted to leave me in Mayong so that I could attend Bolen- bortta's funeral in 1998, Mom wasn't happy about it. I think it was the city-bred girl in her that had stirred her doubts. I think it was the kind of news that invaded our breakfast tables that had made her shudder, wondering how safe I would be if I stayed back" (36).

Even Pablo's parents often tie the political violence to the village. They consider their home in Guwahati to be much safer than their ancestral home in Mayong. When Pablo stayed at Mayong after Bolen-bortta's funeral, he was sent home to be safeguarded from the horrific incidents taking place in the village. He knew he would be safe in his home, but he wondered, what would happen to those in the village, "where would they go?" (105). They had to face the horror each and every day. Although the insurgency was taking place in the entire state, its harshest impact was experienced in the village.

City life kept people away from the real problems, but the villagers truly suffered because of the socio-political violence. One of the passengers on the bus to Mayong expresses his agony: "People in Guwahati don't care. They love bandhs and it is only people like us who suffer because if we don't work for a day, we don't get rice" (33). This reveals how rural people not only suffered mentally and physically, but also economically. Their livelihood was at stake during each bandh. They were usually farmers, labourers or daily wage workers. They could not stay at home and enjoy bandhs like city residents. The passenger adds, "I am a farmer, Dasbabu. If there is a bandh, so much of my goods are wasted. I can't send them to Guwahati and they rot on the trucks. I don't deal with potatoes and grains. My main produce is vegetable. I lose thousands and thousands of rupees" (33).

Since the secret killings mainly targeted young men, many families lost their breadwinner, leading them into terrible financial crises. A woman is seen pleading with assassins to spare her husband and highlights, "his wife had fallen on the body of the man and asked them to kill her and not him, told the assassins that he was the only earning member of the family and that he had a small job in a local government school as a bearer" (69). This

incident echoes how the loss of life could lead to starvation for the entire family, which was even more dreadful than death.

Language and education were also a barrier for rural residents. The corrupt bureaucratic state did not help them overcome these barriers, instead pushed them further to the margins. Pablo's uncle, Prosonto-da says, "It's good that you can speak English so well, so many things become easier in this country if you know that language. I wish I could speak English as well. I wouldn't be stuck here then" (22). He believes that English can help him escape the vicious cycle of disruption. Although educated, he was still frustrated by the state of his village and its residents: "He was stuck in a village that was so close to Guwahati where nothing happened in terms of progress. Not even the roads were good enough to get out of the village" (22).

English is indeed seen as a language that can shield people from violence. "And he is smart enough to deal with any situation. He knows four languages, for God's sake!" (37). These lines, spoken by Pablo's father, suggests that knowing multiple languages could ensure safety amidst violent attacks. Language, thus, becomes a weapon of the privileged. Likewise, Pablo's uncle, Prosonto's education did not help him much. The college he founded along with some of his friends was not being nationalized, despite five years of effort. He had to bribe each and every concerned officer to get his file moving through the "labyrinths of bureaucracy" (23). This reflects how the entire political and bureaucratic system was corrupted. The consequences of this dysfunction were endured by ordinary citizens, who were denied personal growth amidst the unrest.

Economical fall out and language barriers were not concerns for the city's residents. For them bandhs and riots were extra holidays to enjoy at home. They were happy and safe at their homes while the violence took place in public spaces. Safety was a privilege they enjoyed without even realising it. They were not being raided, killed or raped in their homes unlike villagers. He highlights:

People in Guwahati bought videocassettes, meat and drinks the night before bandh so that they could have fun at their homes. I didn't want to listen to him because I was suddenly filled with embarrassment as this was true. It was true that people complained when bandhs were called out on the second Saturdays, saying, what was the use of calling a bandh on a second Saturday? (34)

The people complaining about bandhs on second Saturdays suggest their ignorance to the social dysfunctional. They fail to understand the depth of the situation and do not even care to know the reason behind the bandh. Since it causes them no inconvenience, it does not matter

what happens beyond their social horizon. The residents of the city do not come into direct contact with the dreadful part of the unrest. They only hear about the killings in stories narrated by others or in news reports. Such news is only a part of their discourses and does not truly affect their lives directly. Although riots did occur in cities, they never really entered or affected private spaces. The violence occurred mainly in public places. "During bandhs shops were gutted and restaurants were pelted with stones. Thus, the shops in cities were kept closed" (31). Staying at home was sufficient to keep city dwellers safe. Even closing shops did not affect them much, since they were not farmers or labourers like rural residents. Though city people face no direct physical threats, they were psychologically affected by the unrest, filled with fear and uncertainty.

Violence and disorder became normalised in the lives of people in urban and rural Assam during the insurgency period. As the narrator remarks, "Mom hadn't looked too convinced: as if it was abnormal not to have shutdown, some unrest, some killing or an unhappy organisation calling for trouble" (31). Violence shaped daily lives, impacting people physically, mentally and economically. It became a barrier to personal and social development in Assam during the separatist movement.

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Revolutionary Idealism and Moral Fracture: The Troubles as told by Patrick Radden Keefe in *Say Nothing*

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ABSTRACT

Revolutionary idealism fueled both the motivation and the downfall of the Troubles in Northern Ireland. In Say Nothing, Patrick Radden Keefe illustrates the paradox through the lives of Dolours Price, Brendan Hughes and Gerry Adams. Even though they shared a common cause, their personal choices led them to different paths. As time passed by, the trajectory of their primary goal began to shift, increasingly influenced by their actions and decisions. The aim of the Irish Republican Army (IRA), a paramilitary group, was a united Ireland and it was driven mostly by radical actions. The idealism that inspired the militants' bravery justified their brutal acts. This research paper argues that Say Nothing demonstrates the delicate nature of revolutionary idealism, showing that, although it can lead to positive changes in society, the methods used to achieve those goals will often lack ethical grounding.

***Keywords**: Revolutionary idealism, Troubles, the IRA, violence.*

The term, 'the Troubles' refers to the time period of Northern Ireland conflict that lasted for thirty years from 1968 to 1998 until it was resolved by the Good Friday Agreement in 1998. According to the Government of Ireland Act, Ireland was partitioned into Northern Ireland and Southern Ireland in 1921. Northern Ireland remained part of the United Kingdom, while the rest of the country became the Republic of Ireland by 1949.

In Northern Ireland, people classified themselves as unionists or republicans. "For the Republicans, Northern Ireland was Irish . . . For the Unionists, Northern Ireland was British" (Cancellieri 3). The Protestant Unionists or loyalists, held most of the power, whereas Catholic Republicans often faced discrimination in housing, employment, policing and political representation. These injustices led to growing frustration and demands for civil rights during the 1960s. A movement that started peacefully in the pursuit of civil rights quickly turned into an act of violence.

Patrick Radden Keefe (1976-) is an American writer and investigative journalist. He has written five books and numerous articles on a range of topics for publications including The New Yorker, Slate, and the New York Times Magazine. He wrote *Say Nothing: A True Story of Murder and Memory in Northern Ireland* (2018) after four years of research, seven

trips to Northern Ireland and interviews with more than a hundred people. The book tells the powerful and painful story of Northern Ireland during the Troubles. Roddy Doyle's article titled "*Say Nothing* - Part History, Part True Crime - Illuminates the Bitter Conflict in Northern Ireland" captures Keefe's powerful storytelling. His recollection of entering a quiet record shop in Belfast mirrors the silence and lingering tension that Keefe describes.

The Troubles in Northern Ireland was not a simple territorial dispute. The time was driven by intense revolutionary idealism, especially the paramilitaries of the Irish Republican Army (IRA). Nationalist groups that have been formed after colonialism, "asserted their rights to identity and land" (Wisker 50). Likewise, the IRA also aimed to free themselves from colonial power and their ultimate goal was a united, independent Ireland. Dr. Muhammad Tahir Mahmood, in his article titled "From Terrorism to Politics: The Case of the Irish Republican Army", states, "IRA's extremism was based on three beliefs: a complete denial of British supremacy over Northern Ireland; non-cooperation with political institutions to avoid granting them legitimacy; and using violence to gain their objective of a united Ireland". During the Troubles, revolutionary idealism fuelled both political activism and violent mutiny, leading to moral decay.

Revolutionary idealism is the strong belief that society must be completely changed to build a better world. It is a deadlier form of idealism. It often accepts the use of force or radical actions to break away from the existing system. "Two examples that epitomise the concept of revolutionary idealism are the French and Russian Revolutions", says Eric Patterson in his article titled "The Danger of Revolutionary Idealism: The Violence of Collectivism". He also goes on to talk about the collective danger that can arise from revolutionary idealism. Many people who joined paramilitary organisations like the Irish Republican Army (IRA) mostly did so not merely out of rage or desire for vengeance, as they believed themselves to be a part of a noble lineage of resistance. The memory of the past rebellions prominently shaped their sense of identity. It made them modern-day freedom fighters, completing the unfinished struggle.

Revolutionary idealism was inspiring, yet had moral contradictions. In the name of the cause, brutal acts were committed and justified. Bombings, assassinations, abductions and punishment beatings became very common. Mahmood also notes, "the IRA killed approximately 1,800 people between 1969 and 1994, including 600 civilians". More than 3500 people were killed throughout the Northern Ireland conflict, of whom 42% were civilians, 32% were members of British security forces and 16% were members of paramilitary groups.

One of the most haunting examples of the IRA's radicalism is the abduction and murder of Jean McConville and it serves as the base for *Say Nothing*. She was accused of being a

British informer and was made to disappear by the IRA. Her abduction and killing, followed by decades of silence, reveal how idealism can demand obedience at the cost of humanity. Among all the atrocities carried out by the IRA, the disappearance stands out as one of the most morally troubling. Idealism became self-serving, focused more on protecting the group and its reputation than on justice or true freedom. The Good Friday Agreement of 1998 marked a turning point from armed conflict to peaceful negotiation, pushing many former militants into the world of practical politics.

In the case of the Northern Ireland conflict, the idealism was fueled by a combination of personal suffering, historical memory and political oppression. For many young nationalists, the state's denial of civil rights to Catholics was not a political issue but was a moral betrayal. It ignited a vision of a freer and united Ireland in them. Many youths were drawn into this atmosphere, among them were Dolours Price (1950-2013), Brendan Hughes (1948-2008) and Gerry Adams (1948-). These three were the three important figures, whose early journeys into revolutionary activism were shaped by the same fire of belief, though they later walked different paths.

The Irish Republican Army (IRA) was established in 1919 as the direct successor to the Irish Volunteers, a militant nationalist group founded in 1913. Its primary aim was to bring an end to British rule in Ireland through armed resistance and to help make Ireland independent. During the War of Independence of Ireland (1919–1921), the IRA utilised guerrilla warfare tactics to pressure the British government into negotiations. A dispute over the extensive use of violence soon caused the IRA to crack. In December 1969, the IRA split into 'Official' and 'Provisional' wings after a Sinn Féin summit in Dublin. The Provisionals, who were also known as the 'Provos' felt that violence was an essential component of the fight to free Ireland from the British. Meanwhile, the Officials favoured parliamentary methods and shunned violence after 1972.

Personal Trajectories of Key Figures

Dolours Price was a prominent member of the IRA who grew up in a household filled with republican minds. Born in Belfast, Northern Ireland in 1950, she was raised with strong nationalist ideals. Her father, Albert Price was a well-known figure in the Irish republican movement and had been interned for his activities. He would talk about his past missions and internments. Keefe documents, "When Dolorus was little, she would sit on Albert's lap and he would tell her stories about joining the Irish Republican Army when he was still a boy, in the 1930s, and about how he had gone off to England as a teenager to carry out a bombing raid" (10). He was a veteran of earlier republican struggles and helped pass down the ideologies of

Irish nationalism to his children. He always emphasised that the British presence in Northern Ireland was unlawful and had to be resisted.

Christina Price, Dolours Price's mother, also supported the cause and endured the hardships of raising a family during the disturbed time. Most of the republican women, like Chrissie, were members of the IRA Women's Council and Keefe mentions how they were called as "the Cumann na mBan" (10). These women provided support to the volunteers through first aid, nursing and acting as messengers. The Prices were not only a family of fighters but also storytellers. And so, Dolours grew up hearing legends about heroes of the rising. Keefe, also opines, "Dolours had an aunt, Bridie, one of Chrissie's sisters, who had taken part in the struggle in her youth. On one occasion in 1938, Bridie had been helping to move a cache of explosives when it suddenly detonated. The blast shredded both of Birdie's hands to the wrist, disfiguring her face and blinding her permanently. She was twenty-seven when it happened." (12-13)

These family stories became Dolours' earliest lessons in politics, justice, and sacrifice. These stories ignited the fire of idealism within her.

Both Dolours and her sister, Marian Price, became involved in Irish republicanism in the late 1960s. Dolours' quest for freedom intensified after Bloody Sunday in 1972, when British soldiers shot and killed fourteen unarmed civil rights protesters in Derry. Soon after, she joined the Provisional IRA with her sister Marian. They became part of an elite IRA unit known as, "The Unknowns" (103). The Unknowns were tasked with various secretive activities, including abduction and killing, often targeting individuals suspected of being informers, who were later known as "the disappeared" (5).

The Price sisters wanted to serve as frontline soldiers, demonstrating that they are equally capable as the other men in the IRA. Keefe says, "Marian was said to be an expert sniper and was referred to, among British squaddies, as 'the Widowmaker.' Dolours would become known in the press as 'one of the most dangerous young women in Ulster'" (51). In 1973, she volunteered for a bombing operation in London. After being arrested, she embarked on a hunger strike to demand transfer to a Northern Irish prison. For Dolours, it was a fight for identity. She insisted on being recognised as a political prisoner and a soldier but not a criminal. Even as her body weakened, her commitment to the cause remained strong. The burning passion for a free Ireland motivated her to push further.

If Dolours Price represented the deeply emotional, sacrificial face of revolutionary idealism, Brendan Hughes represented its steadfast conscience. Keefe mentions "The soldiers referred to him as 'Darkie', or 'the Dark', on account of his complexion, and the name stuck,

a battlefield sobriquet'' (65). Hughes was a commander in the IRA and one of the most respected leaders within the prison system. Keefe says how he:

> . . . adhered to a philosophy, instilled in him at a young age by his father, that if you want to get people to do something for you, you do it with them. So, he wasn't just sending men on operations - he went along on the machines himself. Dolours Price first met Hughes when she joined the IRA, and she was dazzled by him. 'He seemed to be a hundred places at the one time,' she recalled, adding, 'I don't think he slept.' (64)

Hughes viewed the British presence as a form of colonial domination that could only be undone through force. He lived his life accordingly, never seeking personal reward, instead only national liberation.

Hughes' most powerful demonstration of revolutionary idealism can be seen during the hunger strikes of 1980, when he led IRA prisoners in the Maze Prison in demanding political status. For Hughes, the hunger strike was not simply a strategy but a form of war. He firmly believed that martyrdom could ignite public consciousness and force change. This belief, however, reveals the darker side of idealism as he records:

> A team of seven was selected. They would be led by Hughes, who had decided to participate in the strike: he had always taken pride in not asking a subordinate to do anything he was not prepared to do himself . . . For weeks, Hughes sat in his cell, growing weaker and more frail, his cheeks sunken, his ragged black beard and long hair giving him the look of an ancient sooth-sayer. (194)

He was prepared to endure sufferings, and even death for the cause. He always considered himself a soldier and socialist but the ideology did not consume him. He found a delicate balance between passion and pragmatism, navigating the harsh realities of life while remaining steadfast in his pose.

In contrast, Gerry Adams came to the Republican movement with a sharper focus on political strategy. Raised in a Catholic ghetto in West Belfast, Adams witnessed the marginalisation of his community. But unlike Dolours, who was directly involved in the movement through actions, Adams positioned himself as a thinker. He was someone who understood that sustaining the armed struggle required ideological discipline and long-term planning. In Keefe's words, "Adams had always walked a fine line within the ranks of the Provos, as a strategist rather than an operational man" (228). Though he has always publicly denied being a part of the IRA, numerous testimonies and sources suggest that he played a key role in shaping the Provisional IRA's doctrine and operations in the early years. Over time,

Adams began to pivot away from armed struggle, choosing instead to build Sinn Féin, a political party into a force capable of negotiating peace.

While Dolours' idealism was active and personal, Adams' was calculated and enduring. His transition from revolutionary paramilitant to politician represented a rethinking of how principles may be realised rather than their rejection. In this, Adams personified the shift from insurgency to diplomacy. This shift represents a different kind of idealism, which is pragmatic, adaptable, and perhaps ethically compromised. Adams' trajectory suggests that revolutionary ideals can be repurposed or diluted in the service of diplomacy. To many people, including Hughes and Price, this shift felt like betrayal but to a few others, it was political maturity. In the end, the cost of idealism is measured not only in lives lost but in the trust that was fractured among comrades.

At one time, Hughes and Gerry Adams were close. They fought side by side in the early 1970s and shared the same vision of revolutionary idealism. As Adams turned towards politics, he started to strongly deny his past involvement with the IRA, and Hughes felt betrayed. He accused Adams of abandoning the movement's core values for personal and political gain. These accusations became public through the Boston College tapes, which was called the Belfast Project, where Hughes gave confessional interviews under the agreement that they would be released after the interviewee's death. In these tapes, Hughes directly accused Adams for being involved in IRA operations, including the abduction and murder of Jean McConville. Keefe recounts, "Hughes couldn't remember Adams himself actually throwing stones or petrol bombs, but he was very effective at orchestrating others . . . Fearless and cunning, Hughes could mastermind any operation, but Adams had a sort of mind that could perceive the broader political context and the shifting tectonics of the conflict" (70). The tapes revealed the painful, hidden truth that Adams was the mastermind behind almost every operation. Hughes' confessions reveal not only the personal rift between the two men but also the intricate interplay of power, memory, and legacy within the IRA's ranks.

The lives of Dolours Price and Gerry Adams, when placed side by side, present a fascinating study in revolutionary temperament. The same conflict shaped both, yet they embodied different expressions of idealism. Their stories reflect the dual nature of revolutionary idealism, which is both a source of courage and a potential path to compromise or complicity. It also reminds us that the paths taken by revolutionary figures are rarely linear and often fraught with moral complexity.

Revolutionary idealism is often carried with moral clarity when first embraced. But over time, the demands of secrecy erode clarity, the burden of guilt, and the weight of lives

taken in the name of freedom. Together, these three lives tell the full story of revolutionary idealism in the Troubles. They reflect the different ways people bear the weight of belief through sacrifice, loyalty, and silence. Revolutionary idealism cannot remain untouched by history. It will be tested, twisted, and in some cases, destroyed. Idealism is a fragile construct and under the pressure of violence, secrecy and betrayal, it can easily collapse into complicity.

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Eco-modernist Ideals and Climate Solutions in Kim Stanley Robinson's *The Ministry for the Future*

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ABSTRACT

The representation of Eco-Modernism in the contemporary world is examined with particular attention to how it redefines the relationship between technology, sustainability, and environmental consciousness in an age of accelerating environmental change. Kim Stanley Robinson's one of the major works is The Ministry for the Future. As the climate crisis has become an urgent concern, this novel brings an innovative vision on technological and political grounds, which can be reshaped and tamed via human efforts in order to stabilize the planet. This study explores how Robinson integrates Eco-Modernism ideas through the battle of ideas such as geoengineering, decarbonization, and reform of the global finance system, where the narrative is centered on human responsibility and climate justice. Using the theoretical framework of Eco-Modernism, the paper analyzes the consequences of unchecked advancements and how humans can share the responsibility in the act of rewriting politics, building technologies that support a sustainable future. The findings of the paper suggest that Eco-Modernism is an optimistic approach towards the future; however, that's not the ultimate solution. It also sheds light on power structure and inequalities. The paper argues that Robinson offers a balanced Eco-Modernism roadmap with technological advancement and human visionary.

Keywords*: Eco-Modernism, technology, climate change, future, environmental sustainability.*

The accelerating climate emergency has intensified debates over whether technological modernization can rescue humanity from ecological collapse. Eco-modernism emerges within this debate as a framework that rejects both apocalyptic fatalism and primitivist retreat. Instead, it argues that technological innovation, economic restructuring, and institutional reform can enable humanity to "decouple" growth from environmental degradation. This paper argues that *The Ministry for the Future* stages eco-modernism not merely as ideological endorsement but as a contested and evolving response to planetary crisis. Through geoengineering proposals, financial instruments like the carbon coin, and institutional mechanisms for climate governance, the novel dramatizes both the promise and the ethical tensions embedded in eco-modernist thinking. By employing a fragmented, multi-voiced narrative structure, Robinson complicates techno-optimism and exposes the uneven political terrain upon which climate solutions unfold.

Although the term eco-modernism has circulated since the 1990s, it gained prominence with the 2015 *Ecomodernist Manifesto*, authored by scholars including Ted Nordhaus and Michael Shellenberger of the Breakthrough Institute. The manifesto asserts that humanity can reduce environmental pressures through intensified technological innovation, urbanization, and energy modernization, it advocates shrinking humanity's ecological footprint not by reducing development but by accelerating it in more efficient forms. The manifesto states: "Humanity must shrink its impacts on the environment to make more room for nature, while we reject… that human societies must harmonise with nature to avoid economic and ecological collapse."

Central to eco-modernism is the concept of decoupling—separating economic growth from resource extraction. However, critics have noted the persistence of the rebound effect, wherein efficiency gains often lead to increased consumption rather than reduction. This tension between theoretical optimism and practical complexity becomes crucial in Robinson's narrative world. One of the novel's most controversial eco-modernist interventions is solar radiation management through aerosol injection. The real-world precedent for such thinking lies in the 1991 eruption of Mount Pinatubo, which released aerosols into the stratosphere and temporarily reduced global temperatures by approximately 0.5°C. This event demonstrated that atmospheric intervention could measurably alter climate systems.

In the novel, similar aerosol spraying is undertaken deliberately. However, Robinson does not present this solution triumphantly. Instead, he situates it within geopolitical secrecy, ethical ambiguity, and uneven global consent. The narrative voice shifts between documentary explanation and anxious speculation, reflecting the instability of technological control. By embedding geoengineering within political negotiation and public anxiety, Robinson interrogates the eco-modernist assumption that technological capacity automatically ensures ethical legitimacy. Thus, geoengineering in the novel becomes both plausible and troubling: a necessary emergency measure that exposes humanity's precarious authority over planetary systems.

Beyond atmospheric intervention, the novel introduces structural economic reform through the carbon coin—a blockchain-backed currency designed to reward decarbonization. A character explains, "It will be money earned by removing carbon from the atmosphere . . . a new currency for a new future" (174). Here, Robinson imagines ecological restoration as the foundation of value creation. This aligns with Nicholas Stern's argument that markets must internalize climate risk in order to function sustainably. However, the novel's dialogic structure complicates this optimism. The carbon coin is debated, resisted, modified, and politically contested.

The multi-perspectival narration shifting between bureaucratic reports, personal testimonies, economic analysis, and anonymous commentaries prevents the reader from perceiving this reform as simple solutionism. Instead, financial innovation appears fragile, dependent on global cooperation and institutional trust. A crucial dimension of the novel, and one underexplored in the original draft, is its multi-voiced narrative structure. Robinson employs: Documentary-style chapters, Interspersed scientific exposition, Personal trauma narratives, Economic analyses, Collective and anonymous voices. This polyphonic design mirrors the distributed nature of climate responsibility. No single voice controls the narrative; instead, authority is fragmented. This narrative strategy challenges the eco-modernist tendency toward centralized technological mastery.

For example, the traumatic experience of Frank May destabilizes institutional rationality. His psychological scars from the opening heatwave in India foreground the human cost of delayed climate action. Meanwhile, Mary Murphy's bureaucratic pragmatism represents institutional eco-modernism in action. The tension between personal grief and technocratic planning underscores the ethical weight of climate governance.

Through this structural multiplicity, Robinson suggests that climate solutions cannot emerge from singular authority but require contested, collective negotiation. The novelist observes, "Revolutions don't involve guillotines anymore . . . Invisible revolutions, technical revolutions, legal revolutions" (506). This statement encapsulates Robinson's eco-modernist vision: transformation occurs through systems - law, finance, infrastructure rather than spectacle. However, the tone is not wholly celebratory. The ellipsis and ironic phrasing ("Alas") signal ambivalence. Change is necessary, but it is incremental, procedural, and often invisible. The "War for the Earth," said to begin on "Crash Day" (229), reflects how catastrophe catalyses reform. Yet Robinson's staging of crisis also critiques reactive governance.

The novel implies that technological solutions emerge only after devastating loss, raising questions about whether eco-modernism is proactive or perpetually crisis-driven. While eco-modernism emphasizes innovation, Robinson foregrounds inequality. Climate interventions affect nations unevenly. The Global South bears disproportionate suffering, and institutional power remains concentrated in elite financial networks.

By embedding eco-modernist strategies within geopolitical negotiation, the novel highlights the entanglement of technology and power. Solutions are never purely technical; they are political. This critical dimension prevents the narrative from collapsing into techno-utopianism. *The Ministry for the Future* presents eco-modernism as both possibility and problem. Through geoengineering, economic redesign, and institutional reform, the novel

imagines pathways toward climate stabilization. Yet its polyphonic narrative structure, ethical tensions, and focus on inequality complicate simplistic optimism.

Robinson ultimately offers a cautiously hopeful roadmap: technological advancement must converge with political reform, collective responsibility, and structural justice. Eco-modernism, in this vision, is not the ultimate solution but a framework requiring constant interrogation and democratic negotiation. By dramatizing climate intervention within contested narrative space, the novel transforms eco-modernism from abstract theory into lived political imagination.

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Land as Identity: Reconstructing Selfhood in Perumal Murugan's *Fire Bird*

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ABSTRACT

The profound interconnection between land and identity in Fire Bird by Perumal Murugan is explored, highlighting how geography, memory, and cultural belonging shape individual and collective identities within the narrative. The narrative centres on Muthu, a farmer whose sense of self is intrinsically shaped by the ancestral land he inherits. When familial conflict compels him to divide and abandon this land, Muthu experiences a profound loss that extends beyond material displacement. The separation separates his ties to pride, heritage, and belonging, generating emotional turmoil, isolation, and an acute sense of rootlessness. Through Muthu's arduous journey toward rebuilding his life in a new landscape, the novel illustrates how land functions not merely as physical territory but as a repository of memory, lineage, and self-worth. This study argues that Fire Bird portrays land as a foundational element of identity in rural society, its loss symbolising the fragmentation of selfhood and its reclamation representing the arduous process of reconstructing one's place in the world.

Keywords*: Identity, displacement, rootlessness, Land and identity, Selfhood,*

Land plays a vital role in the lives of rural communities, functioning not only as a source of livelihood but also as a marker of identity, respect, and security. Murugan's *Fire Bird* vividly portrays the profound connection between land and selfhood through the character of Muthu. Because for him, land is not merely a possession but a living extension of his existence, something that shapes his values, emotions, and social standing. The ancestral land he inherits embodies family pride, collective memory, and the labour of generations, giving him a distinct place within the community. In many of the villages in Indian society, landownership determines one's dignity and social worth; those without land are often regarded as insignificant or powerless. Those without land are often rendered invisible or powerless. As Yi-Fu Tuan observes, "Place is security, space is freedom" (*Space and Place*, 1977). Muthu's land offers him both security through rootedness and freedom through self-respect, the writer while explaining this idea says, "Muthannan did not have the heart to leave his village (19)." His confidence and identity are thus constructed through his intimate relationship with the land.

The relationship between land and identity may be further illuminated through the work of Yi-Fu Tuan, who in *Space and Place* distinguishes between "space" as abstract openness and "place" as space endowed with meaning through lived experience. For Tuan, place is not merely geographical location but a site of emotional investment, memory, and belonging. This theoretical distinction is crucial in understanding how land in *Fire Bird* operates not as a physical backdrop but as an existential anchor. The protagonist's attachment to land becomes a process through which fractured selfhood is reconstructed, transforming territory into identity-bearing place.

The novel also reveals how land structures family relationships, shaping both unity and division. What begins as a property division gradually escalates into emotional conflict. The quarrel between Muthu and his brothers demonstrates how land becomes a source of jealousy, rivalry, and resentment. The following lines expose deep-rooted hierarchies within rural families, where power and voice are determined by birth order and property rights, "The eldest would suggest strategies for how to go about it . . . The youngest had to quietly accept whatever was given to him (54)." Murugan foregrounds a harsh rural reality in which land disputes fracture familial bonds, replacing trust and affection with bitterness.

Muthu's wife Peruma and her connection to land vividly shows how land shapes identity in rural life. Murugan writes, "Land offered a sense of permanence. It was not just a means of livelihood; it was life itself (114)." This clearly shows that for Peruma and her family land is more than property. Their daily routine of working on the fields, care for the ancestral soil and struggle to protect it show how their identity is fully connected to land both physically and emotionally. In rural communities identity shapes through the knowledge and skills people develop in working within their fields. This resonates with Raymond Williams's assertion that land is "a form of lived relationship, not an abstract possession" (*The Country and the City*, 1973). A person's ability to cultivate crops, manage water resources, care for the soil, and conserve natural assets becomes an integral part of their identity, shaping both self-perception and the way the community perceives them.

Even when everything appears lost, Muthu refuses to surrender to despair. Determined to rebuild his life, he begins cultivating fresh land in an unfamiliar place. Each step he takes in the fields becomes a step toward rediscovering his fractured self. As Murugan poignantly observes, "Everywhere he went, he felt like a stranger, as though the soil itself knew he did not belong" (60). Gradually, through sustained labour and perseverance, Muthu starts to regain confidence and reconstruct his identity. The new land offers him renewed purpose and hope, teaching him that while identity can be shattered by loss, it can also be rebuilt through effort

and resilience. In this process, Muthu demonstrates that land is not only inherited through lineage but can also be earned through commitment and toil. The newly cultivated land thus emerges as a powerful symbol of rebirth, affirming that life and identity can grow again from suffering.

The emotional suffering Muthu endures after leaving his land reveals the profound psychological impact of displacement. He is not merely physically separated from his home but also mentally estranged from his past and sense of identity. The unfamiliar environment intensifies his feeling of unbelonging, making him feel as though he belongs nowhere. Muthu's struggle mirrors the experiences of countless migrants who move from village to village in search of a place they can call home. Caught between what they have lost and what they are attempting to rebuild, their identities become unstable and fragmented. Through Muthu's journey, Murugan powerfully illustrates how displacement erodes stability and rootedness, leaving individuals emotionally vulnerable, empty, and insecure.

Muthu's persistent search for new soil embodies the idea of identity as a process of reconstruction rather than a fixed inheritance. Though rejected and humiliated in village after village, he refuses to abandon his quest for land. His resilience is powerfully crystallised in the metaphor of the firebird - a mythical creature that survives destruction by rising from its ashes. Murugan writes, "Like the firebird, he too had to make a nest anew, wherever he found a patch of earth willing to hold him" (147). This line marks a significant shift in the narrative, where land is no longer understood solely in terms of ancestral continuity but also as a site of renewal and possibility. For Muthu, the act of re-rooting becomes an assertion of identity against despair. Even when the soil is unfamiliar, planting himself upon it signifies a new beginning and the gradual construction of belonging where none had previously existed.

Throughout *Fire Bird*, land emerges as a powerful symbol of respect, memory, stability, and self-worth. The loss of land leads to emotional collapse, while the acquisition of land offers the promise of renewal and continuity. For Murugan, land is not merely property or soil; it is life itself. A person without land is portrayed as a person without history or home, underscoring the novel's central assertion that identity is deeply and inseparably tied to the land to which one belongs.

Fire Bird powerfully affirms that land is integral to identity in rural society. Through Muthu's journey from loss to renewal, Murugan shows that land carries memory, dignity, and purpose. The loss of land fragments identity, while reclaiming land enables its reconstruction. Ultimately, the novel insists that land is not merely earth or property - it is history, belonging, and life itself.

Murugan's *Fire Bird* compellingly establishes land as a central force in the formation, fragmentation, and reconstruction of identity in rural society. Through Muthu's journey, the novel demonstrates that land is not merely an economic asset but a profound source of memory, dignity, and belonging. The loss of ancestral land shatters Muthu's sense of self, leaving him displaced, emotionally fractured, and socially marginalised. This rupture reveals how deeply identity is rooted in land within agrarian communities, where ownership and cultivation determine social worth and personal stability.

At the same time, *Fire Bird* resists a narrative of irreversible loss. Muthu's determined efforts to cultivate new land affirm that identity, though disrupted, is not beyond recovery. By re-rooting himself in unfamiliar soil, he reconstructs his selfhood through labour, resilience, and hope. The metaphor of the firebird underscores this process of renewal, suggesting that identity can rise anew from devastation. Ultimately, Murugan's novel affirms that while land anchors identity through ancestral continuity, it also offers the possibility of rebirth. *Fire Bird* thus presents land as both origin and renewal also an enduring foundation upon which selfhood is continuously shaped, challenged, and reclaimed.

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பட்டினப்பாலையில் வணிக வாழ்க்கை

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கட்டுரைச் சுருக்கம்

சங்க இலக்கியங்கள் பண்டைத்தமிழரின் வாழ்வியலை எடுத்துரைக்கும் ஆவணங்களாக உள்ளன. அகமும் புறமும் இரண்டறக் கலந்த அவர்தம் வாழ்க்கையை அறிய செவ்வியல் இலக்கியங்களே துணைநிற்கின்றன. இச்செவ்விலக்கியங்களுள் ஒன்றான பட்டினப்பாலை பழந்தமிழர் வணிக வாழ்க்கைமுறையைக் காட்டும் கண்ணாடியாகத் திகழ்கின்றது. சங்க இலக்கியங்களில் வணிகம் பற்றிய செய்திகள் பட்டினப்பாலையில் அதிக அளவில் இடம் பெற்றுள்ளன. மேலும் ஏற்றுமதியும் இறக்குமதியும் அதிக அளவில் நடைபெற்றதற்கான சான்றுகளும் காணக்கிடைக்கின்றன. இவ்வாறு பழந்தமிழர் கடல்கடந்து வணிகத்தில் கொடிகட்டிப் பறந்தாலும் அறநிலையில் வழுவாது வணிகம் செய்ததைப் பட்டினப்பாலை உணர்த்துகின்றது.

முன்னுரை

சங்க இலக்கியங்களுள் ஒன்றான கடியலூர் உருத்திரங்கண்ணனார் எழுதிய பட்டினப்பாலையில் பட்டினம் என்பது சோழவேந்தன் கரிகாலனது காவிரிபூம்பட்டினத்தையும் பாலை என்பது ஐந்திணைகளில் ஒன்றான பாலைத்திணையையும் சுட்டுகின்றது. காவிரிபூம்பட்டினம் வணிகநகரமாகும். அங்கு பொருட்களை விற்பனை செய்யும் விற்பனை அங்காடிகள் இருந்துள்ளன. பகலில் இயங்கும் அங்காடிகளை நாளங்காடி என்றும் இரவில் இயங்கும் அங்காடிகளை அல்லங்காடி என்றும் அழைத்தனர். பட்டினப்பாலை முன்வைக்கும் வணிகம் சார்ந்த செய்திகளைப் பற்றி இக்கட்டுரை விவரிக்கின்றது.

பாலைத்திணையும் வணிகமும்

வணிகம் எனும் சொல்லை மேலோட்டமாகப் பார்த்தால் அது புறம் சார்ந்த சொல் போன்று தோன்றினாலும் அது அகவாழ்வுடன் நெருங்கிய தொடர்புடையது. அன்பின் ஐந்திணைகளில் ஒன்றான பாலைத் திணையில் அமைந்த பாடல்கள் பிரிவுத் துயரை முன்வைப்பவை ஆகும். பிரிவானது போர், தூது, கல்வி, பொருள்தேடல் எனும் பல காரணங்களால் நடைபெறும். அதில் பொருள்வயிற் பிரிவு என்பது தலைவன் பொருள் சம்பாதிப்பதற்காக தலைவியை விட்டு பிரிந்து செல்வது ஆகும். இதில் பொருள் தேட பழந்தமிழர் மேற்கொண்ட வழிமுறைகளில் முக்கியமானது வணிகம் ஆகும். காப்பிய காலத்திலும் இதனை நாம் காணமுடியும். சிலம்பில் பொருள் ஈட்ட கோவலன் வணிகம் செய்ய முடிவெடுக்கின்றதும் மணிமேகலையில் ஆதிரையின் கணவன் சாதுவன் பொருள் தேட மரக்கலத்தில் வணிகர்களுடன் சென்றதும் இடம்பெற்றுள்ளது.

சுங்கச்சாவடி

மக்களைக் காக்க மக்களிடமிருந்தே அரசு பெறும் பொருளுக்கு வரி என்று பெயர். இறக்குமதிப் பொருள்களுக்கும், ஏற்றுமதிப் பொருள்களுக்கும் அரசு சுங்கவரி விதித்ததால்

பண்டைக்காலத்தில் அரசுக்கு அதிக வருமானம் வணிகத்தின் மூலம் கிடைத்தது. காவிரிப்பூம்பட்டினத்தின் துறைமுகத்தில் இறக்குமதி பண்டங்களுக்கும், ஏற்றுமதி பண்டங்களுக்கும் சுங்கவரி விதிக்கப்பட்ட செய்தி பட்டினப்பாலையில் இடம்பெற்றுள்ளது. சுங்கச் சாவடிகளில் காவல் பணியில் ஈடுபடுபவர்கள் அரசனின் பொருளைக் காக்கும் புகழுடைய மரபினர் என்றும், அவர்கள் கதிரவனின் தேரை செலுத்துகின்ற குதிரைகளைப் போன்று நாள்தோறும் ஓய்வின்றி சோர்வின்றி சுங்கவரி வசூல் செய்யும் தம் பணியை சிறப்பாகச் செய்தனர் என்றும், பண்டத்தின் நிறைக்கும் மதிப்புக்கும் ஏற்ப வரி வசூலிக்கப்பட்டன என்றும்

நல்இறைவன் பொருள் காக்கும்
தொல்இதைத் தொழில் மாக்கள்
காய் சினத்த கதிர்ச்செல்வன்
தேர்பூண்ட மாஅ போல
வைகல் தொறும் அசைவுஇன்றி
உல்கு செயக் குறை படாது (பட்டி. 120-125)

எனும் பாடலடி புலப்படுத்துகின்றது.

பண்டகச்சாலை

சோழநாட்டின் தலைநகராகவும் துறைமுகமாகவும் விளங்கிய பூம்புகாரில் ஏற்றுமதி, இறக்குமதிப் பொருட்கள் ஏராளமாகக் குவிந்து கிடந்தன. நிலத்திலிருந்து வந்த பண்டங்களும் நீர் வழியாக வந்த பண்டங்களும் சுங்கச்சாவடிக்குள் அனுப்பப்படுகின்றன. அவை சுங்க அதிகாரிகளால் சோதனையிடப்பட்டதற்கு அடையாளமாகச் சோழனுடைய சின்னமான புலி முத்திரை பொறிக்கப்பட்டு பண்டகச்சாலைக்கு அனுப்பப்பட்டன. இதனை,

நீரினின்றும் நிலத்து ஏற்றவும்
நிலத்தினின்று நீர்ப் பரப்பவும்
அளந்து அறியாப் பல பண்டம்
வரம்பு அறியாமை வந்து ஈண்டி
அருங் கடிப் பெருங்காப்பின்
வலியுடைய வல் அணங்கின் நோன்
புலிப் பொறித்து புறம் போக்கி
மதி நிறைந்த மலி பண்டம்
பொறி மூடைப் போர் ஏறி (பட்டி. 129-137)

என்னும் பாடலடிகள் மெய்ப்பிக்கின்றன. சுங்கச்சாவடிகளில் வரி வசூலித்தப் பின்பு பொருட்களை பண்டகச்சாலையில் பாழடையாமலும், திருட்டுப் போகாமலும் பாதுகாக்கும் பணியையும் செய்தனர். இவ்வாறு சிறந்த பாதுகாப்பும் காவலுமுடைய புகார் நகர பண்டகச்சாலையில் வந்து குவியும் பொருள்கள் நிலமானது வளையும்படி மிகுதியாக வந்ததாகக் கூறப்படுகிறது.

வணிக அறம்

சுங்கச்சாவடியில் புலி முத்திரை பொறிக்கப்பட்டு பண்டகச்சாலையில் வந்து குவியும் பொருட்கள் வணிகர்களால் பல்வேறு இடங்களுக்குக் கொண்டு செல்லப்பட்டு விற்கப்பட்டன.

பூம்புகாரில் வாழ்ந்த வாணிகர்கள் அறத்தை அடிப்படையாகக் கொண்டு நடுநிலைமையோடு பழிக்கு அஞ்சி வணிகம் செய்தனர். பொருட்களை வாங்கி விற்கும் வணிகர்கள் பிறர் பொருளையும் தம் பொருள்போல் நினைத்து, அளவில் மிகுதியாக வாங்காமலும் அளவில் குறைத்து விற்காமலும் நடுவுநிலைமையுடன் செயல்பட்டனர்.

நெடு நுகத்துப் பகல் போல
நடுவு நின்ற நல் நெஞ்சினோர்
வடு அஞ்சி வாய் மொழிந்து
தமவும் பிறவும் ஒப்ப நாடிக்,
கொள்வதூஉம் மிகை கொளது
கொடுப்பதூஉம் குறைகொடாது,
பல்பண்டம் பகர்ந்து வீசும்... (பட்டி. 206-211)

என்று பட்டினப்பாலை வணிகர்களின் நேர்மையையும் நடுவுநிலைமையையும் எடுத்துக் கூறுகின்றது.

பண்டமாற்று முறை

வணிகர் தம் பொருள்களை பண்டமாற்று முறையில் விற்றனர். பண்டமாற்று என்பது ஒருபொருளைக் கொடுத்து மற்றொரு பொருளைப் பெறுவதாகும். பண்டைக்காலத்தில் இப்பண்டமாற்று முறையே வணிகர்களிடம் அதிகமாக நடைமுறையில் இருந்தது.

வெள்ளை உப்பின் கொள்ளை சாற்றி
நெல்லொடு வந்த வல்வாய்ப் ப.ற்றி
பணைநிலைப் புரவியின் அணைமுதல் பிணிக்கும் (பட்டி.29-31)

எனும் பாடலடி காவிரிப்பூம்பட்டினத்தின் கடற்கரை உப்பங்களிகளில் உப்பை விற்று அதற்கு ஈடாக நெல்லை ஏற்றி வந்த படகுகள் வரிசையாகக் கட்டப்பட்டு இருந்தன என்றுரைக்கின்றது. இது உப்பிற்கு மாற்றாக நெல் பெறப்பட்டதை எடுத்தியம்புகின்றது. இது தொடக்ககால வணிக முறையாகும்.

ஏற்றுமதி இறக்குமதி

காவிரிப்பூம்பட்டினத்திற்கு வெளிநாடுகளில் இருந்து மரக்கலங்களின் மூலமாகக் குதிரைகள் இறக்குமதி செய்யப்பட்டன. சேர நாட்டிலிருந்து மிளகு மூட்டைகள் வந்தன. இமயமலையிலிருந்து மணிகளும் பொன்னும், குடகு மலையிலிருந்து சந்தனமும் அகிலும் வந்தன. தென்கடல் முத்தும் கீழ்கடல் பவளமும் கங்கை, காவிரி ஆற்று நீரால் விளைந்த பொருட்களும் வந்து குவிந்தன. சீனத்திலிருந்து வாசனைப் பொருள்களும், ஈழத்திலிருந்து உணவுப் பொருள்களும் வந்தன.

நீரின் வந்த நிமிர்பரிப் புரவியும்
காலின் வந்த கருங் கறி மூடையும்
வடமலைப் பிறந்த மணியும் பொன்னும்
குடமலைப் பிறந்த ஆரமும் அகிலும்
தென்கடல் முத்தும் குணகடல் துகிரும்

கங்கை வாரியும் காவிரிப் பயனும்
ஈழத்து உணவும் காழகத்து ஆக்கமும்
அரியவும் பெரியவும் நெரிய ஈண்டி
வளந்தலை மயங்கிய நனந்தலை மறுகின்
நீர் நாப் பண்ணும் நிலத்தின் மேலும்" (பட்டி. 185-194)

இவ்வாறு நிலம், நீர் என இரண்டின் வழியாகவும் பொருள்கள் புகாருக்கு விற்பனைக்குக் கொண்டு வரப்பட்டதை இப்பாடலில் காணமுடிகிறது. அதுபோன்று சங்கு, முத்து, தானியங்கள், காய்ந்த மீன், வெண்மையான உப்பு, இனிய புளி, வளையல்கள் என பாண்டிய நாட்டுப் பொருட்கள் பல கப்பல்கள் வாயிலாக அயல் நாடுகளுக்கு ஏற்றுமதி செய்யப்பட்டதும் பட்டினப்பாலை வாயிலாக அறிய முடிகின்றது.

துறைமுகம்

புகார் நகரம் ஏற்றுமதி இறக்குமதியில் சிறந்து விளங்க ஏதுவாக சிறந்த துறைமுக வசதி காணப்பட்டது. அங்கு படகுகள் அதிக அளவில் காணப்பட்டதை,

பணைநிலைப் புரவியின் அணைமுதல் பிணிக்கும் (பட்டி.31)

எனும் பாடலடி உறுதிபடுத்துகின்றது. காவிரிப்பூம்பட்டினத்தின் கடற்கரையில், உப்பை விற்று அதற்கு ஈடாக நெல்லை ஏற்றி வந்த படகுகள் வரிசையாக நிறுத்தப்பட்டிருந்த காட்சி, குதிரைகளை வரிசையாக கட்டியிருப்பதைப் போல காணப்பட்டன. மேலும் அரும்பெரும் பொருள்களை அயல்நாடுகளிலிருந்து கடல்வழிக் கொண்டுவந்த மாபெரும் மரக்கலன்கள் புகார்த்துறையில் பொலிவுடன் அசைவது, தறியில் கட்டுண்டு அழகுற அசைந்து நிற்கின்ற யானைகளைப் போன்றுள்ளதாக,

வெளில் இளக்கும் களிறு போல
தீம் புகார்த் திரை முன் துறை
தூங்கு நாவாய் துவன்று இருக்கை (பட்டி. 172-174)

என்று வணிகத்திற்கு ஏற்ற துறைமுக வசதி இருந்ததைப் புலவர் காட்சிப்படுத்தியுள்ளார்.

வணிகநகரம்

பழந்தமிழர் அயல்நாடுகளுக்குச் சென்று வணிகத்தில் ஈடுபட்டிருந்ததைப் போன்று அயல்நாட்டு வணிகர்கள் புகார் நகருக்கு வந்து வணிகம் செய்ததை பட்டினப்பாலை வழி அறிய முடிகின்றது. இவ்வாறு பல நாடுகளிலிருந்தும் வியாபாரிகள் வந்து வணிகம் செய்ய ஏற்ற சாதகமான சூழல் புகார் நகரில் நிலைபெற்றதை,

பல் ஆயமொடு பதி பழகி
வேறு வேறு உயர்ந்த முதுவாய் ஒக்கல்
சாறு அயர் மூதூர் சென்று தொக்காங்கு
மொழிபல பெருகிய பழிதீர் தேஎத்துப்
புலம் பெயர் மாக்கள் கலந்து இனிது உறையும் (பட்டி.213-217)

எனும் பாடலடி மெய்ப்பிக்கின்றது. வணிகத்துக்குப் உலகப்புகழ் பெற்ற புகார் நகரில், அக்காலத்தில் பலநாடுகளைச் சேர்ந்த பலமொழி பேசும் மக்கள் வந்து தங்கி வணிகம் செய்தது உறுதியாகின்றது.

முட்டாச்சிறப்பு

பட்டினப்பாலையில் பொருள்வயிற் பிரிய எண்ணிய தலைவன் செலவழுங்கும் போது

முட்டாச் சிறப்பின் பட்டினம் பெறினும்
வார்இருங் கூந்தல் வயங்குஇழை ஒழிய
வாரேன் வாழிய நெஞ்சே (பட்டி. 218-220)

என்று தன் நெஞ்சுக்கு உரைக்கும் பகுதியில் குறைவற்ற செல்வத்தையுடைய காவிரிபூம்பட்டினத்தையே தருவதாக இருந்தாலும் அழகிய கூந்தலையுடைய என் தலைவியைப் பிரியமாட்டேன் என்று தலைவன் ஒரு முடிவுக்கு வருகின்றான். தலைவன் ஒரு வணிகன் என்பதால் தன் தலைவிக்கு ஈடாக காவிரிப்பூம்பட்டினத்தையே கொள்வதாக இருந்தாலும் என்று பொருளுடன் ஒப்பிட்டுக் கூறுகின்றான். இவ்வாறு நூல் முழுவதும் அகவுணர்வினை வணிகத்துடன் பிணைத்து உருத்திரங்கண்ணனார் பாடியுள்ளார்.

முடிவுரை

அரசர், அந்தணர், வணிகர், வேளாளர் என்று வகைப்படுத்தப்பட்ட மக்களில் வணிகமக்களின் வாழ்வியல் சங்க இலக்கியமான பட்டினப்பாலையில் அகஉணர்வுடன் இணைத்துச் சிறப்பாக விவரிக்கப்பட்டுள்ளது. வணிகநகரம், வணிகதுறைமுகம், வணிகமுறை, வணிகஅறம், வணிகவரி, வணிகசாலை என்று பழந்தமிழரின் வணிகம் சார்ந்த செய்திகளை ஒரே இலக்கியத்தில் கடியலூரார் தெளிவாக தொகுத்துரைத்துள்ளார். அங்காடிகளில் பெயர் பலகைகளுக்கு மாற்றாக ஒவ்வொரு பொருளுக்கும் ஒவ்வொருவிதமான கொடிகளை பறக்கவிட்ட செய்தியையும் குறிப்பிட்டு தமிழரின் வணிகதிறனை உலகுக்கு உணர்த்தியுள்ளார்.

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கட்டுரைச் சுருக்கம்

வைணவ ஆழ்வார்களில் ஒருவரான ஆண்டாள் பாடியதே திருப்பாவை. திரு என்பது மரியாதைக்குரிய சொல். பாவை என்றால் பெண் என்பது பொருள். வணக்கத்திற்குரிய பெண் தெய்வமான ஆண்டாள் பாடியதால் இது திருப்பாவை என்று பெயர் பெற்றது. பாவை என்ற சொல்லுக்கு நோன்பு என்ற பொருளும் உண்டு. சங்க காலம் தொடங்கி இன்று வரை பல பெயர்களுடன் பெண்களால் நோன்பு நோற்கப்படுகிறது. பழங்காலத்தில் வாழ்ந்த தமிழர்கள் வழிபாடெல்லாம் தனி ஒருவர் வழிபாடாக இல்லாமல், சமுதாயத்தின் நலம் கருதிய வழிபாடாக இருந்தது. இதேப்போன்று, மார்கழி மாதத்திலும் பெண்கள் நோன்பு நோற்றதை எடுத்துரைத்து, நோற்க வேண்டிய காலத்தையும் நோன்பின் போது கடைபிடிக்க வேண்டிய சடங்குகளையும் நோன்பினால் கிடைக்கும் பயன்களையும் இந்நூல் அழகுற எடுத்துரைக்கின்றது. இந்நூல் முழுக்க முழுக்க பக்தி சிறப்பு மிக்கதாக இருப்பினும், திருப்பாவை கூறும் சிறப்பியல்புகளை ஆராய்வதாக இக்கட்டுரை அமைந்துள்ளது. திருப்பாவையின் சிறப்பு, அதன் பக்தி பெருக்கு மட்டுமல்ல. பார்க்கோவை முழுவதும் விரவிக் கிடக்கும் வரமாக கிடைத்த தமிழ் மணம் எனலாம்.

முன்னுரை

இறைவனிடம் கொண்ட அன்பை வெளிப்படுத்தும் தமிழ் இலக்கியங்களின் ஒருவகையான பக்தி இலக்கியம், பழந்தமிழர்களின் நம்பிக்கை, வழிபடும் மரபு, பக்தி உணர்வுகளையும் வெளிப்படுத்த நாயன்மார்கள் ஆழ்வார்கள் பாடிய பாடல்கள், பதிகங்களாகவும் பிரபந்தங்களாகவும் இலக்கிய வடிவம் பெற்றன.**"மண்ணில் நல்ல வண்ணம் வாழலாம்"** என்ற சம்பந்தரின் பாடல் வரி அவர் பக்தி உணர்ச்சியில் திளைத்திருந்த பாங்கை நமக்கு எடுத்துரைக்கிறது. இறைவனைப் புகழ்ந்து பல பேர் பாடி இருந்தாலும் வைணவ சமயத்தின் பன்னிரு ஆழ்வார்களில் ஒருவரான ஆண்டாள் இறைவனை நோன்பு நோற்று புகழ்ந்து பாடிய பாடல்களின் தொகுப்பே ஆண்டாள் திருப்பாவை. இத்திருப்பாவை கூறும் சிறப்பியல்புகளை ஆய்வதாக இக்கட்டுரையானது அமைந்துள்ளது

பாவைநோன்பு

கோகுலத்து உள்ள ஆயர்கள் மழை பெய்யாதகுறையை நீக்க வேண்டி தங்கள் பெண்களை மார்கழி நோன்பு நோற்கச் சொல்ல, பெண்கள் அருகிலுள்ள தோழிமார்களையும் அதிகாலையில் அழைத்துக் கொண்டு, யமுனா நதியில் மார்கழி நீராடி நோற்று, பயன் அடையப்பெற்றார்கள். பரிபாடல் ஆசிரியர் நல்லந்துவனார், இந்நோன்பை "அம்பா ஆடல்" என்ற பெயரால் அழைப்பதை,

"அம்பா ஆடலின் ஆய்தொடிக் கன்னியர் ....
தாயருகா நின்று தவத்தைந் நீராடுதல்" (பரிபாடல்11 - 81,91)

இப்பரிபாடற்பகுதியால் அறிய முடிகிறது.

நம் முன்னோர்கள் தாம் விரும்பிய கணவனை அடையும் பொருட்டும் நல்ல கணவனை அடையும் பொருட்டும் பாவை நோன்பு இருந்து வழிபட்டனர்.சங்ககால தை நீராடல், தைப்பாவை நோன்பு மரபு சிறிது மாற்றம் பெற்று இறைவனையே கணவனாக அடைய பக்தி இலக்கிய காலத்தில் மார்கழி பாவை நோன்பு மேற்கொள்ளப்பட்டது. எந்த ஒரு நற்செயலையும் செய்வதற்கு முன்பே அதற்கேற்ற நல்ல நாள் பார்ப்பது நம் மரபு. அவ்வகையில் பாவை நோன்புக்குரிய நாளான மார்கழி மாதப் பௌர்ணமி நாளில் கன்னிப்பெண்கள் பாவை நோன்பு நோற்றனர். ஆழ்வார்களில் ஒருவரான ஆண்டாளும் விரதம் இருந்து விடியும் முன்பே நீராடுவதன் மூலம் இறைவனின் அருளைப் பெறலாம் என பிற பெண்களையும் துயில் எழுப்பிக்கொண்டு ஆற்றில் நீராடி இறைவனைத் துதித்து வழிபட அழைப்பதை,**"மார்கழித் திங்கள் மதிநிறைந்த நன்னாளால் நீராடப் போதுவீர் போதுமினோ நேரிழையீர்"** என்ற பாசுரத்தில் காணலாம்.

தன் அடியிற் பணியாதவரை வெற்றி கொள்ளும் குணங்களை உடைய கோவிந்தனே! உன்னைப்பாடி,உன்னிடம் நாங்கள் வேண்டும் பேற்றினைப் பெற்று, மேலும் நாங்கள் பெறக்கூடிய பரிசில் உண்டு.அப்பரிசில் நாட்டார் புகழும்படி இருத்தல் வேண்டும். அவை சூடகம், தோள்வளை, தோடு, செவிப்பூ போன்ற அணிகலன்கள் எல்லாமும் வேறுபலவும் உன்னாலும் நப்பின்னையாலும் அணிவிக்கப்பட நாங்கள் அணிவோம்.உங்களால் அணிவிக்கப்பட்ட ஆடைகளை உடுத்திக் கொள்வோம். அதன் பின்பு, பாலாலே சமைத்த சோற்றில் அது கண்ணுக்குத் தோன்றாமல் மறையும் படியாக அதன்மீத செய்து பெய்து அது தங்கி தேங்க இடமில்லாமல், முழங்கை மேல் வழிந்து வரும்படியாகக் கூடியிருந்து குளிர வேண்டும். நோன்பு தொடக்கிய காலத்தில், நெய் உண்ணோம்; பால் உண்ணோம்; நாட்காலே நீராடி மையிட்டு எழுதோம்; மலரிட்டு நாம் முடியோம் என்பதை ஆண்டாள் **"சூடகமே தோள்வளையே தோடே செவிப்பூவே**

பாடகமே என்றனைய பல்கலனும் யாம் அணிவோம்

ஆடை உடுப்போம், அதன்பின்னே பாற்சோறு

மூட நெய்பெய்து முழங்கை வழிவாரக்

கூடியிருந்து குளிர்ந்தேலோர் எம்பாவாய" (திருப்பாவை -27)

பாடுகிறாள். மார்கழியில் பூக்கும் மலர்கள் அனைத்தும் இறைவனுக்கே உரியன. தீய சொற்களைப் பேசுவதையும், பிறரைப் பற்றி கோள் சொல்வதையும் தவிர்த்து, இறைவனைப் பாடிப் புகழ்ந்து, தர்மங்கள் செய்ய வேண்டும். இதனால் அனைத்துப் பாவங்களும் நீங்கும் என்றும், இறைவனின் திருவடியை அடையலாம் என்றும் நம்பப்படுகிறது.

ஓளி

கற்கால மனிதன் தான் எவற்றைக் கண்டெல்லாம் அச்சமுற்றானோ அவற்றையெல்லாம் வழிபடு பொருளாக்கி வழிபாடு செய்தான். அவ்வகையில் தோன்றிய வழிபாடு தனக்கு வாழ்வாதாரத்தை அளித்த இயற்கையின் மீதும் நன்றி செலுத்தும் விதமாகவும் வளர்ச்சியுற்றது. ஞாயிறு போற்றுதும் ஞாயிறு போற்றுதும் என்று சூரிய வழிபாடும் திங்களைப் போற்றுதும் திங்களைப் போற்றுதும் என்று சந்திர வழிபாடும் இலக்கியங்களில் இடம் பெற்றுள்ளது. அதிகாலை எழுதல் நம் தமிழ் மரபு. **"கீழ்வானம் வெள்ளென் றெருமை சிறுவீடு"** என்று

ஆண்டாளும் **"கோழிச் சிலம்ப சிலம்பும் குருகும் எங்கும் ஏழில் இயம்ப இயம்பும் வெண்சங்கு எங்கும்"**என்று மாணிக்கவாசகரும் கதிரவன் கிழக்கு திசையில் உதிப்பதும் கோழி, குருகு முதலிய பறவைகள் எழுப்பும் சத்தத்தையும் அதிகாலையில் எழுப்பப்படும் சங்கின் ஒலியையும் குறிப்பிடுகிறார். தேவர்களுக்குரிய மாதம் மார்கழி மாதம். அதனால் தான் மார்கழி மாதம் இறை வழிபாட்டிற்குரிய மாதமாகிறது. அறிவியல் கூற்றுப்படி அதிகாலை நேரம் உயிர் வாயு எங்கும் பரவி இருப்பதால் அந்நேரத்தில் மனிதர்கள் துயில் எழுந்து குளத்தில் நீராடி தம் பணிகளை செவ்வெனே செய்வதற்கு உரியதாகிறது. ஆரோக்கியத்திற்கும் அடிகோலுகிறது. **"வெள்ளி எழுந்தது வியாழன் உறங்கிற்று"** என்பதைத் தொண்டரடிப்பொடியாழ்வார், "கதிரவன் குணதிசைச் சிகரம்வந் தணைந்தான் கனைரு ளகன்றது காலையம் பொழுதால்"என்றும் "தூமணி மாடத்துச் சுற்றும் விளக்கெரிய தூபம் கமழத் துயிலணைமேல் கண்வளரும் மாமான் மகளே! என்ற திருப்பாவை பாடல் தூமணி மாடத்தில் எங்கும் விளக்குகள் எரிகின்றன. ஒரே பிரகாசமாய் இருக்கிறது. ஆண்டாள் உள்ளத்தில் பகவான் பிரகாசமாய் வீற்றிருக்கிறான். சூரியன், சந்திரன், மற்றும் தீபம் போன்ற ஒளி தரும் பொருட்களை தெய்வங்களாக கருதி வழிபடுவதால், சூரியனின் ஒளியையும், நிலவின் குளிர்ச்சியையும், தீபத்தின் பிரகாசத்தையும் ஆண்டாள் கூறுவதாய் இப்பாசுரம் அமைந்துள்ளது.

மழை

மழை பற்றிய அறிவியல் உண்மைகளை 1200 ஆண்டுகளுக்கு முன்பே ஆண்டாள் தனது பாடல்களில் பதிவு செய்துள்ளார். இது இயற்கையோடு இணைந்து ஆண்டாள் வாழ்ந்ததையும், அளப்பரிய அறிவியல் ஞானத்துடன் திகழ்ந்ததையும் காட்டுகிறது. இந்த அறிவியல் செய்தியை கண்ணனின் பழக்கத்திற்கு வழக்கத்திற்கும் உருவகப்படுத்தி பாசுரம் ஆக்கி இருப்பது ஆண்டாளின் சிறப்பு. அறிவியல் உடன் கற்பனை இழைக்கும் இந்த இடத்தில் எங்கும் இயல்பாக கோவிந்தனின் குணத்துடன் அதை பொருத்தி காட்டுவது வியப்பு. **'ஊழி முதல்வன் ஒருவன் உருவம் போல் மெய் கருத்து"** என்ற உவமையை கொடுக்கின்றார். கடலின் உள்ளே இறங்கி, நீரை முகந்துகொண்டு வரவேண்டும் அங்கு மணல்தான் மீதம் உள்ளது என்று சொல்லும் அளவுக்கு, நீரையெல்லாம் கொண்டு வரவேண்டும். மின்னி, முழங்கி, வில்லிட்டுக் கொண்டு பெரிய ஆர்ப்பாட்டத்தோடு வரவேண்டும். நிறைமாதக் கருக்கொண்ட மகளிர், மெல்ல மெல்ல மலை ஏறினாற் போல் தொடு வானத்தினின்றும் உச்சிவானத்துக்கு ஏறிவரவேண்டும். காலம் முதலான அனைத்துக்கும் காரணனான திருமாலின் உருவம் போல் மேகத்தின் உடல் கருமைநிறம் அடைய வேண்டும். எம்பெருமான் கையில் உள்ள சக்கரம்போல் மின்னுதல் வேண்டும். பெருமான் கையில் இருக்கும் வலம்புரிச்சங்கம் போல் (முழங்க வேண்டும். திருமால் கையில் உள்ள வில்லால் தள்ளப்பட்ட அம்பு மழை போல், வானத்திலிருந்து மழை பொழிய வேண்டும். என மழைக்கடவுளை விளித்துக் கூறுவதாய் இப்பாசுரம் அமைந்துள்ளது. **"ஓங்கி உலகளந்த உத்தமன் பேர்பாடி**

நாங்கள் நம்பாவைக்குச் சாற்றுநீ ராடினால்

தீங்கின்றி நாடெல்லாம் திங்கள் மும்மாரி பெய்து

ஓங்குபெரும் செந்நெல் ஊடு கயலுளக (திருப்பாவை -3)

என்ற மூன்றாம் பாடலில் பாவை நோன்பால் உண்டாகும் பயன்களையும் எடுத்துக்கூறுகிறது. நாடு முழுதும் மாதம் மும்மாரி பெய்யும், வயல்களில் நெற் பயிர் ஓங்கி வளரும். அவற்றிடையே கயல் மீன்கள் துள்ளும். பசுக்கள் நிறையப்பால் கொடுக்கும். எங்கும் நீங்காத செல்வம் நிறையும் என்பது அப்பயன்களாகும். இதனை விவேகசிந்தாமணி, வேதியர்க்காகவும் வேந்தர்க்காகவும் மாதர்களுக்காகவும் மூன்று மழைபெய்யும் என்பதை 'மாதம் மூன்று மழை எனப் பெய்யு மே' என்கிறது. பத்து நாள்களுக்கு ஒரு முறை என ஆண்டு முழுவதும் மழை, வறட்சியையும் தவிர்த்து, வெள்ளக்கேடும் இல்லாமல் அளவோடு ஊறெண்ணெய் விட்டாற்போல் மழை பொழியும் என்கின்றது.

மலர்கள்

எங்களை முன்னதாகவே வந்து எழுப்புவேன் என்று வீரம் பேசிய பெண்ணே! கொடுத்த வாக்கை மறந்ததற்காக வெட்கப்படாதவளே! உங்கள் வீட்டின் பின்வாசலிலுள்ள தோட்டத்து தடாகத்தில் செங்கழுநீர் மலர்கள் மலர்ந்து விட்டன. ஆம்பல் மலர்கள் தலை கவிழ்ந்தன. காவி உடையணிந்த துறவிகள் தங்கள் வெண்பற்கள் ஒளிவீச கோயில்களை நோக்கி, திருச்சங்கு முழக்கம் செய்வதற்காக சென்று கொண்டிருக்கின்றனர். ஆனால், பெண்ணே! சங்கும் சக்கரமும் ஏந்திய பலமான கரங்களை உடையவனும், தாமரை போன்ற விரிந்த கண்களையுடையவனுமான கண்ணனைப் பாட இன்னும் நீ எழாமல் இருக்கிறாயே! என்பதை

"உந்து மதகளிற்றன் ஓடாத தோள் வலியன்
நந்தகோ பாலன் மருமகளே! நப்பின்னாய்!
கந்தங் கமழுங் குழலீ! கடைதிறவாய்" (திருப்பாவை -18)

நான்கு புறத்திலிருந்து கோழிகள் கூவுகின்றன, குயில்களும் கூவுகின்றன. பூக்களுக்கே வாசனை தரக்கூடிய கூந்தலை உடைவளே, பூக்கள் போல கைகள் உடைய பெண்ணே, உன் கணவன் பெருமைகளை பாடி, அவன் அருள் பெற வந்துள்ளோம். பூக்கள் இறைவனுக்கே சொந்தமானவை என்று நம்பியதால், ஆண்டாள் தான் அணிந்த மாலைகளையே இறைவனுக்குச் சூடினாள். இதன் காரணமாகவே அவள் **"சூடிக்கொடுத்த சுடர்க்கொடி"** என்று அழைக்கப்படுகிறாள். பூக்கள் பெரும்பாலும் இறைவனின் அழகையும், தெய்வீகத்தையும், இயற்கையின் வளத்தையும் விவரிக்கவே பயன்படுத்தப்படுகின்றன.

பறவை மற்றும் விலங்கினங்கள்

பறவைகள் பெரும்பாலும் செடி கொடிகள், மரங்கள் நிறைந்த சோலைகள், நந்தவனங்கள் ஆகியவற்றில்தான் குடியிருக்கும். பெரியாழ்வாரும் அரங்கனுக்குப் பூமாலை சூட்டுவதற்காகப் பூக்கள் பறிக்க எப்பொழுதும் நந்தவனத்திலேயேதான் இருப்பார். இது ஆறாம் பாசுரமாகும். இப்பாசுரம் பெரியாழ்வாரை எழுப்பும் பாசுரமாகும். பொழுது விடிந்ததற்கு அடையாளமாக பறவைகள் எழுந்து ஒலிஎழுப்புவது, **"புள்ளும் சிலம்பின காண் புள்ளரையன் கோயிலில்**
வெள்ளை விளிசங்கின் பேரரவம் கேட்டிலையோ?" (திருப்பாவை -6)

என்று காட்டப்பட்டுள்ளது. .நப்பின்னை பிராட்டியே! மணம் கமழும் கூந்தலை உடையவளே! அதிகாலை வேளையில் சேவல்கள் அனைத்து திசைகளில் இருந்தும் கூவுகின்றன. அது உனக்கு கேட்கவில்லையா? இயற்கையின் மீது விருப்பம் கொண்ட நீ, கொடிகள் படர பந்தல்களை அமைந்துள்ளாய். அப்பந்தல்களில் அமர்ந்து குயில் உள்ளிட்ட பறவைகள் குரல் எழுப்புகின்றன. அதுவும் உனக்கு கேட்கவில்லையா? பொழுது விடிந்துவிட்டது. கண்ணன் புகழ் பாட, எங்களுடன் நீயும் வர வேண்டும் என்று நப்பின்னை பிராட்டியை தோழிகள் அழைக்கின்றனர்.

மழைக்காலத்தில் மலையிலுள்ள குகையில் உறங்கும் பெருமை மிக்க சிங்கம் விழிக்கிறது. அதன் கண்களில் நெருப்பு பொறி பறக்கிறது. நாற்புறமும் நடமாடி பிடரி மயிரை சிலிர்த்து, பெருமையுடன் நிமிர்ந்து கர்ஜனையுடன் வெளியே கிளம்புகிறது. அதுபோல, காயாம்பூ நிறத்தையுடைய கண்ணனே! எங்கள் கோரிக்கைகளைப் பரிசீலனை செய்து நிறைவேற்றி அருள வேண்டும் என்றும், பசியால் கதறித் திரியும் தங்கள் கன்றுகளை எண்ணிய எருமைகள் தங்கள் மடியில் சொரியும் பாலைச் சிந்தியபடியே அங்குமிங்கும் செல்கின்றன. அவை சொரிந்த பால் இல்லத்து வாசல்களை சேறாக்குகின்றது. இந்த அளவுக்கு விடாமல் பால் சொரியும் எருமைகளுக்கு சொந்தக்காரனான ஆயனின் தங்கையே! நாராயணனின் பெருமையைப் பாடுகிறோம். கறப்பார் இல்லாமையால் கதறிக்கொண்டு, கன்று பசியால் என்ன பாடுபடுகிறதோ என்று இரங்கின எருமைகளின் தாயன்பும், இப்பாசுங்கள் மூலமாக நாம் நன்கு அறிய முடிகிறது.

முடிவுரை

திராவிட மொழிகளில் தொன்மையானது தமிழ் மொழி. கால மாற்றத்தால் தம்மைப் புதுப்பிக்கும் வகையில் பல புத்திலக்கிய வடிவங்களைப் பெற்றது தமிழர்களின் வாழ்வியல் முறை சார்ந்த மதிப்புகள் எண்ணற்றவையாக இருப்பினும் பக்திப் பனுவல்களான திருப்பாவை ஆண்டாள் வழங்கிய புதுமை படைப்பு. அறிவியல் கவித்திறனுடன் இணைந்த எண்ணங்களும் பக்தி மணம் கமளும் இலக்கியமும் ஆன இந்த திருப்பாவையில் காணப்படும் தமிழர்தம் பக்தியையும் அதை அடியொற்றிய மரபுசார் வழிபாட்டையும் இயற்கையோடு இணைந்து பெருவாழ்வு வாழ்ந்த அறிவுப் பெண் கோதை ஆண்டாளின் அளப்பரிய அறிவியல் ஞானமும் மிளிர்ந்திருப்பதை திருப்பாவை பாசுரங்கள் மூலமாக நாம் நன்கு அறிய முடிகிறது.

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கட்டுரைச் சுருக்கம்

நீர் என்பது மனித வாழ்வின் அடிப்படை. நீரினைப் பொறுப்பான முறையில் பயன்படுத்துவதும், சேமிப்பதும், பாதுகாப்பதும் அவசியம். பழந்தமிழன் நீரின் முக்கியத்துவத்தை அறிந்து, நீரின் தேவையைப் பூர்த்திசெய்யவும், நீர்ப்பற்றாக்குறையைத் தவிர்க்கவும், சுற்றுச்சூழலைப் பாதுகாக்கவும் நீர் மேலாண்மையை கடைபிடித்துள்ளான். குளம், குட்டை, ஏரி, கால்வாய், தடுப்பணை, பெரிய அணைக்கட்டுகள் கட்டி உபரிநீரை தேக்கிவைத்து, வறண்ட காலத்தில் தேக்கி வைத்த நீரினை விவசாயம், தொழில், வீட்டு உபயோகம் மற்றும் இதர தேவைகளுக்குப் பயன்படுத்தி உள்ளான். நீர் மேலாண்மை என்ற சொல்லானது நீர்நிலைகளை அமைத்தல், மழை நீரை சேகரித்தல், நிலத்தடி நீரை அதிகப்படுத்துதல், தடுப்பு அணைகளை அமைத்தல், சொட்டுநீர்ப் பாசனத்தை மேம்படுத்துதல், நீர்த்தேக்கங்களை சரியான முறையில் தூர்வாரி பராமரித்தல் போன்றவற்றைக் குறிப்பிடுகிறது. நீர் அதிகம் கிடைக்கக்கூடிய மழைக்காலத்தில் மழைநீரை சேமித்து வறண்டகாலத்தில் சேமித்த நீரினைப் பயன்படுத்துதலும் நீர் மேலாண்மையே. மேலும் குளங்களில் உள்ள நீரினை நிலத்தடி நீர்க்குழாய்கள் வழியாக அறிவியல் தொழில்நுட்பத்துடன் நிலத்தடி வழியாக விவசாயத்திற்குப் பயன்படுத்தியுள்ளமை வியக்கத்தக்கது. நீரின்றி அமையாது உலகு என்பது பழந்தமிழர் உணர்ந்த பேருண்மை.

முன்னுரை

மனிதனின் அடிப்படைத்தேவைகளில் ஒன்றாக விளங்கக்கூடியது நீர். நீர் என்பது உயிரின் மூலாதாரம். பூமியில் உள்ள ஒவ்வொரு உயிரினமும் நீரின் மீது சார்ந்துள்ளது. நீரின்றி அமையாது உலகு எனத் திருவள்ளுவர் கூறியபடி நீர் இல்லாமல் வாழ்க்கை சாத்தியமில்லை. நீர் ஒரு இயற்கை வளமாக இருந்தாலும் அதனை சரியான முறையில் பராமரிக்காவிட்டால் அது பற்றாக்குறையானதாக மாறும். தமிழ் மக்கள் பண்டைய காலத்திலிருந்தே நீரின் மதிப்பை உணர்ந்து அதற்கான மேலாண்மையைத் தங்கள் வாழ்க்கையின் ஓர் அங்கமாகக் கொண்டிருந்தனர். சங்ககால மக்கள் மழைநீரை சேமித்து, சேமித்த நீரை விவசாயத்திற்குப் பயன்படுத்தினர். மேலும் விவசாயிகள் ஆற்றின் நீரைத் தங்கள் நிலங்களுக்கு வழிமாற்றி பயிர்களை வளர்த்தனர் என்பதற்கான ஆதாரங்கள் தமிழ் இலக்கியங்களில் காணப்படுகின்றன. இவை அனைத்தும் தமிழர் சமூகத்தின் சூழல் உணர்வையும் நீர் மேலாண்மை அறிவையும் வெளிப்படுத்துகின்றன. தமிழ் இலக்கியங்கள் குறிப்பிடும் நீர் மேலாண்மை குறித்த செய்திகளை இக்கட்டுரை வழி ஆராய்வோம்.

நீர் மேலாண்மை

நீர் மேலாண்மை என்ற சொல்லானது நீர்நிலைகளை அமைத்தல், மழை நீரை சேகரித்தல், நிலத்தடி நீரை அதிகப்படுத்துதல், தடுப்பு அணைகளை அமைத்தல், சொட்டுநீர்ப் பாசனத்தை மேம்படுத்துதல், நீர்த்தேக்கங்களை சரியான முறையில் தூர்வாரி பராமரித்தல்

போன்றவற்றைக் குறிப்பிடுகிறது. நீர் அதிகம் கிடைக்கக்கூடிய மழைக்காலத்தில் மழைநீரை சேமித்து வறண்டகாலத்தில் சேமித்த நீரினைப் பயன்படுத்துதலும் நீர் மேலாண்மையே. மக்களும் தங்கள் வாழ்வியல் பயன்பாடுகளில் நீரின் அவசியத்தை உணர்ந்து நீரினைப் பாதுகாத்தல் அவசியம்.

திருக்குறளில் நீர்

திருக்குறள் நீரின் முக்கியத்துவத்தையும், அதன் மேலாண்மையின் அவசியத்தையும் வலியுறுத்துகிறது. நீர் இல்லாமல் உலகம் இல்லை என்று கூறி மழை நீரின் முக்கியத்துவத்தை வள்ளுவர் வான்சிறப்பு எனும் அதிகாரத்தில்,

நீரின்றி அமையாது உலகெனின் யார்யார்க்கும்
வானின்றி அமையாது ஒழுக்கு. (குறள் - 20)

என்று மழை இல்லையேல் எந்த உயிரினமும் உலகில் வாழ முடியாது. அதுபோல மழை இல்லையேல் ஒழுக்கமும் நிலைபெறாது என மழையின் அவசியத்தைக் குறிப்பிடுகிறார். மேலும்

துப்பார்க்குத் துப்பாய துப்பாக்கித் துப்பார்க்குத்
துப்பாய தூஉம் மழை. (குறள் - 12)

எனும் குறட்பா வழி மழையானது உண்பவர்களுக்குத் தேவையான உணவை விளைவிப்பதோடு தாகம் கொண்டவர்களுக்குத் தானும் ஓர் உணவாக விளங்குகிறது என்கிறார். மழையினால் விவசாயம் பெருகும். உணவு உற்பத்தியும் அதிகரிக்கும். இத்தகைய சிறப்புமிக்க மழைநீர் அனைத்து விதமான செயல்பாட்டிற்கும் பயன்படுகிறது.

சிலப்பதிகாரத்தில் நீர் மேலாண்மை

சிலப்பதிகாரத்தில் இளங்கோவடிகள் மழையின் சிறப்பையும் மழைநீரை சேமித்து நாட்டை வளப்படுத்தும் பொறுப்பை உடையவன் நாட்டை ஆளும் மன்னனே என்பதை,

இடியுடைப்பெருமழை எய்தா ஏகப்
பிழையா வினையுள் பெருவளம் சுரப்ப
மழைபிணித்து ஆண்ட மன்னவன் (சிலப்பதிகாரம்-26-28)

என்னும் பாடல் வழி முறையாகப் பெய்யும் மழை நீரை ஏரி, குளங்களில் சேமித்து மழையில்லாக் காலங்களில் தக்க முறையில் பயன்படுத்தி நாட்டைவளம் பெறச் செய்பவனே திறமையான மன்னன் என்றும், மன்னனின் கடமை மழை நீரை சேமித்தல், நீர் நிலைகளைப் பாதுகாத்தல் ஆகியன எனவும் குறிப்பிடுகிறார்.

சங்க இலக்கியங்களில் நீர் மேலாண்மை

சங்க இலக்கியங்கள் இயற்கை மையப்பட்ட வாழ்க்கை முறையைக் காட்டுகின்றன. அக்காலத்தில் தமிழர்கள் நிலப்பரப்பை ஐந்து நிலங்களாகப் பிரித்தனர். குறிஞ்சி, முல்லை, மருதம், நெய்தல், பாலை என்பன. இதில் மருத நிலம் விவசாய நிலமாகையால் இங்கு நீர் மேலாண்மை முக்கியப் பங்கு வகித்தது. சங்க இலக்கியங்களில் ஆறுகள், குளங்கள், ஏரிகள், நீர்ப்பாசளக் கால்வாய்கள் பற்றிய குறிப்புகள் ஏராளம் காணக்கிடக்கின்றன.

மழை நீரை சேமித்து வைப்பதற்கு ஏற்ற நீர் நிலைகளை அமைப்பதும் மன்னனின் தலையாயக் கடமைகளில் ஒன்றாகவே பார்க்கப்பட்டது என்பதை குடபுலவியனார் புறநானூற்றுப் பாடலில்

நிலன் நெளி மருங்கில் நீர்நிலை பெருகத்
தட்டோர் அம்ம, இவன் தட்டோரே
தள்ளாதோர் இவண் தள்ளாதோரே. (புறநானூறு - 18: 28 - 30)

என்று பாண்டியன் நெடுஞ்செழியனுக்கு போரை விரும்பாதே! நான் சொல்வதை ஏளனம் செய்யாமல் நிலம் நெளிந்து எங்கெங்கெல்லாம் பள்ளமாக இருக்கிறதோ, அங்கெல்லாம் நீர்நிலை அமையும்படி தடுத்து கரை அமைத்த மன்னர்களே இவ்வுலகில் என்றென்றும் அழியாப் புகழைப் பெற்று வரலாற்றில் இடம் பிடிப்பர். அவ்வாறு நீரைத் தடுத்து நிறுத்தாதவர் இவ்வுலகில் பதியாதவர் ஆவார். எனவே நீர்நிலைகளைப் பெருகச்செய்து உன்னை இவ்வுலகில் நிலைநிறுத்திக்கொள்க என அறிவுறுத்துகிறார். ஒரு மன்னன் நிலைத்தப் புகழைப் பெற வேண்டுமானால் அவன் புதிய நீர்நிலைகளை உருவாக்க வேண்டும் என்பது குடபுலவியனார் கருத்து.

அறிவியல் தொழில்நுட்பத்தில் நீர் மேலாண்மை

குளம்

புதிதாக உருவாக்கப்படும் நீர்நிலை எவ்வாறு அமைய வேண்டும் என்பதைக் கபிலர்

அறையும் பொறையும் மணந்த தலைய
எண் நாள் திங்கள் அணைய கொடுங் கரைத்
தெள் நீர்ச் சிறு குளம் கீள்வது மாதோ. (புறநானூறு -118)

என்று வேள்பாரி ஆண்ட பறம்பு மலை பாறைகளும் பாறைக்குன்றுகளும் நிறைந்த நாடு. அதில் தெளிந்த நீரை உடைய குளம் ஒன்று இருந்தது. அதனைச் சிறுகுளம் என வழங்கி வந்தனர். எட்டுநாள் வளர்ந்த பிறைநிலா காணப்படுவது போல அதன் தோற்றம் இருந்தது என ஏரியின் வடிவமைப்பைக் கூறுகிறார். ஏரியானது நீளம் குறைவாகவும், அதிக நீர் கொள்ளளவு கொண்டதுமான அமைப்பான எட்டாம் பிறை வடிவத்தில் இருக்கவேண்டும் எனவும் குறிப்பிடுவது சிறப்பிற்குரியது.

அகநானூற்றுப் பாடல் ஒன்றில் நக்கண்ணையார் எனும் பெண்பாற்புலவர் தலைவியின் புலம்பல் வாயிலாக,

பெருங்குளக் காவலன் போல
அருங்கடி அன்னையும் துயில்மறந்தனளே. (அகநானூறு- 252: 13-14)

என்று நள்ளிரவில் பொழியும் பனியிலும், மழைத்திவலைகளிலும், இருள்சூழ்ந்த நடுயாமத்திலும் சிறிய கரையை உடைய பெரிய குளத்தைக் காக்க மன்னன் உறங்காமல் இருப்பது போல் என்றுரைத்து நீர்நிலைகளைப் பாதுகாக்கும் பாதுகாவலர்களை ஒத்த மன்னர்கள் பலர் சங்ககாலத்தில் இருந்தனர் என்பதைத் தெளிவுபடுத்துகிறார்.

சொர்க்கத்திற்குப் போவதற்கான எளிய வழியைச் சொல்கிறார் காரியாசான்.

குளந்தொட்டு கோடுபதித்து வழிசீத்து
உளந்தொட்டு உழுவயல் ஆக்கி வளந்தொட்டுப்
பாகுபடும் கிணற்றோடு என்று இவ்ஐம்பால் படுத்தான்
ஏகும் சுவர்க்கத்து இனிது. (சிறுபஞ்சமூலம் -66)

மக்கள் வேளாண்மைத்தொழில் செய்வதற்கு வேண்டிய தண்ணீரை அள்ளி வழங்கும் பெரிய குளங்களைத் தோண்ட வேண்டும். மரக்கிளைகளை நட்டு வளர்த்து மக்களுக்கு குளிர் நிழல் தரும் சோலைகளை உண்டாக்க வேண்டும். கற்களும் முட்களும் இன்றி மக்கள் நடப்பதற்கு, வண்டி ஓட்டுவதற்கு ஏற்றவாறு வழியமைத்துக் கொடுக்கவேண்டும். மக்கள் பசியின்றி வாழ கட்டாந்தரையாய் காய்ந்து கிடக்கும் நிலத்தை உழுநிலமாக்கி, பின்னர் விளைநிலமாக்க வேண்டும். மக்களின் குடிநீர் தேவைக்கு வேண்டிய கிணறுகளைக் கட்டிக் கொடுக்கவேண்டும். இந்த ஐந்தையும் தன்னலம் கருதாமல் உலக நலன் கருதிச் செய்பவனே இனிதாகச் சொர்க்கம் செல்வான் என்று இப்பாடல் வழியாக குளம், கிணறு வெட்டி நீர்மேலாண்மை மேற்கொள்வதை வலியுறுத்துகிறார். மேலும் குளம், கிணறு வெட்டி நீரினைப் பாதுகாப்பது அறச்செயல் என்றும் குறிப்பிடுகிறார்.

சுருங்கை

நீர்மேலாண்மைக்கான உத்திகள் பல காப்பியகாலத்தில் கையாளப்பட்டுள்ளன. அவற்றுள் சுருங்கை என்பது தற்போது நடைமுறையில் நாம் பயன்படுத்தி வரும் நிலத்தடி நீர் குழாய் என்றும், மதகு போன்ற சிறிய வழி என்றும் கூறலாம். சுருங்கை என்பதற்கு தூம்பு என்றும் பெயர் கொள்ளலாம். ஏரிகள் அல்லது குளங்களில் நீரை வெளியேற்ற உதவும் மதகில் உள்ள துளை அல்லது குழாய். இந்தத் தூம்பானது உபரி நீரை வெளியேற்றவும், நீர் வீணாவதைத் தடுக்கவும், குளத்தின் மருங்குகள் உடைவதைத் தடுக்கவும் பயன்படுத்தப்பட்டது. அக்காலத்தில் சுருங்கை பயன்படுத்தப்பட்ட செய்தியை,

பெருங்குள மருங்கில் சுருங்கைச் சிறுவழி
இரும் பெரு நீத்தம்புகுவது போல (அறவணர் தொழுத காதை :80-81)

என குளத்தில் உள்ள மதகாகிய சிறிய வழியில் மிகப்பெரிய வெள்ளம் புகுவதைப் போல என மணிமேகலை குறிப்பிடுகிறது.

கற்சிறை

கற்சிறை என்பது கல்லால் கட்டப்பட்ட நீர் அணை எனப் பொருள்படுகிறது. கல் அணை என்பது கல்லணை என்பதைக் குறிக்கிறது. உலகின் பழமையான அணைகளில் ஒன்றான கல்லணை சோழ மன்னன் கரிகாலனால் கட்டப்பட்டது. காவிரி ஆற்றின் குறுக்கே கட்டப்பட்ட கல்லணை பழமையான நீர்ப்பாசன அமைப்புகளில் ஒன்று. இந்த கல்லணை குறித்து சங்க இலக்கியங்களில் ஒன்றான மதுரைக்காஞ்சி,

வருபுனல் கற்சிறை கடுப்ப இடையறுத்து
ஒன்னார் ஓட்டிய செருப்புகல் மறவர் (மதுரைக்காஞ்சி:725-726)

என்று மிகுதியாக வருகின்ற ஆற்று நீரினை கல்லணை நின்று தாங்கினாற்போல் படைதாண்டி வருகின்ற பகைவர்களை தடுத்து, அப்படையைத் தாக்கி அழிக்கும் வீரம் உடைய மறவர்கள்

இருந்தனர் என்பதை மாங்குடி மருதனார் பாடுகிறார். காவிரி ஆற்றில் மிகுதியாக பொங்கி எழுந்து ஆர்ப்பரித்து வந்த நீரைக் கற்களைக்கொண்டு சிறைப்பிடித்து, தடுத்தி நிறுத்தினான் என்ற செய்தி புலப்படுகிறது. இக்கல்லணையே பின்னாளில் உலக நாடுகள் பல அணைகள் கட்டுவதற்கான முன்னோடியாக இருந்தது என்பதை ஆங்கிலப்பொறியாளர் சர் ஆர்தர் காட்டனின் கல்லணை குறித்த ஆராய்சசியிலிருந்து தெரிந்துகொள்ளலாம்.

கற்சிறை குறித்த செய்தி மணிமேகலையில்

'சிறையும் உண்டோ செழும்புனல் மிக்குழீஇ' என்றும்

தொல்காப்பியத்தில்,

வருவிசைப் புனலைக் கற்சிறைபோல

ஒருவன் தாங்கிய பெருமையானும்

என்றும் கற்சிறை என்னும் சொல் பயன்படுத்தப்பட்டுள்ளதை அறிந்துகொள்ளலாம்.

முடிவுரை

மனித இனம் தோன்றிய நாள்முதல் மனிதன் தான் செய்த வேளாண்மைத் தொழிலுக்கு அத்தியாவசியமான தண்ணீரை மலையின் பள்ளங்களிலும், கிணறு, குளம், குட்டை, ஏரி போன்றவற்றிலும் தேக்கி வைத்து விட்டு, மழை இல்லாத காலங்களில் தேக்கி வைத்த நீரினைப் பயன்படுத்தி வேளாண்மை செய்துள்ளான் என்பதைத் தமிழ் இலக்கியங்கள் சுட்டுகின்றன. இவ்வாறாகப் பலவகையான நீர்ப்பாதுகாப்பு நிலைகளைக் கண்டறிந்து, அதனைப் பயன்படுத்திய தமிழன் நீர் மேலாண்மை செய்யவும் கற்று வைத்திருந்தான். மட்டுமல்லாது நீரினை வெளியேற்ற நிலத்திற்கு அடியில் நிலத்தடி குழாய்களை அறிவியல் தொழில்நுட்பத்துடன் நிறுவி, அதனைக் கையாளும் நுட்பத்தினையும் துணிந்து செய்தனர். சோழன் கரிகாலன் கட்டிய கல்லணையே உலக அணைக்கட்டுகளுக்கெல்லாம் முன்னோடியாக இருந்தது என்பது உலகஅரங்கில் தமிழனுக்குக் கிடைத்த பெருமை. இக்கட்டுரை வாயிலாக தமிழர்கள் அறிவியல் முன்னேற்றம் அறியாத சங்க காலத்தில் அறிவியல் தொழில்நுட்பம் மிகுந்தவர்களாகவும், கட்டுமானத்திறன் பெற்றவர்களாகவும் திகழ்ந்தனர் என்பதை அறிந்துகொள்ளலாம்.

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நெய்தல் நில மக்களின் வாழிடங்கள்

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நெய்தல் நிலம் என்பது சங்க காலத் தமிழர்களின் ஐந்நிலக் கோட்பாட்டில் கடற்கரை மற்றும் கடற்சார் பகுதிகளைச் சுட்டுகிறது. இம்மக்களின் வாழிடங்கள் பெரும்பாலும் இயற்கைச் சூழலுக்கேற்ப எளிமையாகவும் பயன்பாட்டிற்கு ஏற்ற வகையில் அமைக்கப்பட்டிருந்தது. கடற்காற்று மற்றும் புயலும் தாக்காதவாறு வீடுகள் தாழ்வாகவும் காற்று ஓட்டத்திற்கு ஏற்ற வகையில் அமைக்கப்பட்டுள்ளன. நெய்தல் நில மக்களின் வாழிடங்கள் அவர்களின் தொழில் சுற்றுச்சூழல் நிலை மற்றும் சமூக வாழ்வியலுடன் எவ்வாறு நெருக்கமாக இணைந்துள்ளன என்பதை ஆராய்வதே இவ்வாய்வின் நோக்கமாகும்.

முன்னுரை

இலக்கியங்கள் மக்களின் வாழ்க்கையை விளக்கும் காலக் கண்ணாடியாகத் திகழ்கின்றன. சங்க காலத்தில் தோன்றிய பாட்டும், தொகையும் மக்களின் வாழ்வினை தெளிவுற எடுத்துரைக்கின்றன. மக்கள் தாம் வாழும் நிலப்பகுதிக்கேற்ப வாழ்க்கைச் சூழலை அமைத்துக் தொண்டனர். குறிஞ்சி, முல்லை, மருதம், நெய்தல் பாலை என்ற ஐவகை நிலப் பாகுபாடுகளிலும் ஒவ்வொரு வகையான வாழ்க்கை முறையைக் காண முடிகின்றது. மக்கள் பல வாழ்வியல் நெறிமுறைகளையும் மற்றும் பண்பாட்டு பின்புலங்களோடு இயைந்த பழக்க வழக்கங்களையும், நம்பிக்கைகளையும் தங்கள் வாழ்க்கை அனுபவங்களிலிருந்து உருவாக்கி அவற்றை வாழ்வியலோடு இணைத்துக் கொண்டனர். குடும்பம், இனம், தொழில், விழாக்கள், வழிபாடுகள், சடங்குகள், வாணிகம் ஆகியன பொது வாழ்வியலின் நெறிமுறைகளாக அமைந்திருந்தன. இந்த அடிப்படையில் நெய்தல் நில மக்களின் வாழிடங்களின் தனித்தன்மைகளை ஆராயும் விதமாக இக்கட்டுரை அமைகின்றது.

நெய்தல் நிலம்

கடலைச் சர்ந்த நிலம் நெய்தல் நிலம். கடற்கரையை அடுத்த பெருமணற் பகுதியில் கடல் வளத்தை நம்பி வாழும் மக்கள் கூட்டத்தினரே இவர்கள். இங்குள்ள மக்கள் கடற்கரையை ஒட்டியும், உப்பங்கழியை ஒட்டியும், தாழை வேலிகளுடனும் வாழ்ந்தனர். இந்த ஊர்களை “பாக்கம்“ என்பர். இங்குள்ள மக்கள் “பெருங்கடற் பரதவர்“ என்றும், இவர்கள் வாழ்ந்த ஊர் “சிறுகுடி“ என்றும் “கானல் சிறுகுடி“ என்றும் அழைக்கப்படுகிறது. நெய்தல் நிலம் மணற்பாங்கானதோடு உவர் தன்மையானதும் ஆகும். கடல் அலைகளால் கரையில் உள்ள பள்ளங்களில் கடல்நீர் நிரம்பி, மிகுதியான வெப்பத்தால் அந்த கடல்நீர் ஆவியாகி மேலே சென்றுவிடும். நீரிலுள்ள உப்பு நிலத்தில் படிந்துவிடுகிறது. இதன் காரணமாகவே இந்நிலம் மிகுந்த உப்புதன்மையுடன் காணப்படுகிறது.

நெய்தல் நில அமைப்பு

உப்பங்கழிகளில் முண்டகச் செடிகள் மலர்ந்து நிற்கும் குளிர்ந்த கடற்பரப்பை உடையது நெய்தல் நிலம். அம்மணற் பரப்பின்மேல் ஞாழல் மரத்தினது தாழ்ந்த பூங்கொத்துகள் நிறைந்த

கிளையின்மேல் பறவைகள் தங்கியிருக்கும் அழகிய துறையாகும். வெள்ளை நாரைகள் ஒலிச் செய்கின்ற குளிர்ந்த மணம் வீசுகின்ற கடற்கரையிலே உள்ள பூக்கள் நிறைந்த சோலையிலுள்ள புதிய மலர்களைக் கலக்கச்செய்து கிறுக்கிடும் அலைகள் உடையது நெய்தல் நிலம். மேலும், வலிமை மிக்க அலைகள் வந்துமோத முட்கள் பொருந்திய இலைகள் கொண்ட தாழையின் பூ பொன் போன்ற அன்னத்தையுடைய புன்னைப் பூக்களோடு ஒன்றுகலந்து நறுமணம் வீசும் நெய்தல் நிலம் முழக்கத்தையுடைய அலைகள் எறிந்த முத்தம், வெண்ணிற மணற்பரப்பில் விழுந்து பொன்னைப் போன்று மின்னும் குளிர்ந்த நிலம் என்பதனை,

"..... முழங்குகடல்

திரைதரு முத்தம் வெண்மணல் இமைக்கும்

தண்ணம் துறைவன் வந்தென," (ஐங்105:2-3)

குறிக்கப்பெற்ற சங்க இலக்கியப் பாடல்கள் வழி உணர முடிகிறது.

நெய்தல் நில மக்கள்

சங்க இலக்கியம் நெய்தல் நில மக்களைப் பரதவர், நுளையர், பரத்தியர், நுளைச்சியர், வலையர், உமணர் மற்றும் பாணர் எனவும். நெய்தல் நிலத் தலைவனைத் துறைவன், புலம்பன், கொண்கன் மற்றும் சேர்ப்பன் என்றும் குறிப்பிடுகிறது.

பரதவர்

பரதவர் பகற்காலத்தில் சென்று மாலை மயங்கும் நேரத்தில் திரும்புவர். அவர்கள் இரவிலே விளக்குகளை ஏற்றிக் கொண்டு கடலிலே சென்று சுறா மீன்களை வேட்டையாடி வைகறையிலே திரும்புவார்கள். மீன் வேட்டையில் வல்ல பரதவர்கள் விடியற்காலையில் கடலில் சென்று வலைகொண்டு மீன்களைப் பிடிப்பர். பின்னர், அவற்றை வாரி எடுத்து நுண்ணிய மணற்பரப்பில் காய வைப்பர். இரவு முழுக்க கடல் தொழில் செய்துவிட்டு, அடுத்த நாள் அதிகாலையில் கரை திரும்புவார்கள். இரவு பிடித்த மீன்களைக் கடற்கரையில் வளர்ந்திருக்கும் மரங்களின் அடியில் குவித்து வைத்திருப்பார்கள். அதன் பிறகு மாலை நேரங்களில் கள்ளைக் குடித்து மகிழ்வர். பழைய படகுகளைச் சரிசெய்து கொண்டு புதிய வலையால் கடலில் கொம்புடைய மீன்களைப் பிடித்துக் கொண்டு வருவர். சிறுகுடியில் வாழ்ந்து பெருங்கடலில், மீன் வேட்டையாடுவர். மேலும், கடற்பரப்பில் கொல்லும் தன்மையுடைய சுறா மீன்களைப் பிடிப்பதை விட்டு வலம்புரி முத்தினை மூழ்கி எடுப்பர். இவ்வாறாக சங்க இலக்கியத்தில் பரதவர் பற்றிய செய்திகள் இடம்பெறுகின்றன.

"வேழம் நிரைந்து வெண்கோடு விரைஇ

தாழை முடித்துத் தருப்பை வேய்ந்த

குறியிறைக் குரம்பை பறியுடை முன்றில்

கொடுங்காற் புன்னகோடு துமித்து இயற்றிய

பைங்காய் தூங்கும் பாய்மணற் பந்தர்" (பெரும் 263-267)

என்னும் பாடல்வழி அறிய முடிகிறது.

மீனவர்களின் தலைமக்கள்

சங்ககாலத்தில் மீனவர்களின் தலைவர்களாக வாழ்ந்தவர்கள் "புலம்பன், துறைவன், சேர்ப்பன், வலைஞன், கொண்கன், உமணன் மற்றும் பாணன்" என்னும் பெயர்களால் அழைக்கப்படுகின்றனர். பறவைகள் இரைதேடும் மென்மைத் தன்மையுடையவன் புலம்பன்

என்றும், சிறிய பூக்களையுடைய கொன்றை மரங்கள், மணக்கும் பெரிய கடலின் கரைப்பகுதியை உடையவன் சேர்ப்பன் என்றும், சரக்குகளை ஏற்றிச்செல்லும் தங்கும் துறையின் தலைவன் துறைவன் என்றும், அவன் நீலநிறம் கொண்ட வானத்தின் மீனைப் போலச் சிறிதாக மெல்லமெல்ல ஒளிவீசும் துறையை உடையவன் என ஐங்குறுநூறு பல இடங்களில் துறைவன் பற்றிப் பேசுகிறது.

"பாய்திரைப் பாடுஓவாப் பரப்புநீர் பனிக்கடல்
தூஅற துறந்தனன் துறைவன் என்று அவன் திறம்
நோய்தெற உழப்பார்கண் இமிழ்தியோ?-எம்போலக்
காதல் செய்து அகன்றாலை உடைமையோ?" (கலி:129)

என்னும் வரியில் துறைவன் என்னும் சொல் கடற்கரைத் தலைவனைச் சுட்டுவது தான் என்பதை நல்லந்துவனாரின் வரிகள் வெட்ட வெளிச்சமாக்கிக் காட்டுகிறது.

வாழிடங்கள்

மனிதனின் அடிப்படைத் தேவைகளுள் மூன்றாவதாக அமைவது உறைவிடமாகும். வரலாற்றுக்கு முற்பட்ட காலத்தில் ஆதிமனிதன் மலைகளிலும், காடுகளிலும் அலைந்து திரிந்தான் ஆற்றங்கரைப் பகுதியில் நாகரிகம் தோன்ற ஆரம்பித்த காலக்கட்டத்தில் தான் பண்டைய மனிதன் நிலையாக ஓரிடத்தில் தங்கிவாழ முற்பட்டான். நாடோடி வாழ்க்கை நிலையிலிருந்து நிலையாக ஓரிடத்தில் தங்கி வாழ வேண்டும் என்ற எண்ணம் தோன்றிய போது தான் வாழிடம் அமைக்கும் எண்ணம் மனிதனுக்குத் தோன்றியிருக்க வேண்டும் எனலாம். கடலும் கடல்சார்ந்த நிலப்பகுதியில் பரதவ மக்கள் வாழ்ந்த வாழிடங்கள் சேரி, சிறுகுடி, பாக்கம், பட்டினம் சீறூர் எனப் பலவாறு அழைக்கப்பட்டன. பரதவ மக்கள் கடலை அடுத்த வெண்மணல் பரப்பில் சிறுசிறு குடிசைகளை அமைத்துக் கொண்டு வாழ்ந்தனர். சிறு சிறு குடில்கள் கும்பல் கும்பலாக அமைந்து குடியிருந்தனர்.

சீறூர்

நெய்தல் நிலத்தில் சிறுகுடிகளை அடுத்து அமைந்திருந்த சீறூர் பகுதியிலும் பரதவர்களது குடியிருப்புக்ள இருந்தன. சீறூர்கள் கடற்கரை மணல்மேட்டில் அமைந்தவை பனை மரங்களால் சூழப்பட்டவை. புலால் நாற்றம் வீசுபவை நீரினை வேலியாகச் சூழ்ந்து ஆரவாரம் மிக்கதாக இருப்பதை,

"பணைகொள் வெம்முலை பாடுபெற்று உவக்கும்
பெண்ணை வேலி உழைகண் சீறூர்"

என்னும் நற்றிணைப் பாடல் அடிகளால் அறியலாம்.

மூதூர்

பரதவ மக்கள் நெய்தல் நிலத்தில் அமைந்திருந்த குடியிருப்புகள் புலம்பெயராமல் தலைமுறை தலைமுறையாக வாழ்ந்து வருவதால் அக்குடியிருப்புகள் மூதூர் என்று அழைக்கப்படுகிறது. மேலும் இக்குடியிருப்பு சேரி என்றும் சொல்லப்படுகிறது. ஒரே இனத்து மக்கள் சேர்ந்து வாழ்வதால் அது சேரி என்ற அழைக்கப்பட்டு வருகிறது..

பாக்கம்

நெய்தல் நிலத்தில் அமைந்திருந்த ஊர்கள் பாக்கம் என்றும், பட்டினம் என்றும் அழைக்கப்பட்டன. சங்க இலக்கியங்களிலும் பாக்கம் என்ற பெயரில் பல இடங்களில் வழங்கப்பட்டு வந்தது. இப்பாக்கத்திலும் பரதவரது குடியிருப்பகளே இருந்தன.
தழைத்த முற்றிய பனையோலைகளையும், முள்களையும் சேர்த்துக் கட்டப்பட்ட வேலிக்குள் உயர்ந்த பனை மரங்கள் சூழ்ந்த வெண்மணல் மேட்டிலுள்ள ஊர்ப் பரதவர் பாக்கம் என்பதை,

"ஒலிகா வோலை முள்மிடை வேலி
பெண்ணை இவரும் ஆங்கண்
வெண்மணல் படப்பை எம் அழுங்கல் ஊரே"

என்று நற்றிணைப் பாடல் அடிகள் எடுத்தியம்புகின்றன. இவற்றால் பரதவர் பாக்கம் வெண்மணல் மேட்டில் பனைமரச் சூடிலில் பெயரால் இன்றும் பரதவர் குடியிருப்புகள் வழங்கி வருகின்றன.

பட்டினம்

பட்டினம் என்பது துறைமுகத்தோடு கூடிய நகரமாகும். கடல் வாணிகச் செழிப்பால் நெய்தல் நிலத்திலிருந்த பட்டினங்கள் பன்னாட்டு நகரங்களது விளங்கின உள்நாட்டு வாணிகர்களும், வெளிநாட்டு வாணிகர்களுமு இப்பகுதியில் வாழ்ந்தனர். கடல் வாணிகத்தின் செல்வ செழிப்பால் பட்டினங்களில் வானளாவிய வீடுகள் கட்டப்பட்டிருந்தன ஆகவே பட்டினம் என்பது ஏழைப் பரதவர்கள் வாழும் இடமன்று, வானனளா மாட மாளிகைகள் நிறைந்தது. அகன்ற அழகிய தெருக்களை உடையது. வெளிநாடுகளிலிருந்தும், உள்நாடுகளிருமுந்தும் கொண்டு வரப்பட்ட பண்டங்கள் விற்கும் நாளங்காடியும், அல்லங்காடியும் கொண்டது. பண்டகசாலையும் சங்க சாவடியும், மரக்கலன்கள் வந்து போகும் துறைமுகத்தையும உடையது என்பதை,

"மணிநீர் வைப்பு மதிலொடு பெயரிய
பணிநீர்ப் படுவின் பட்டினம்"

என்று சிறுபாணாற்றுப்படை பாடல் அடிகள் விளக்குகின்றன. இதனால் துறைமுகங்கள் உள்ள கடற்கரை நகரங்களே பட்டினங்களாகும் என்பதை அறிய முடிகிறது. தற்காலத்திலும் சென்னைப்பட்டினம், காவல்பட்டினம், குலசேகரப்பட்டினம், நாகப்பட்டினம், விசாகப்பட்டினம் போன்றவை துறைமுகத்தோடு கூடிய நகரங்களாக விளங்குவது குறிப்பிடத்தக்கதாகும்.

பரதவர் குடில்கள்

பரதவர் இல்லங்கள் கடற்கரையை ஒட்டியே அமைக்கப்பட்டு இருந்தன. பரதவர் குடிலின் அமைப்பினையும், தோற்றத்தையும்

"வேழ நிரைந்து வெண்கோடு விரைஇத்
தாழை முடித்துத தருப்பை வேய்ந்த
குறியிறைக் குரம்பைப் பறியுடை முன்றில்
கொடுங்காற் புன்னை கோடுதுமித்து இயற்றிய
பைங்காய் தூங்கும் பாய்மணற் பந்தர்"

என்று பெரும்பாணாற்றுப்படை சிறப்பித்துக் கூறுகிறது. பரதவர்கள் இல்லம் மூங்கில் கோல்களை வரிசையாகச் சார்த்தி வஞ்சி, காஞ்சி ஆகிய மரங்களின் வெண்மையான கொம்புகளை இடையிடையே கலந்து தாழை நாரினால் கட்டித் தருப்பைப் புல்லால் கூரையை வேய்ந்திருப்பர். குறுகிய கூரையை உடைய வீடுகளின் முன் தூண்டில் கம்புகள் வைக்கப்பட்டிருக்கும். இதைப் பார்ப்பதற்குக் கேடயமும், வாளும் வைத்த நடுகல்லின் தோற்றம் போலக் காணப்படும். குடிசைகளின் முற்றத்தில் மீன்பிடிக்கும் வலைகள் இருக்கும். அங்கு இளையவரும் முதியவரும் நிறைந்திருப்பர். வலைஞர் இல்லம் கடற்கரையில் இருப்பதால் குடிக்கும நீருக்காகக் குளம் தோண்டுவர் கடற்கரை நிலத்துக் கிடைக்கும், மூங்கில் கருப்பந்தட்டை, வெள்ளிமரக் கொம்பு, நாணற்புல், தாழை ஆகியவற்றைக் கொண்டு பரதவர்கள் குரம்பைகளை அமைந்தனர். புன்னை மரக் கொம்புகளால் குரம்பையின் முன்னால், பந்தர் அமைக்கப்பட்டுப் பந்தரின் மேல் சுரை, பாகல் கொடிகள் படர்ந்து, காய்கள் தொங்கிக் கொண்டிருக்கும்.

முடிவுரை

பரதவர்கள் மேற்கொண்ட மீன்பிடித்தொழிலால் அவர்களது இருப்பிடம் தனித்துவம் கொண்டு காணப்படுவதை அறிய முடிகின்றது. வலை உணங்கும் பரந்த முற்றம், பரதவர் இருப்பிடத்தின் அளவைக் காட்டுகின்றது. கடலோரப் பகுதிகளில் வீசும் பெருங்காற்றிற்கும், பேரலைகளுக்கும் ஈடுதரக்கூடிய அளவில் பரதவரது இல்லங்கள் எளிமையாக அமைக்கப்பட்டிருந்தன.

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கட்டுரைச் சுருக்கம்

ஒரு நாடு முன்னேற வேண்டுமென்றால் கிராமங்கள் முன்னேற வேண்டும். நாட்டின் பொருளாதார வளர்ச்சிக்கு விவசாயம் முக்கியக் காரணமாகும். நம் நாட்டில் பெரும்பாலான கிராமங்கள் உழவுத் தொழிலை வாழ்க்கையின் ஆதாரமாகக் கொண்டுள்ளன. இதனை வலுவூட்டும் வகையில், 'உழவன் சேற்றில் கால் வைத்தால் தான் நாம் சோற்றில் சுவைக்க முடியும்' என்ற பழமொழியும் வழங்கப்படுகிறது. உழவன் நிலத்தைச் சீர்செய்து செம்மைப்படுத்தி உழுது பயிர்செய்தால் தான் மனிதனின் அடிப்படைத் தேவையான உணவு கிடைக்கும். அப்படிப்பட்ட சிறப்புமிக்க வேளாண்மை குறித்தசெய்திகள் சங்க இலக்கியங்களில் காணமுடிகின்றன. எனவே தமிழ் இலக்கியங்களில் வேளாண்மை பற்றிய கருத்துக்களை ஆய்வதே இக்கட்டுரையின் நோக்கமாகும்.

முன்னுரை

ஒருநாட்டின் முன்னேற்றத்திற்கு அடிப்படை ஆதாரமாகத் திகழ்வது வேளாண்மை. வேளாண்மை செழிப்பாக இருந்தால் தான் அந்நாட்டின் பொருளாதார வளர்ச்சி மேம்படும். இவ்வுலகில் மனிதன் வளம் பெறவேண்டி செய்யும் அனைத்துத் தொழில்களும் தேடல்களும் விவசாயத்தை மையமாகக் கொண்டுள்ளன. இதனை,

"சுழன்றும் ஏர்ப்பின்னது உலகம் அதனால்
உழுந்தும் உழவே தலை" (குறள்- 1031)

என்னும் குறள்வழி சுட்டிப் பாட்டியுள்ளார் வள்ளுவர். தமிழில் வேளாண்மையைக் குறிக்கப் பலசொற்கள் உள்ளன. 'உழவு'என்னும் சொல் உழைத்து வேலை செய்வதைக் குறிக்கிறது. பண்டைத் தமிழர் மேற்கொண்ட தொழில்களில் வேளாண்மை சிறப்பானதாகக் கருதப்பட்டது. பாண்டிய நாட்டுமக்கள் வேளாண்மையிலும் வணிகத்திலும் சிறப்புப் பெற்றிருந்ததை மதுரைக்காஞ்சி குறிப்பிடுகிறது. பாண்டிய மன்னன் தான் ஒரு கையில் கலப்பையையும் மற்றொரு கையில் சமன்செய்து சீர்தூக்கும் கோலையும் ஏந்தி மக்களைக் காத்தான் என்று சிலப்பதிகாரம் குறிப்பிடுகிறது. திருவள்ளுவர் வேளாண்மையின் பெருமைகளையும் உழவர்கள் ஆற்றும் பணிகளையும், வேளாண்மை முறைகளையும் விவரிக்க திருக்குறளில் ஒரு அதிகாரத்தை ஒதுக்கியிருப்பது வேளாண்மையின் பெருமைகளை உலகறியச் செய்கிறது.

வேளாண்மை விளக்கம்

தமிழ் இலக்கியங்கள் வேளாளர், உழவர் ஆகியோர் வாழ்வு நெறிபற்றிப் பல பாடல்களில் குறிப்பிடுகின்றன. 'உழவர் உலகத்தார்க்கு ஆணிவேர்' என்பர். உழவர்கள் தம் கலப்பையை நம்பி இருந்தனர். அறுவடை செய்யப்பட்ட நெல் மலைபோல் குவித்துவைக்கப்பட்டிருந்தன. என்று நற்றிணைக் குறிப்பிடுகிறது.

"மலை கண்டன்ன நிலைபுணர் நிவப்பின்
பெரு நெற் பல்கூட்டு எருடை உழவ" (நற்- 60)

வளமான மண்ணுக்கு அளவான நீர் இன்றியமையாததாகும். "ஆடிப்பட்டம் தேடிவிதை" என்ற பழமொழிக்கு ஏற்ப உழவர்கள் பெருமழை பெய்த விடியற்காலத்தில் தம் நிலத்தைக் கலப்பைகளால் மண் கீழ் மேலாக மாறும்படி உழுதனர். மீண்டும் மழை பொழியவே மழையால்

நிலம் எங்கும் நன்கு ஈரம் படிந்ததனால் மறுபடியும் உழுதனர். உழுதசாலில் அவர்கள் விதைகள் ஒன்றுக்குப் பலவாக முளைத்து நாற்றுக்களாக நின்றன. இதனை அகநானூற்றில்,

"பேர்உறை தலைஇய பொரும்புலவர் வைகறை
ஏர்இடம் படுத்த இருமறுப் பூழிப்
புறம்மாறு பெற்றபூவல் ஈரத்து
ஊன் இழித் தன்னசெஞ்சுவில் நெடுஞ்சால்
வித்திய மருங்கின் விதை பலநாறி" **(அ.நாநூ: 194)**

இப்பாடலின் முலம் பண்டைத் தமிழ்மக்கள் வேளாண் செய்தமுறையைப் பற்றி நாம் அறிந்துகொள்ள முடிகின்றது.

விளைபொருட்கள்

பண்டைத் தமிழர்கள் உழவுத் தொழிலுடன் வேறு சில பயிர்களையும் பயிரிட்டுள்ளனர். தற்காலத்தில் 'மகசூல்' என்று போற்றப்படுவதை முற்காலத்தில் 'பயிர்' என்ற சொல்லால் குறிப்பிட்டுள்ளனர்.நெல்,கரும்பு,தினை,வரகு,பாகற்காய்,பீர்கங்காய்,சேப்பங்கிழங்கு,உளுந்து என்று ஒவ்வோரு நிலங்களிலும் அதன் தன்மைக்கும் மண் வளத்திற்கும் ஏற்பவும் பயிர்கள் பயிரிடப்பட்டன.

நெல்

மருத நிலத்தில் 'வெண்ணெல்' பயிர் செய்துள்ளனர். ஆற்றுநீர் குளத்து நீர் பாய்ச்சி வேளாண்மை செய்துள்ளனர். வயல்களில் நெற்கதிர்களை அறுத்து நெற்குவியலாக வைத்ததை,**"அரிகால் போழ்ந்த தெரிபகட்டு உழவர்" (அ.நாநூ: 41)** என்னும் அடி குறிப்படுகின்றது. பின் கடா விட்டுக் கதிர்களைப் பிணையல் அடிக்கச் செய்வார்கள். காற்றில் நெல்லைத் தூற்றி நெல்லை வீட்டுக்கு எடுத்துச் செல்வர். இதனை அகநானூற்றில்,

"தாழ்சினை மருதம் தகைபெறக் கவனியே
நீர்சூழ் வியன்களம் பொலியபோர்வுஅழித்து
கள்ஆர் களமர்பகடுதலைமாற்றி
கடுங்காற்று எறிய,போகிய துரும்புடன்" (அ.நாநூ: 366)

இவ்வாறு நெல் பயிரிடுதல் முதல் அறுவடை செய்யும் நிகழ்வுகள் வரை அகநானூறு குறிப்பிடுகின்றது.

கரும்பு

நெற் பயிறுக்கு எவ்வாறு முக்கியத்துவம் கொடுத்து பயிர் செய்துள்ளார்களோ அவ்வாறு கரும்பையும் மருதநிலத்து மக்கள் பயிர்செய்துள்ளனர். இதனை,

"களவன் மண்அளைச் செறிய, அகல்வயல்
கிளைவிரி கரும்பின் கணைக்கால் வான்பூ" (அ.நாநூ: 235)

என்னும் அகநானூற்றுப் பாடலின் மூலம் அறிந்துகொள்ள முடிகின்றது. "மேலும் பண்டையமக்கள் தினை அரிசிச் சோற்றில் கரும்புச்சாறும் பாலும் கலந்த உண்டனர். இதனை அகநானூற்றில்,

"இருங்கதிர் அலமரும் கழனிக் கரும்பின்"
விளைகழை பிழிந்த அம்தீம் சேற்றொடு
பால்பெய் செந்நெற் பாசவல் பகுக்கும்" (அ.நாநூ- 237)

என்றபாடல் பதிவுசெய்துள்ளது. கரும்பை உணவாகப் பயன்படுத்தியதை இதன் வழி அறியமுடிகிறது.

தினை

குறஞ்சி நிலமக்கள் தினை பயிர்களையே அதிகமாகப் பயிரிட்டார்கள். தினை புனத்தைக் காக்கும் மகளிர் கிளியை ஓட்டும் ஓசையைக் கேட்டக் கிளிக்கூட்டம் தம் இனம் அழைக்கிறது என்று கருதி தினை புனத்திற்கு கிளிகள் வந்துவிடுகின்றன. இதனை,

"ஏனல்அம் காவலர் ஆனாது ஆர்த்தொறும்
கிளிவிளி பயிற்றும் வெளில்ஆடு பெருங்சினை" (அ.நாநூ 12)

என்றபாடல் மூலம் பழங்காலத்தில் பெண்களும் தினைபுனம் காத்தனர் என்பதை அறிந்துகொள்ள முடிகின்றது. மேலும் வேடுவன் சுட்டெரித்த தோட்டத்தில் கரிந்து ஈரத்தில் வளர்ந்த பசுமையான தினையின் நீண்ட கதிர்களை மகளிர் காத்தனர் என்ற செய்தியை

"தொடுதோல் கானவன் சூடுறு வியன்புனம்
கரிபுறம் கழீஇய பொரும்பாட்டு ஈரத்து
தோடுவளர் வைந்தினை நீடுகுரல் காக்கும்" (அ.நாநூ 368)

இப்பாடல் வழியாக குறிஞ்சி நிலத்து வேடுவர்கள் தமக்கு உணவாக தினை கதிர்கள் பயன்படுத்தினர் என்பதை அறியமுடிகிறது.

வரகு

முற்காலத்தில் மக்கள் வரகு அரிசியையும் தனக்கு உணவாகப் பயன்படுத்தினர் என்பதையும், அவ்வரகினை மருதநிலத்தில் எவ்வாறு பயிர்செய்தனர் என்பதையும் அகநானூற்றில் காணலாம். மேட்டுநிலத்தில் வரகினைப் பயிரிட்டச் செய்தியை அகநானூறு 359 வது பாடலும், 476 மற்றும் 477 –வது பாடலும் தெளிவு படுத்துகின்றது. இதன் மூலம் வரகினை மேட்டு நிலத்தில் பயிர்செய்து பின் அதனை அறுவடை செய்தபிறகு எஞ்சிய பசுமையான அடித்தாள்களைக் கொண்ட பழம் கொல்லையாகிய மேட்டு நிலத்தைச் சுற்றியுள்ள காட்டைத் தீயிட்டுச் சுட்டதால் எழுகின்ற புகை அருவியின் நுண்ணிய நீர்த் துணிகளுடன் கலந்தது என்ற செய்தியை இப்பாடல்கள் வழி அறியலாம். மேலும் பண்டையமக்கள் வரகு அரிசியைப் புளிச்சோறாக சமைத்து அதில் பசும் நெய் ஊற்றி உண்பர் என்ற செய்தியை,

புனவரகின் அவைப்புமாண் அரிசியொடு
கார்வாய்த்து ஒழிந்த ஈர்வாய்ப் புற்றத்து
ஈயல்பெய்து அட்ட இன்புளி வெஞ்சோறு
சேதான் வெண்ணெய் வெம்புறத்து வருக" (அ.நாநூ - 394)

என்றவரிகள் மூலம் மக்கள் வரகு அரிசைசமைத்து உண்டச் செய்தியை அறியமுடிகிறது.

சேப்பங்கிழங்கு

குறிஞ்சி நிலத்தில் அகன்ற சுனையில் தண்ணீர்ப் பருகி நீலநிற இலையைக் கொண்ட சேப்பங்கிழங்கை பன்றி தின்றது. இதனை,

வெதிர்வேர் அன்ன பருஉமயிர்ப் பன்றி
பறைக்கண் அன்ன நிறைச்சுனை பருகி
நீலத் தன்ன அகல்இலைச் சேம்பின்
பிண்டம் அன்ன கொழுங்கிழங்கு மாந்தி (அ.நாநூ -178)

எனும் அகநானூற்றுப் பாடலில் பழந்தமிழர் கிழங்கு வேளாண்மை செய்ததை அறிந்துகொள்ள முடிகின்றது.

களைஎடுத்தல்

நிலத்தில் பயிருடன் சேர்ந்துவளரும் களைகளைக் களைந்தால் தான் பயிற்கள் நன்கு செழித்து வளரும் என்ற அறிவியல் நுட்பத்தை அறிந்திருந்தனர். களையெடுப்பிற்குப் பிறகு விதைத்த விதையானது ஒன்றுக்குப் பலவாக நாற்றாகி நின்றன.

முடிவுரை

நம் நாடு வேளாண்மையை அடிப்படை ஆதாரமாகக் கொண்டது .காலமாற்றத்திற்கு ஏற்ப தொழில்நுட்பம் பல்வேறு பரிணாமங்களில் வளர்ச்சி அடைந்தாலும் நம் பழக்கவழக்கங்களும், பண்பாடும் நம் நாட்டின் அடையாளங்கள். பண்டைத்தமிழர் போற்றிய வேளாண்மையை நாமும்

போற்றுவோம். நம் இளந்தலைமுறையினருக்கு அதன் முக்கியத்துவத்தையும் இன்றிமையாமையும் பறைசாற்றுவோம்.

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A Study on the Influence of the Extension of Support on Life Satisfaction Among Elderly People

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ABSTRACT

Life satisfaction serves as a prominent pointer of quality of life. It reflects an individual's perception of various facets of their existence. The degree of satisfaction practiced by the elderly influences not only their psychological reform but also their physical, emotional, and social well-being. Globalization has led to changes in the economic framework, a decline in societal values, a weakening of social norms and the transformation of extended families into nuclear families. Consequently, the traditional sense of duty and obligation that the younger generation feels towards their elders has diminished over time. The older generation finds itself in a challenging position, facing the erosion of traditional values on one side and the lack of a sufficient social security system on the other (Gormal 2003). Therefore, this study aims to survey the impact of support extension on life satisfaction among the elderly. A total of 209 respondents were chosen for the study through a simple random sampling method. The nature of the study is descriptive.

Keywords: *Life Satisfaction, Extension of support, Elderly People.*

Introduction

Life satisfaction among the elderly, in a broad sense, pertains to the individual's ability to adjust and cope with circumstances. This differs from one person to another. Elderly individuals who are physically fit and capable of performing daily activities autonomously tend to experience greater life satisfaction compared to those who are reliant on others. Population-based research involving diverse samples of elder adults has revealed that multiple factors contribute to life satisfaction. For example, a study involving 105 individuals aged 80 and above found that poor health had a low correlation with life satisfaction. In compare, personality traits were found to have a stronger association with life satisfaction (Hilleras et al. 2023).

Aging can be branded as a gradual decline in both physical and psychological functions, leading to a simultaneous reduction in the body's ability to maintain homeostatic balance and the individual's adaptability to various stressors, which consequently heightens the risk of illness and mortality (Dey, 2003). Family care and support manifest in various forms, such as functional, financial, or emotional assistance. While emotional or financial support can be

extended across distances, the provision of functional care on a regular basis is heavily reliant on geographic proximity. Geographic distance poses a significant barrier to the ability to care for family members consistently. In a survey conducted in Sweden, 38 percent of respondents who reported having a parent in need of support specified that they were unable to assist due to geographic distance (Malmberg and Sundström 2006). This discussion focuses on the effect of support extension on life satisfaction among the elderly.

Review of Literature

Gana K, (2023) reported findings from both unconditional and conditional models, which included time-invariant factors such as age, gender, and education, as well as time-varying covariates like self-perceived health. These findings indicated a linear increase in life satisfaction (LS) over an 8-year period. As anticipated, the results revealed significant random variation in both the intercept and slope, suggesting that participants begin at different levels and experience changes at varying rates.

Objectives:

1. To evaluate the demographic profile of the respondents
2. To assess the charming of life satisfaction of the respondents
3. To assess the influence of extension of support on life satisfaction of the aging

Methodology

The nature of the study is descriptive. The Coimbatore City Corporation comprises 100 wards, from which ward number 72 was chosen using a simple random sampling method. The voters' list was obtained from the area councilor to compile a population list for identifying elderly individuals aged 65 and above. This ward includes 40 streets. The overall population totals 10,960. Among these, there are 715 elderly individuals aged 65 and above, from which 209 respondents were selected. The data collection tools were developed based on a review of existing literature. The gathered data were evaluated utilizing SPSS.

Analysis and Interpretation

Differences between the mean scores of the life satisfaction of the aging in terms of their age group, education, income and availability of children

Sl. No	Variables	Category	No	Mean	SD
1.	Age	65–70 71–75	100 63	21.9135 20.1017	4.0677 4.2414

		76-80	26	20.0000	2.9530
		81 & above	20	21.5500	4.4423
2.	Education	Graduates /Post Graduates	10	21.8750	4.1384
		High School	84	21.7093	2.1671
		Primary	56	21.6071	3.2512
		Illiterate	57	19.7288	4.6824
3.	Family Income	Without Income	90	21.0795	4.5213
		With Income	121	21.1653	3.7911
4.	Availability of Children	Only Sons	32	21.4375	5.0669
		Only Daughters	27	21.5185	2.8739
		Both Sons and Daughters	137	21.5036	3.5233
		No Children	13	15.6154	5.6501

- The average scores offered in the table indicate that the young-old, specifically individuals aged 60 to 70 years, experience better life satisfaction compared to other age groups, while respondents over 85 years exhibit relatively lower levels of satisfaction.
- The average scores auxiliary reveal that individuals with an education level up to high school report higher life satisfaction than their counterparts.
- Within the elderly population, income does not appear to influence life satisfaction among older adults.
- Elderly individuals with children tend to report higher life satisfaction than those without children.

Regression of Life Satisfaction on Socio-economic variables

Independent Variables	Beta	Sig
Age	-.017	.809
Education	-.192	.008
Family Size	.076	.280
Family Income	.198	.009
Number of available adult children	.071	.295
R^2	.125	
N	209	

As observed from the beta values of the above table education has significant negative effect while family salary has significant positive effect on life satisfaction. All the five

autonomous variables together explain 12.5 percent of variation in life satisfaction of the elderly.

Level of Life Satisfaction of the Respondents

Life Satisfaction	Percentage	Mean	SD
Low	6.2	2.11	.477
Moderate	76.1		
High	17.7		

The above table shows that majority of the respondents have life satisfaction at moderate level.

Regression of Life Satisfaction on Extension of Support

Beta	t	Sig	R^2	F	Sig
.400	6.274	.000	.160	39.361	.000

The Beta Co-efficient in the above table shows that extension of maintenance has significant positive effect on life satisfaction. The R square value shows that extension of support explains 16.0 percent of variation in life satisfaction.

Conclusion

Life satisfaction refers to a comprehensive evaluation of an individual's feelings and attitudes regarding their life at a specific moment, which can differ from negative to positive. It is one of the three primary indicators of well-being, alongside positive affect and negative affect (Diener, 1984). The research indicates that education exerts a significant negative impact, whereas family income and the provision of support have a considerable positive influence on life satisfaction. The majority of respondents report a moderate level of life satisfaction.

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