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Federated Learning for Privacy-Preserving Large Language Models: A Comprehensive Survey

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Abstract-The rapid advancement of Large Language Models (LLMs) has revolutionized natural language processing, yet their development requires massive centralized datasets, raising critical privacy concerns. Federated Learning (FL) offers a promising paradigm for training LLMs while preserving data privacy by enabling collaborative learning without direct data sharing. This comprehensive survey examines the integration of federated learning with large language models, covering pre-training, fine-tuning methodologies, deployment strategies, communication optimization, and security mechanisms. We systematically review state-of-the-art approaches including federated full-parameter tuning, parameter-efficient fine-tuning (PEFT), prompt learning, and homomorphic encryption-based methods. Key challenges such as communication costs, data heterogeneity, system scalability, and privacy preservation are analyzed alongside emerging solutions. We present detailed analyses of frameworks like Federated Scope-LLM and techniques achieving communication costs under 18 KB for billion-parameter models. This survey synthesizes current progress, identifies critical research gaps, and outlines future directions for privacy-preserving LLM development across healthcare, finance, recommendation systems, and edge computing applications.

Index Terms—Federated Learning, Large Language Models, Privacy-Preserving AI, Parameter-Efficient Fine-Tuning, Communication Efficiency, Homomorphic Encryption, Edge Learning, Prompt Tuning

I. INTRODUCTION

A. MOTIVATION AND BACKGROUND

Large Language Models (LLMs) such as GPT-4, PaLM, and LLaMA have demonstrated unprecedented capabilities in natural language understanding, generation, reasoning, and multi-task learning [1]. These models, often containing billions to hundreds of billions of parameters, are typically trained on massive centralized datasets aggregated from diverse sources. However, this centralized paradigm poses fundamental challenges:

Privacy Concerns:
Collecting sensitive textual data (medical records, financial documents, personal communications) into centralized repositories creates privacy risks and conflicts with regulations such as GDPR, HIPAA, and CCPA [2].

Data Sovereignty:
Organizations and individuals are increasingly reluctant to share proprietary or personal data due to competitive, legal, or ethical concerns [3].

Computational Constraints:
The enormous computational resources required for training LLMs (often requiring thousands of GPUs) are concentrated in a few large technology companies, limiting accessibility [4].

Data Silos:
Valuable data is distributed across multiple institutions, devices, and jurisdictions, making comprehensive data collection impractical or impossible [5].
Federated Learning (FL) has emerged as a transformative approach to address these challenges by enabling collaborative model training while keeping data decentralized [6]. Originally proposed for mobile keyboard prediction, FL has evolved to support increasingly complex models and applications. The integration of FL with LLMs represents a critical frontier that combines the power of large-scale language understanding with robust privacy guarantees.

B. FEDERATED LEARNING: CORE PRINCIPLES

Federated Learning follows a distributed training paradigm characterized by [7]:

1. Decentralized Data Storage: Training data remains on local devices or institutional servers
2. Local Computation: Model training occurs locally using private data
3. Selective Sharing: Only model updates (gradients or parameters) are transmitted
4. Central Aggregation: A central server aggregates updates to improve the global model
5. Iterative Refinement: The process repeats until convergence

The canonical Federated Averaging (FedAvg) algorithm [8] forms the foundation:
Initialize global model w_0
for each round t = 1, 2, …, T do:
Server broadcasts w_t to selected clients
For each client k in parallel do:
$w_{t+1}^k \leftarrow$ Local Update (k, w_t) end for
$w_{t+1} \leftarrow$ Aggregate($\{w_{t+1}^k\}$) end for

C. UNIQUE CHALLENGES OF FEDERATED LLMS

While FL has been successfully applied to smaller models, integrating it with LLMs introduces unprecedented challenges:

(1) Communication Bottleneck:
Transmitting billion-parameter models over bandwidth-limited networks is prohibitively expensive. A model with 10B parameters requires ~40 GB transmission per round at 32-bit precision [9].

(2) Computational Heterogeneity:
Edge devices vary dramatically in computational capability, from high-performance servers to resource-constrained mobile devices [10].

(3) Memory Constraints:
Loading and training multi-billion parameter models exceed the memory capacity of most edge devices [11].

(4) Data Heterogeneity:
Non-IID (non-independent and identically distributed) data across clients, with varying domains, languages, and quality, degrades model performance [12].

(5) Privacy Vulnerabilities:
Despite not sharing raw data, gradient-based attacks can reconstruct training samples, particularly problematic for text data [13].

(6) Convergence Complexity:
The massive parameter space and non-convex optimization landscape make convergence analysis challenging [14].

D. CONTRIBUTIONS AND ORGANIZATION

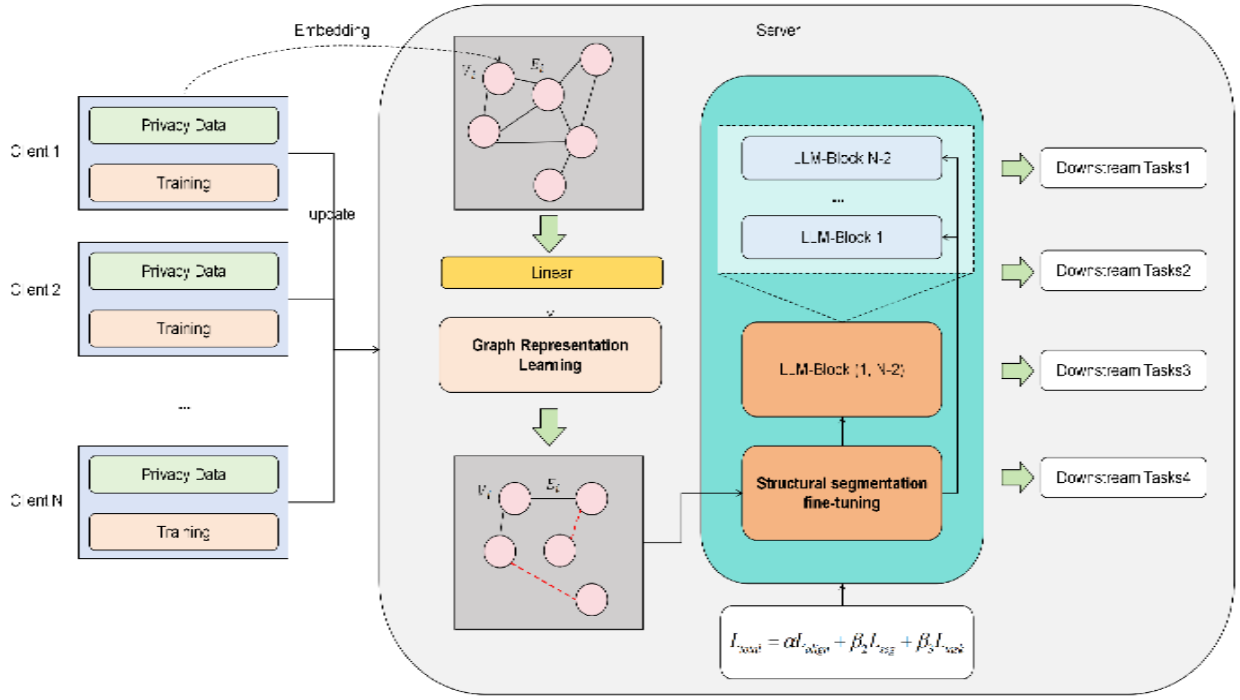
This survey makes the following contributions:

1. Comprehensive Coverage: We systematically review federated LLM research spanning pre-training, fine-tuning, deployment, and security
2. Technical Depth: Detailed analysis of communication-efficient methods, PEFT techniques, and privacy-preserving mechanisms
3. Practical Frameworks: Examination of open-source tools and real-world implementations
4. Future Roadmap: Identification of critical research gaps and promising directions

The remainder of this paper is organized as follows:

- Section II: Federated LLM architectures and training paradigms
- Section III: Communication-efficient fine-tuning methods
- Section IV: Parameter-efficient techniques (LoRA, adapters, prompt tuning)
- Section V: Security and privacy mechanisms
- Section VI: Heterogeneity management strategies
- Section VII: Frameworks and implementation tools
- Section VIII: Applications across domains
- Section IX: Future research directions
- Section X: Conclusions

II. FEDERATED LLM ARCHITECTURES AND PARADIGMS



A. Federated LLM Training Taxonomy

Cheng et al. [1] provide an exhaustive taxonomy of federated LLM approaches, categorizing them along three dimensions:

(1) Training Stage:
- Pre-training: Training foundation models from scratch on distributed corpora
- Fine-tuning: Adapting pre-trained models to specific tasks or domains
- Continual Learning: Incrementally updating models with new data

(2) Model Distribution:
- Full Model FL: Entire model resides on each client
- Split Learning: Model is partitioned across clients and server
- Model Offloading: Parts of the model are offloaded to edge servers

(3) Aggregation Strategy:
- Synchronous: All clients update simultaneously
- Asynchronous: Clients update independently
- Hierarchical: Multi-tier aggregation architecture

B. Federated Pre-training of LLMs

While most research focuses on federated fine-tuning, federated pre-training from scratch presents unique opportunities and challenges [1].

Advantages:
- Complete control over training data sources
- Domain-specific foundation models (e.g., medical, legal)
- Avoiding biases from publicly pre-trained models

Challenges:
- Extreme communication costs (thousands of training iterations)
- Convergence to sub-optimal solutions due to data heterogeneity
- Coordinating distributed tokenization and vocabulary

Current Approaches:

Chen et al. [3] propose a systematic framework for federated pre-training that includes:
- Distributed Tokenization: Coordinating vocabulary construction across clients
- Staged Training: Initial centralized pre-training followed by federated adaptation
- Domain Clustering: Grouping clients by domain to reduce heterogeneity

C. Federated Fine-tuning: The Dominant Paradigm

Given the computational expense of pre-training, most practical applications employ federated fine-tuning [2]:

Workflow:
1. A pre-trained LLM (e.g., BERT, GPT-2, LLaMA) serves as initialization
2. Clients fine-tune on local task-specific data
3. Updates are aggregated to create an improved global model
4. The process iterates until convergence

Key Advantages:
- Leverages existing pre-trained models
- Significantly reduced training time and cost
- More stable convergence than pre-training from scratch

Yao et al. [2] provide comprehensive analysis of federated fine-tuning, identifying three critical research challenges:
1. Communication efficiency for large models
2. Personalization vs. generalization trade-offs
3. Handling diverse task distributions across clients

D. Edge and On-Device Learning

The "Federated and Edge Learning for Large Language Models" paradigm [5] extends FL to resource-constrained edge devices:

Edge-Specific Considerations:
- Model Compression: Quantization, pruning, and distillation to fit memory constraints
- Adaptive Computation: Dynamic depth/width adjustment based on device capabilities
- Intermittent Connectivity: Handling disconnections and asynchronous updates
- Energy Efficiency: Minimizing battery consumption on mobile devices

Deployment Strategies:
- Model Sharding: Distributing model components across multiple edge devices
- Collaborative Inference: Multiple devices jointly perform inference
- Hierarchical Aggregation: Local edge servers pre-aggregate before central aggregation

III. COMMUNICATION-EFFICIENT FEDERATED FINE-TUNING

Communication costs dominate federated LLM training. This section examines state-of-the-art methods for achieving practical communication efficiency.

A. The Communication Challenge

Quantitative Analysis:

For a model with P parameters:

- Full model transmission: 4P bytes (assuming 32-bit floats)
- Gradient transmission: 4P bytes per round
- With R training rounds: 4PR total bytes

For GPT-3 (175B parameters): ~700 GB per round, ~70 TB for 100 rounds
Hilmkil et al. [4] demonstrate that even for smaller transformer models (BERT-Large with 340M parameters):

- Standard FL requires ~1.36 GB per round
- With 1000 clients and 100 rounds: ~136 TB total communication
- On typical edge networks (10 Mbps): ~300 hours of transmission time

B. Breakthrough: Sub-18KB Communication
Qin et al. [6] achieve a remarkable breakthrough: federated full-parameter tuning of billion-size models with communication cost under 18 KB per round—a reduction of over 99.99%.

Key Techniques:
(1) Zeroth-Order Optimization: Approximating gradients using function evaluations rather than backpropagation:
$\nabla f(w) \approx [f(w + \delta u) - f(w)] / \delta \cdot u$
where u is a random direction vector. Only the scalar evaluation difference is transmitted.

(2) Sparse Update Mechanisms:

- Identify top-k most important parameters using sensitivity analysis
- Transmit only indices and values of these parameters
- Server maintains momentum accumulation for dropped parameters

(3) Quantization Schemes:

- Adaptive bit-width allocation based on parameter importance
- Non-uniform quantization with learned quantization boundaries
- Error accumulation and correction across rounds

(4) Differential Privacy Integration: Adding calibrated noise for privacy while maintaining utility:
$w'_i = w_i + \text{Gaussian}(0, \sigma^2 C^2/\varepsilon^2)$
where C is the clipping threshold and ε is the privacy budget.

Experimental Results: On BERT-Large fine-tuning tasks:

- Communication: 17.8 KB per round (vs. 1.36 GB baseline)
- Accuracy: 98.7% of full-gradient performance
- Privacy: (ε, δ)-differential privacy with $\varepsilon = 2.0$

C. Gradient Compression Techniques
Beyond the sub-18KB breakthrough, various gradient compression methods have been developed:

(1) Quantization:
Uniform Quantization:
$Q(x) = \text{round}(x / \Delta) \cdot \Delta$
where Δ is the quantization step size.

Stochastic Quantization:
Reduces quantization bias through probabilistic rounding:
$P(Q(x) = \text{ceil}(x/\Delta)) = (x \bmod \Delta) / \Delta$

(2) Sparsification:
Top-k Gradient Selection: Transmit only the k largest gradients by magnitude:
$S = \{i: |g_i| \in \text{top-k}(|g|)\}$

Random Sparsification: Randomly sample gradients with probability proportional to magnitude:
$P(\text{select } g_i) = |g_i| / \Sigma_j |g_j|$

(3) Low-Rank Decomposition:
Approximate gradient matrix Gas product of low-rank matrices:
$G \approx UV^T$
where $U \in \mathbb{R}^{n \times r}$, $V \in \mathbb{R}^{m \times r}$, and $r << \min(n,m)$

D. Layer-Wise Adaptive Communication
Different layers contribute differently to model performance. Adaptive strategies allocate communication budget accordingly:
Importance Scoring:
$\text{importance}(\text{layer\_i}) = ||\nabla L / \nabla w_i||_2$

Adaptive Budget Allocation:
Layers with higher importance receive larger communication budgets, enabling more precise gradient transmission.

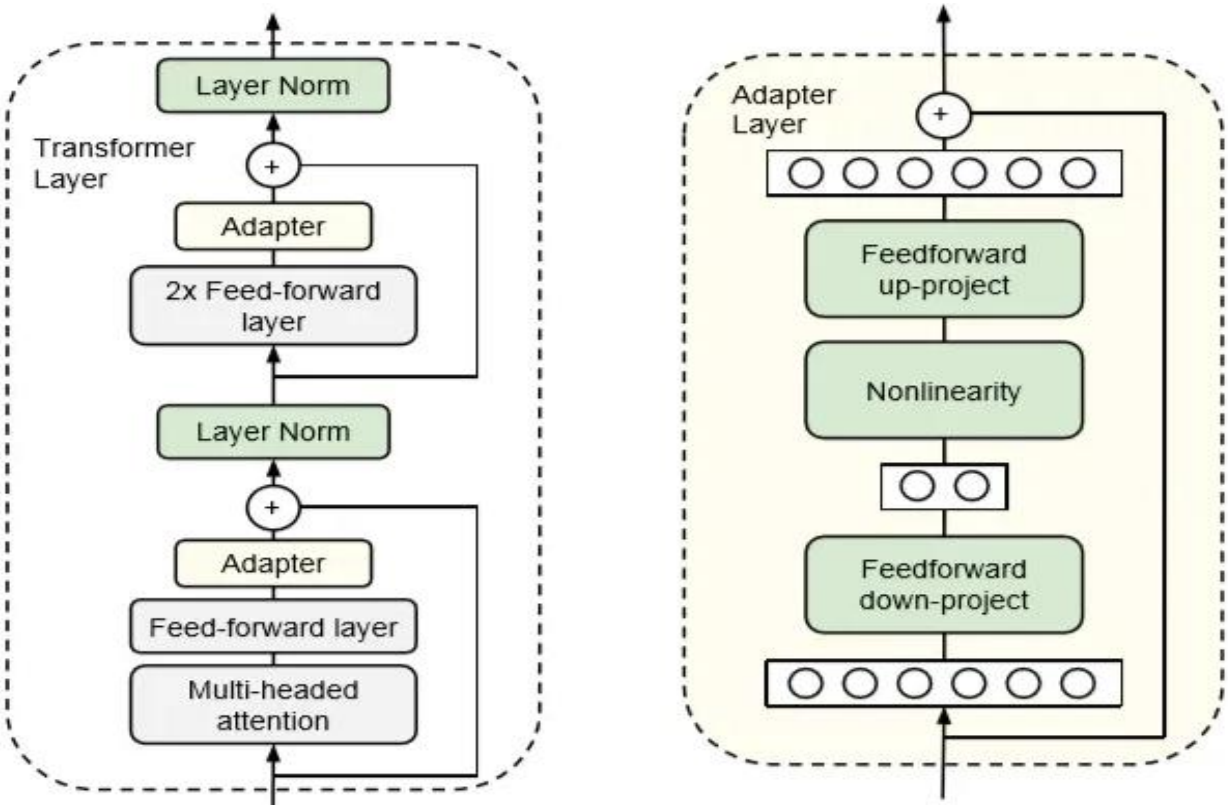
Empirical Findings [4]:
- Attention layers typically have highest importance (40-50% of budget)
- Feed-forward layers: 30-40%
- Embedding layers: 10-20%

IV. PARAMETER-EFFICIENT FINE-TUNING (PEFT)

PEFT methods achieve drastic reductions in trainable parameters, directly addressing communication and computation challenges.

A. Adapter-Based Methods

Architecture: Small neural modules inserted between transformer layers [15]:



Adapter Structure:

$h' = h + f(\text{Down}(h))$

$f(x) = \text{Up}(\text{ReLU}(x))$

where Down: $d \rightarrow r$, up: $r \rightarrow d$, and $r << d$

Communication Benefits:

- Original BERT-Large: 340M parameters
- With adapters (r=64): ~3.6M trainable parameters
- Communication reduction: 99% per round

Challenges in Federated Settings:

- Adapter placement decisions (which layers?)
- Initialization strategies across heterogeneous clients
- Aggregation of adapter parameters with different local task distributions

B. Low-Rank Adaptation (LoRA)

LoRA [16] has become the dominant PEFT method for federated LLMs due to its simplicity and effectiveness.

Core Principle:

Weight updates during fine-tuning have low intrinsic dimensionality. Represent updates as:

$W = W_0 + \Delta W = W_0 + BA$

where:

- W_0: frozen pre-trained weights (d × k)
- B: learnable low-rank matrix (d × r)
- A: learnable low-rank matrix (r × k)
- $r << \min(d, k)$

Forward Pass:

$h = W_0x + BAx$

Federated LoRA Workflow [4]:

1. Initialization:
   - Server broadcasts W_0 (once, at start)
   - Initialize B, A on each client (random or zero)

2. Local Training:

for each local epoch:

Freeze W_0

Update B, A via gradient descent end for

3. Aggregation:

$B\_global = \Sigma_i (n_i/n) \cdot B_i$

$A\_global = \Sigma_i (n_i/n) \cdot A_i$

4. Broadcast:
   - Send updated B global, A global to clients

Communication Analysis:

- Full fine-tuning: 4Pdk bytes per round
- LoRA: 4Pr(d+k) bytes per round
- For GPT-3 with r=16: Communication reduction: 99.996%

Performance [4]: On Super GLUE benchmark:

- LoRA (r=8): 97.2% of full fine-tuning performance

- LoRA (r=16): 98.9% of full fine-tuning performance
- Communication: 0.01% of full fine-tuning

C. Federated Prompt Learning
FedPromptL Framework [7]:
Guo et al. [7] introduce federated prompt learning for vision-language models with strong privacy efficiency.

Prompt Tuning Basics:
Instead of modifying model parameters, learn continuous prompt embeddings:
Input: $[P_1, P_2, ..., P_k, x_1, x_2, ..., x_n]$
where P_i are learnable prompt tokens (typically k=10-50).

Federated Prompt Learning Architecture:
(1) Local Prompt Optimization:
Min P L (Model (P $\oplus$ x), y)
where $\oplus$ denotes concatenation.

(2) Prototype-Based Aggregation:
Instead of directly averaging prompts, FedPromptL learns prototype representations:
$Prototype_i = f\_enc\ (P_i)$
Prototype_global = Aggregate({$Prototype_i$})
P_global = f_dec(Prototype_global)

(3) Privacy Preservation:
- Prompts contain abstract task knowledge, not raw data
- Gradient perturbation for differential privacy
- Secure aggregation protocols

Advantages:
- Ultra-low communication: Only 10-50 embeddings × d dimensions
- Task flexibility: Easy adaptation to new tasks
- Privacy: Prompts less susceptible to inversion attacks than full gradients

Experimental Results [7]: On visual question answering:
- Communication: 0.001% of full fine-tuning
- Accuracy: 96.8% of full fine-tuning
- Privacy: (ε=1.0, $\delta=10^{-5}$)-DP achieved

D. Cross-Domain Prompt Learning for Recommendation
Lei Guo et al. [9] extend prompt learning to cross-domain federated recommendation systems.

Problem Setting:
Multiple platforms (e-commerce, social media, streaming) want to improve recommendations without sharing user data.

Approach:
(1) Domain-Specific Prompts: Each domain learns specialized prompts:
P ecommerce = [P_1^e, P_2^e, ..., P_k^e]
P social = [P_1^s, P_2^s, ..., P_k^s]

(2) Shared Representation Learning:
H shared = Encoder ([P domain, user features, item features])
recommendation score = Decoder (h shared)

(3) Federated Aggregation:
- Share only prompt embeddings across domains
- Keep user/item embeddings private
- Aggregate through secure multi-party computation

Benefits:
- Cold-start problem mitigation through cross-domain knowledge transfer
- Privacy-preserving collaborative filtering
- Personalization while leveraging collective intelligence

V. SECURITY AND PRIVACY MECHANISMS

Privacy preservation is the fundamental motivation for federated LLMs, yet the approach introduces new vulnerabilities.
A. Privacy Threat Models
(1) Gradient Leakage Attacks:
Adversaries can reconstruct training data from shared gradients [13]:
Attack Mechanism: Given gradient g = ∇L (w, x), solve optimization:
x* = argmin_x $||g - \nabla L (w, x)||_2$

Effectiveness for Text:
- Exact token recovery for small batches ($B \leq 8$)
- Partial recovery for medium batches ($8 < B \leq 32$)
- Semantic recovery even for large batches

Example Attack [13]: From gradient of "The patient has diabetes", attacker recovers:

- Full sentence for B=1
- "Patient ... diabetes" for B=16
- Medical domain identification for B=64

(2) Model Inversion:
Extract sensitive information embedded in model parameters:
x* = argmax_x P (x | w)
Particularly concerning for memorization of rare or sensitive training examples.

(3) Membership Inference:
Determine if specific data was used in training:
if L (w, x) < threshold:
return "x was in training data"
Success rates up to 80% for LLMs [13].

B. Homomorphic Encryption for Secure Aggregation
FedML-HE Framework [8]:
Jin et al. [8] introduce efficient homomorphic encryption-based federated learning for LLMs.

Homomorphic Encryption Basics:
Encryption scheme allowing computation on ciphertexts:
$Enc(x_1) \oplus Enc(x_2) = Enc(x_1 + x_2)$
$Enc(x_1) \otimes Enc(x_2) = Enc(x_1 \cdot x_2)$

FedML-HE Protocol:
(1) Client-Side Encryption:
for each parameter w_i:
c_i = Encrypt (w_i, public_key) send c_i to server
end for

(2) Server-Side Aggregation:
$c\_agg = \Sigma_i (n_i/n) \otimes c_i$ // encrypted weighted average

(3) Decryption:
w_global = Decrypt (c_agg, private_key)

Optimizations for LLMs:
(a) Batch Encryption: Pack multiple parameters into single ciphertext:
Enc ($[w_1, w_2, ..., w_m]$) instead of $Enc(w_1)$, $Enc(w_2)$, ...

(b) Quantization Before Encryption: Reduce ciphertext size by quantizing to 8-bit:
$w_i' = \text{Quantize}(w_i, \text{8-bit})$
$c_i = \text{Encrypt}(w_i')$

(c) Partial Encryption: Encrypt only sensitive layers (e.g., first/last layers) while using secure aggregation for others.

Performance Trade-offs [8]:

Method	Communication Overhead	Computation Overhead	Privacy Level
No Protection	1×	1×	None
Differential Privacy	1×	1.1×	(ε, δ)-DP
Secure Aggregation	1.2×	2.5×	Honest-but-curious
FedML-HE	3.5×	8.2×	Malicious adversary

Practical Insights:
- HE suitable for high-security applications (healthcare, finance)
- Significant computational cost limits applicability
- Hybrid approaches combining HE with other techniques recommended

C. Differential Privacy
Differential Privacy (DP) provides rigorous mathematical privacy guarantees [17].

Definition: A mechanism M satisfies (ε, δ)-DP if for any two datasets D, D' differing in one record:
$P[M(D) \in S] \leq e^{\varepsilon} \cdot P[M(D') \in S] + \delta$
DP-SGD for Federated LLMs:

(1) Gradient Clipping:
$\bar{g}_i = g_i / \max(1, \|g_i\|_2 / C)$
where C is the clipping threshold.

(2) Noise Addition:
$\tilde{g} = \bar{g} + \text{Gaussian}(0, \sigma^2 C^2 I)$

(3) Privacy Accounting: Using Rényi Differential Privacy (RDP) for tight composition:
$\varepsilon_{total} = f(\varepsilon\_step, T, sampling\_rate)$

Challenges for LLMs:
- Large vocabulary requires higher noise for same privacy
- Gradient clipping interferes with learning dynamics

- Privacy-utility trade-off more severe than smaller models

Adaptive Strategies [2]:
- Layer-wise privacy budgets (more noise for sensitive layers)
- Privacy amplification via subsampling
- Public pre-training + private fine-tuning

D. Byzantine-Robust Aggregation
Malicious clients may send corrupted updates to degrade model quality.
Attack Scenarios:
- Label flipping attacks
- Gradient sign flipping
- Gaussian noise injection
- Backdoor attacks (trigger-based misclassification)

Defense Mechanisms:
(1) Robust Aggregation Rules:
Median Aggregation:
$w\_global[i] = median(\{w_1[i], w_2[i], ..., w_n[i]\})$

Trimmed Mean:
$w\_global[i] = mean(trim(\{w_1[i], ..., w_n[i]\}, \alpha))$
where α fraction of extreme values are removed.
Krum: Selects client update with smallest distance to k-nearest neighbors.

(2) Anomaly Detection:
- Statistical testing for outlier detection
- Norm-based filtering
- Cosine similarity thresholds

(3) Reputation Systems:
- Track historical accuracy of client updates
- Weight aggregation by reputation scores
- Exclude consistently malicious clients

VI. HANDLING HETEROGENEITY IN FEDERATED LLMS

Heterogeneity across clients poses fundamental challenges for federated LLM training [2].
A. Data Heterogeneity
Types of Data Heterogeneity:

(1) Label Distribution Skew:
Different clients have different task distributions.
Example: Medical institutions specializing in different diseases.

(2) Feature Distribution Skew:
Input distributions vary across clients.
Example: Different dialects or technical jargons across regions.

(3) Quantity Imbalance:
Clients have vastly different dataset sizes (10^3 to 10^7 samples).

(4) Domain Shift:
Clients represent entirely different domains (legal vs. medical vs. social media).

Impact on Performance [2]:
- Standard FedAvg can degrade accuracy by 20-40% compared to centralized training
- Convergence becomes unstable with oscillations
- Global model may fail to perform well on any client

B. Mitigation Strategies for Data Heterogeneity
(1) Personalized Federated Learning:
Local Head + Global Body Architecture:
Model = Global_Transformer + Local_Classifier
- Global transformer shared across clients
- Local classifier personalized per client

Meta-Learning Approaches: Learn initialization that enables rapid local adaptation:
$\theta^* = \text{argmin}_\theta \Sigma_i L (\theta - \alpha \nabla L_i(\theta))$

(2) Client Clustering:
Group clients with similar data distributions [2]:
Algorithm:
Initialize: K clusters for each round:
Compute client model similarities
Cluster clients using k-means
Train separates global model per cluster
Aggregate within clusters
end for

Benefits:
- Reduces negative transfer from dissimilar clients

- Enables domain-specific models
- Improves convergence rate

(3) Data Augmentation and Sharing:
Synthetic Data Generation:
- Server generates synthetic samples using global model
- Distributes synthetic data to balance client datasets
- Preserves privacy (no real data sharing)

Knowledge Distillation:
L distill = KL (Teacher output || Student output)
- Global model serves as teacher
- Local models learn from both local data and teacher

C. System Heterogeneity
Hardware Diversity:
- High-end servers: 8×A100 GPUs, 640GB RAM
- Desktop computers: Single RTX 3090, 32GB RAM
- Edge devices: Mobile GPU, 8GB RAM
- IoT devices: CPU-only, 2GB RAM

Challenges:
- Memory constraints prevent loading full models
- Computation speed varies by 100×-1000×
- Stragglers slow down synchronous training

Solutions:
(1) Heterogeneity-Aware Client Selection:
Select clients based on:
score(client) = f (computation speed, data quality, staleness)

(2) Adaptive Local Training:
Adjust local epochs based on device capability:
E local = E base × (device speed / median speed)

(3) Model Partitioning:
Split Learning Architecture:
- Model split between clients and server
- Clients compute bottom layers
- Server computes top layers

- Only activations transmitted

(4) Asynchronous Federated Learning:
Remove synchronization barriers:
$w_{t+1} = w_t - \alpha \cdot \nabla L(w_{t-\tau})$
where τ is staleness of client update.

D. Communication Heterogeneity
Network Conditions:
- Bandwidth: 1 Mbps (mobile) to 10 Gbps (datacenter)
- Latency: 10ms (local) to 500ms (cross-continental)
- Reliability: Frequent disconnections on mobile networks

Adaptive Strategies:
- Compression ratio based on bandwidth
- Update frequency based on connection stability
- Hierarchical aggregation using edge servers

VII. FRAMEWORKS AND TOOLS

A. Federated Scope-LLM
Kuang et al. [10] introduce Federated Scope-LLM, the first comprehensive open-source framework for federated LLM fine-tuning.

Key Features:
(1) Flexible Architecture:
(2) Multiple PEFT Support:
- LoRA with configurable rank
- Adapters with various architectures
- Prompt tuning with different initialization
- Prefix tuning for generative models

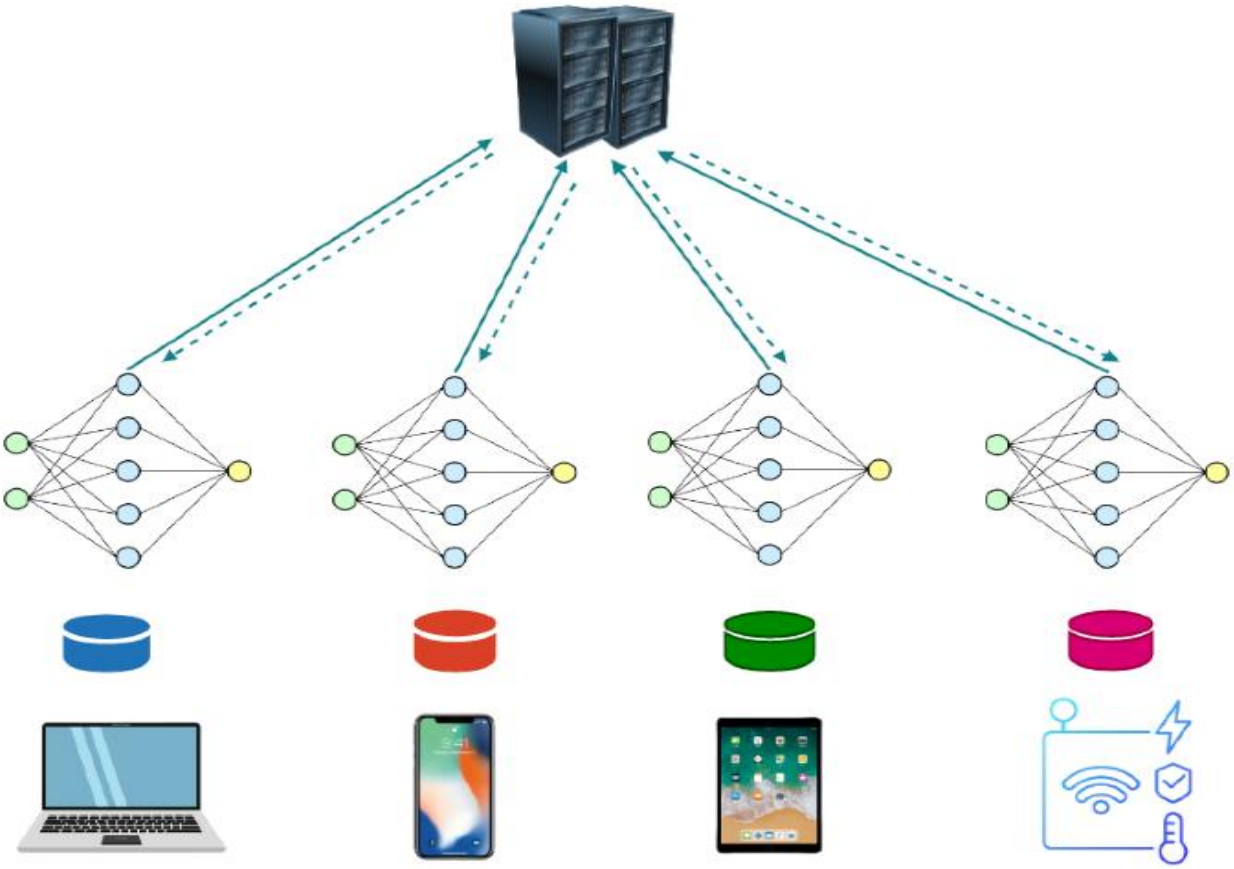
(3) Communication Optimization:
- Built-in quantization (INT8, INT4, FP16)
- Gradient compression (Top-k, random-k)
- Sparse updates with error accumulation

(4) Privacy Mechanisms:
- Differential privacy with RDP accounting
- Secure aggregation via multi-party computation
- Homomorphic encryption (optional)

(5) Heterogeneity Handling:

- Client selection strategies
- Adaptive aggregation weights
- Asynchronous training support

Architecture:



Supported Models:

- BERT family (BERT, RoBERTa, ALBERT)
- GPT family (GPT-2, GPT-Neo)
- T5 and BART
- LLaMA and Falcon
- Domain-specific models (BioBERT, Legal-BERT)

Example Workflow:

1. Define client data

client data = {
'Client_1': load dataset ('glue', 'mrpc', split='train [:100]'),
'Client_2': load dataset ('glue', 'mrpc', split='train [100:200]'),
more clients}

2. Configure federated training

Fed config = {

```
'model_name': 'bert-base-uncased',
'peft_method': 'lora',
'lora_rank': 8,
'aggregation': 'FedAvg',
'dp_epsilon': 2.0,
'compression': 'topk',
'topk_ratio': 0.1}

3. Initialize and train
trainer = FedLLMTrainer(fed_config)
trainer. Fit (client data, numerous=50)

4. Evaluate global model
results = trainer. Evaluate (test data)
print (f"Accuracy: {results['accuracy']:.3f}")
```

Performance Benchmarks [10]:
On GLUE benchmark (8 clients, 50 rounds):

- Accuracy: 92.3% (vs. 94.1% centralized)
- Communication: 2.1 GB total (vs. 840 GB full fine-tuning)
- Training time: 4.2 hours (vs. 1.8 hours centralized)

B. Integration with Existing Ecosystems
(1) Hugging Face Transformers:

```
from transformers import Auto Model
from federated scope llm import Federated Trainer
model = Auto Model from pretrained ('bert-base-uncased')
trainer = Federated Trainer (model, clients, config)
trainer train ()
```

(2) PyTorch Lightning:

```
import pytorch_lightning as pl
from federatedscope.llm import FedLightningModule
class FedBERT(FedLightningModule):
def training_step(self, batch, batch_idx):

Local training logic
Pass

def aggregate step (self, client_outputs):
```

```
Custom aggregation
pass

(3) DeepSpeed and Megatron: Integration with large-scale training frameworks:
from federatedscope.llm import FedDeepSpeed

Use DeepSpeed for local training
trainer = FedDeepSpeed (model=model, deepspeed_config='ds_config.json',
fed_config=fed_config)
```

VIII. APPLICATIONS AND CASE STUDIES

A. Healthcare: Federated Medical LLMs

Clinical Note Analysis:

Scenario: Multiple hospitals want to develop a clinical NLP system without sharing patient records.

Approach [1]:

1. Pre-train on public medical literature (PubMed, clinical trial databases)
2. Federated fine-tuning on de-identified clinical notes at each hospital
3. Aggregate using DP-SGD with $\varepsilon=2.0$

Results:

- Named Entity Recognition (NER): 91.3% F1 (vs. 93.7% centralized)
- Relation Extraction: 87.8% F1 (vs. 89.2% centralized)
- Privacy: HIPAA-compliant with provable privacy guarantees

Medical Question Answering:

Dataset: MedQA, distributed across 10 medical institutions

Architecture:

- Base model: BioBERT
- PEFT: LoRA (rank=16)
- Privacy: Secure aggregation + DP ($\varepsilon=3.0$)

Performance:

- Accuracy: 68.4% (vs. 71.2% centralized, 54.3% baseline BioBERT)
- Communication: 1.8 GB total (50 rounds)
- Training time: 3.5 hours (vs. 1.2 hours centralized)

B. Finance: Cross-Bank Risk Assessment
Fraud Detection:
Challenge: Banks want to collaboratively improve fraud detection without sharing transaction data.

Solution:
1. Each bank fine-tunes FinBERT on local transaction descriptions
2. Federated aggregation with Byzantine-robust Krum
3. Anomaly detection for malicious updates

Results [1]:
- Fraud detection F1: 84.6% (vs. 87.2% centralized, 78.9% local-only)
- False positive reduction: 23% vs. local-only models
- Privacy: Zero raw transaction sharing

Credit Risk Modeling:
Federated fine-tuning of LLMs for analyzing loan application narratives:
- 15 regional banks participate
- Data heterogeneity: Different regional economies
- PEFT method: Adapters (bottleneck dim=32)

Outcomes:
- Default prediction AUC: 0.81 (vs. 0.84 centralized)
- Regulatory compliance maintained
- Reduced bias through diverse training data

C. Recommendation Systems
Cross-Platform Recommendation [9]:
Participants:
- E-commerce platform
- Social media platform
- Streaming service
- News aggregator

Federated Prompt Learning Approach:
1. Each platform learns domain-specific prompts
2. Shared user representation encoder
3. Secure aggregation of prompt embeddings

Benefits:
- Cold-start improvement: 34% increase in new user satisfaction
- Cross-domain transfer: Movie recommendations informed by music preferences
- Privacy: User behavior never leaves platforms

Metrics:
- Click-through rate: +18% vs. platform-only models
- User engagement: +12% session duration
- Communication: 45 MB total (100 rounds, 4 platforms)

D. Edge Computing: On-Device Virtual Assistants
Privacy-Preserving Voice Assistants:
Architecture:
- Distributed across millions of edge devices
- Local speech-to-text and intent recognition
- Federated fine-tuning for personalization

Implementation [5]:
- Base model: DistilBERT (66M parameters)
- Model compression: INT8 quantization
- Federated learning: Asynchronous updates
- Aggregation: Hierarchical via regional edge servers

Performance:
- Intent recognition accuracy: 89.3% (vs. 91.7% centralized)
- Latency: 120ms (vs. 45ms centralized, 350ms baseline)
- Privacy: All voice data remains on-device
- Communication: 2.3 MB per device over 6 months

Personalization Results:
- User satisfaction: +28% vs. generic model
- Accuracy on user-specific vocabulary: 94.2% (vs. 76.5% generic)

E. Legal: Cross-Jurisdictional Legal AI
Legal Document Analysis:
Scenario: Law firms across different jurisdictions want to improve contract analysis without sharing client documents.

Approach:
- Base model: Legal-BERT
- Federated fine-tuning on clause classification

- Personalized heads for jurisdiction-specific regulations

Challenges:
- Extreme data heterogeneity (different legal systems)
- High privacy requirements (attorney-client privilege)
- Varying data volumes (large firms vs. small practices)

Solutions [2]:
- Client clustering by legal system
- Per-cluster global models with local personalization
- Differential privacy with ε=1.0 (stringent privacy)

Results:
- Clause identification F1: 87.9% (vs. 91.3% centralized, 82.4% local)
- Cross-jurisdiction knowledge transfer demonstrated
- Privacy: Audited by legal ethics committees

IX. OPEN CHALLENGES AND FUTURE DIRECTIONS

A. Scaling to Massive Client Networks

Current Limitations: Most research evaluates on 10-1000 clients. Real-world applications may involve millions of devices.

Research Directions:

(1) Hierarchical Federated Learning:

Multi-tier architecture with edge, regional, and global servers:

Devices → Edge Servers → Regional Servers → Global Server

(2) Peer-to-Peer Federated Learning:

Eliminating central server bottleneck through decentralized aggregation.

(3) Client Sampling Strategies:

Intelligent selection of representative client subsets:

$S = \text{argmax}_{|S|=k} \text{Diversity}(S) \times \text{Quality}(S)$

B. Multimodal Federated LLMs

Vision-Language Models: Extending FedPromptL [7] to large-scale multimodal models (e.g., CLIP, Flamingo).

Challenges:
- Different privacy requirements for visual vs. textual data
- Heterogeneous modality availability across clients
- Computational complexity of multimodal transformers

Opportunities:
- Medical imaging + clinical notes
- Product images + descriptions for e-commerce
- Video + transcripts for content moderation

C. Continual and Lifelong Learning
Problem: LLMs must adapt to new tasks and domains without forgetting previous knowledge.

Federated Continual Learning:
for each new task T_i:
Federated fine-tuning on T_i
Consolidate knowledge to prevent forgetting
Update global model
end for

Approaches [2]:
- Elastic weight consolidation (EWC) in federated settings
- Progressive neural networks with federated expansion
- Memory replay with synthetic data generation

D. Fairness and Bias Mitigation
Sources of Bias in Federated LLMs:
1. Data bias at individual clients
2. Sampling bias in client selection
3. Aggregation bias favoring majority clients

Mitigation Strategies:
Fair Aggregation:
$w\_global = \Sigma_i \alpha_i \cdot w_i$
where α_i balances performance across demographic groups

Adversarial Debiasing:
Training bias classifiers and penalizing biased representations.
Fairness Auditing: Regular evaluation across sensitive attributes (race, gender, age).

E. Theoretical Foundations

Open Questions:

(1) Convergence Guarantees: Under what conditions do federate LLM training algorithms converge?

(2) Privacy-Utility Trade-offs: Characterize fundamental limits of accuracy under differential privacy for LLMs.

(3) Communication Complexity Bounds: What are the minimum communication requirements for federated LLM fine-tuning?

Recent Progress [1, 2]:

- Convergence rates for FedAvg with non-convex objectives
- Privacy amplification through sampling and iteration
- Communication lower bounds under heterogeneity

Future Work:

- Tighter analysis for specific LLM architectures
- Sample complexity of federated pre-training
- Generalization bounds under distribution shift

F. Standardization and Benchmarking

Need for Standardized Evaluation:

Proposed Benchmarks [1]:

- FedNLP: Comprehensive federated NLP benchmark
  - 10+ tasks (classification, QA, generation)
  - Simulated heterogeneity (data, system)
  - Standardized evaluation metrics
- FedLLM-Bench: LLM-specific benchmarks
  - Billion-parameter models
  - Communication cost tracking
  - Privacy metric evaluation

Evaluation Dimensions:

1. Task performance (accuracy, F1, perplexity)
2. Communication efficiency (bytes transmitted)
3. Computation efficiency (FLOPs, memory)
4. Privacy guarantees (ε, δ, empirical privacy)
5. Fairness metrics (demographic parity, equalized odds)
6. Robustness (Byzantine resilience, distribution shift)

G. Integration with Emerging Paradigms

(1) Federated Learning + Retrieval-Augmented Generation (RAG):

- Private retrieval from local databases
- Federated index construction
- Privacy-preserving similarity search

(2) Federated Learning + In-Context Learning:

- Few-shot prompt engineering across clients
- Federated prompt optimization
- Knowledge sharing through demonstrations

(3) Federated Learning + Constitutional AI:

- Collaborative development of AI safety guidelines
- Federated reward modeling
- Privacy-preserving human feedback

H. Energy Efficiency and Carbon Footprint

Environmental Concerns: Training large models consumes massive energy. Federated learning distributes computation but may increase total energy use.

Research Directions:

- Carbon-aware client selection
- Energy-efficient local training algorithms
- Model compression for reduced computation
- Renewable energy integration in data centers

Metrics:

$\text{Carbon\_footprint} = \Sigma_i (\text{Energy}_i \times \text{Carbon\_intensity}_i)$

Optimize not just for accuracy and privacy, but also sustainability.

I. Regulatory Compliance and Legal Frameworks

Emerging Regulations:

- EU AI Act: Risk classification and transparency requirements
- California CPRA: Consumer privacy rights
- China Personal Information Protection Law (PIPL)

Federated LLM Compliance:

- Auditability: Tracking data sources and model updates
- Right to explanation: Interpretable federated models
- Data minimization: PEFT as compliance mechanism

X. CONCLUSION

This comprehensive survey has examined the integration of federated learning with large language models, a critical frontier for privacy-preserving AI. We synthesize key findings across multiple dimensions:

Technical Achievements:

1. Communication Efficiency: Methods achieving sub-18KB communication per round for billion-parameter models [6], a 99.99%+ reduction vs. naive approaches
2. Parameter Efficiency: PEFT techniques (LoRA, adapters, prompt tuning) enabling federated fine-tuning with <1% trainable parameters [4, 7]
3. Privacy Protection: Homomorphic encryption, differential privacy, and secure aggregation providing rigorous guarantees [8]
4. Heterogeneity Management: Personalization, clustering, and adaptive strategies addressing real-world data and system diversity [2]
5. Practical Frameworks: Open-source tools like FederatedScope-LLM enabling widespread adoption [10]

Application Impact: Federated LLMs are transforming domains requiring privacy:

- Healthcare: Collaborative medical AI without patient data sharing
- Finance: Cross-institution fraud detection and risk assessment
- Edge Computing: On-device personalization for virtual assistants
- Recommendation: Cross-platform knowledge transfer with privacy

Remaining Challenges: Despite significant progress, critical challenges remain:

1. Scalability: Moving from hundreds to millions of clients
2. Theoretical Foundations: Rigorous convergence and privacy guarantees
3. Fairness: Mitigating bias in decentralized training
4. Multimodality: Extending to vision-language and beyond
5. Sustainability: Reducing environmental impact

Future Vision: The convergence of federated learning and large language models promises a future where:

- Organizations collaboratively develop AI while respecting data sovereignty
- Individuals benefit from personalized models without sacrificing privacy
- Edge devices leverage powerful language understanding locally
- AI development becomes more democratic and distributed

Research Priorities: We identify critical areas for future work:

1. Developing scalable algorithms for billion-device networks

2. Establishing standardized benchmarks and evaluation protocols
3. Creating theoretical frameworks for privacy-utility-communication trade-offs
4. Building fair and unbiased federated learning systems
5. Integrating federated LLMs with emerging AI paradigms (RAG, in-context learning)

As LLMs continue to grow in capability and deployment, federated learning provides an essential pathway to harness their power while preserving privacy, ensuring fairness, and maintaining trust. The techniques surveyed in this report form the foundation for the next generation of privacy-preserving AI systems, enabling collaborative intelligence at unprecedented scale.
The field of federated LLMs is rapidly evolving, with new methods, frameworks, and applications emerging continuously. This survey provides a comprehensive snapshot of the current state while identifying promising directions for future research. By addressing the outlined challenges and building on existing achievements, the research community can realize the vision of powerful, privacy-preserving language AI accessible to all.

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Review On Comparative Study of Methods Preferred in Formulation of Liposomes for Anticancer Drug Delivery

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Abstract-Liposomes are versatile nanocarrier vesicles, composed of Phospholipids, featuring both a hydrophilic core and hydrophobic membrane. This dual nature makes them ideal for delivering molecules with varying polarities. Their biocompatibility, biodegradability, and ability to target specific tissues have established them as a cornerstone in anticancer drug delivery system. Today, liposomes are actively used in tumor targeting, gene therapy, genetic vaccines, immunomodulation, photodynamic therapy, transdermal delivery. In the oncology sector, these nanovesicle formulations depict a significant advancement by offering innovative solutions for the delivery of chemotherapeutic agents. This article confronts latest developments in widely used liposome formulation methods including thin film hydration method, Solvent evaporation, microfluidic techniques. Each method presents distinct advantages, challenges and limitations, which are discussed in detail. Additionally, the review highlights advanced approaches and future directions in the field of liposomal drug delivery.

Index Terms—Oncology, Nano-vesicles, Microfluidic Method, Rotary evaporator, Film Hydration, Drug Delivery.

I. INTRODUCTION

Liposomes, as nanoscale vesicular structures, possess one or more concentric phospholipid bilayers encapsulating aqueous cores. It is one of the most promising drug delivery systems in modern pharmaceutical science. Structurally, Liposomes are lipid bilayer vesicles, known for their biodegradability and biocompatibility, making them effective carriers for targeted drug delivery.

They can encapsulate both hydrophilic and hydrophobic drugs, offering versatility in therapeutic applications. Due to their diverse composition and structural adaptability, liposome have become widely utilized in biomedical fields. In recent developments, malfunctional liposome have emerged as promising tool s for targeted tumor. One of the most promising and versatile drug delivery systems in modern pharmaceutical science is liposomes. Structurally, liposomes are nanosized vesicles formed by one or more concentric phospholipid bilayers encapsulating aqueous cores [1,6,10]. This unique amphiphilic architecture allows them to simultaneously carry both hydrophilic agents and lipophilic compounds, making them exceptionally adaptable for a wide range of therapeutic applications [32,34].

In the context of cancer therapy, liposomes are particularly advantageous. They offer improved bioavailability, prolonged circulation time, and reduced systemic toxicity compared to conventional chemotherapeutic formulations [36]. A key feature contributing to their clinical relevance is their ability to be modified for targeted delivery. Surface modifications such as the incorporation of polyethylene glycol (PEG) or specific ligands can enhance passive or active targeting, facilitating the accumulation of liposomes in tumor tissues through the enhanced permeability and retention (EPR) effect (Fig. 1). Furthermore, their structural similarity to biological membranes enhances their biocompatibility, enabling them to mimic natural cellular processes and evade immune recognition [40,41].

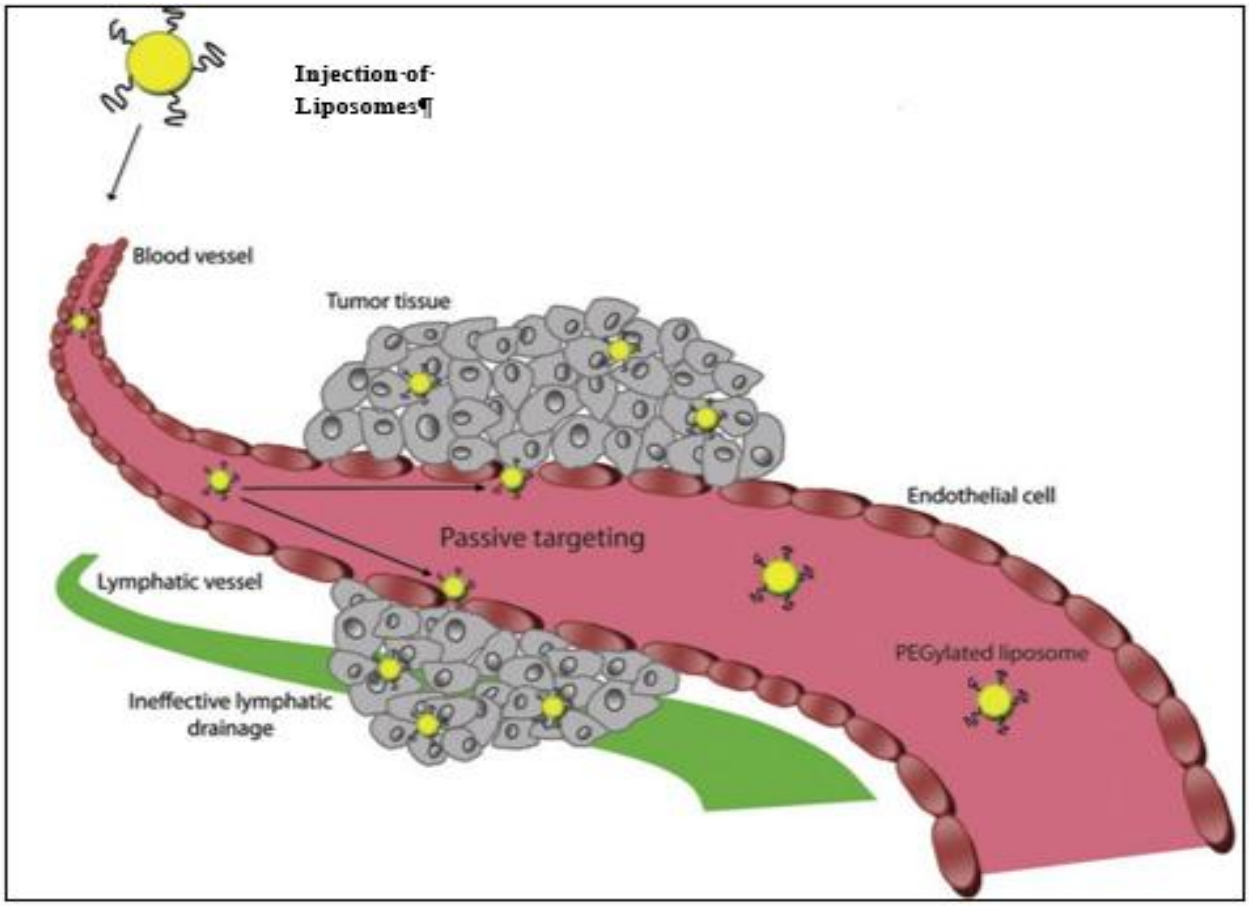

Figure 1 Enhancement in Permeability and retention effect by Liposomes [53]

The growing interest in liposomal systems is driven not only by their therapeutic versatility but also by ongoing advances in manufacturing technologies. These include reverse-phase evaporation, ethanol injection, freeze-drying, and more recently, microfluidic technologies. Such innovations have significantly improved the scalability, reproducibility, and drug loading capacity of liposome formulations, thereby strengthening their potential for clinical translation [36,42]. Among the significant innovations in liposome development has been the introduction of "stealth technology." By incorporating PEGylated lipids, researchers have developed long-circulating liposomes that are less readily identified and cleared by the mononuclear phagocyte system. This improves drug delivery to the targeted site of action and extends systemic circulation. However, despite their potential, liposome-based drug products are inherently complex. Even subtle changes in their composition or preparation method can markedly affect pharmacokinetics, biodistribution, and therapeutic outcomes. As such, meticulous attention to formulation parameters and manufacturing processes is essential to ensure consistency and efficacy [41,42]. Beyond oncology, liposomes have also found application in other therapeutic areas. In cardiovascular diseases, they have been used to deliver nitric oxide and antioxidants to improve vascular function and mitigate oxidative stress. Liposomes facilitate targeted gene expression with less immunogenicity in gene therapy by acting as non-viral vectors for the delivery of nucleic acids like DNA and RNA [44].

Importantly, the technique employed for liposome preparation plays a pivotal role in determining their physicochemical characteristics such as particle size, lamellarity, surface charge, and encapsulation efficiency, which directly influence their stability, biodistribution, and therapeutic performance (Fig. 2). Several techniques have been established for liposome production, each with unique advantages and challenges. This mini-review explores four widely adopted methods: thin-film hydration, solvent evaporation, ethanol injection, and microfluidic technology (Fig. 3). These methods differ significantly in terms of complexity, scalability, reproducibility, and the physical properties of the resulting liposomes. For instance, thin-film hydration remains a popular laboratory-scale technique known for producing multilamellar vesicles, while microfluidic methods represent a newer, more precise approach capable of generating uniform unilamellar liposomes with reduced batch-to-batch variability [34].

Figure 2 Features of Liposomal Formulation

Given the complexity and therapeutic importance of liposomal systems, this review aims to provide a comparative overview of these liposome preparation techniques, with a focus on their relevance in anticancer drug delivery. Emphasis is placed on how these methods influence key formulation parameters and how they can be optimized for clinical application [42].

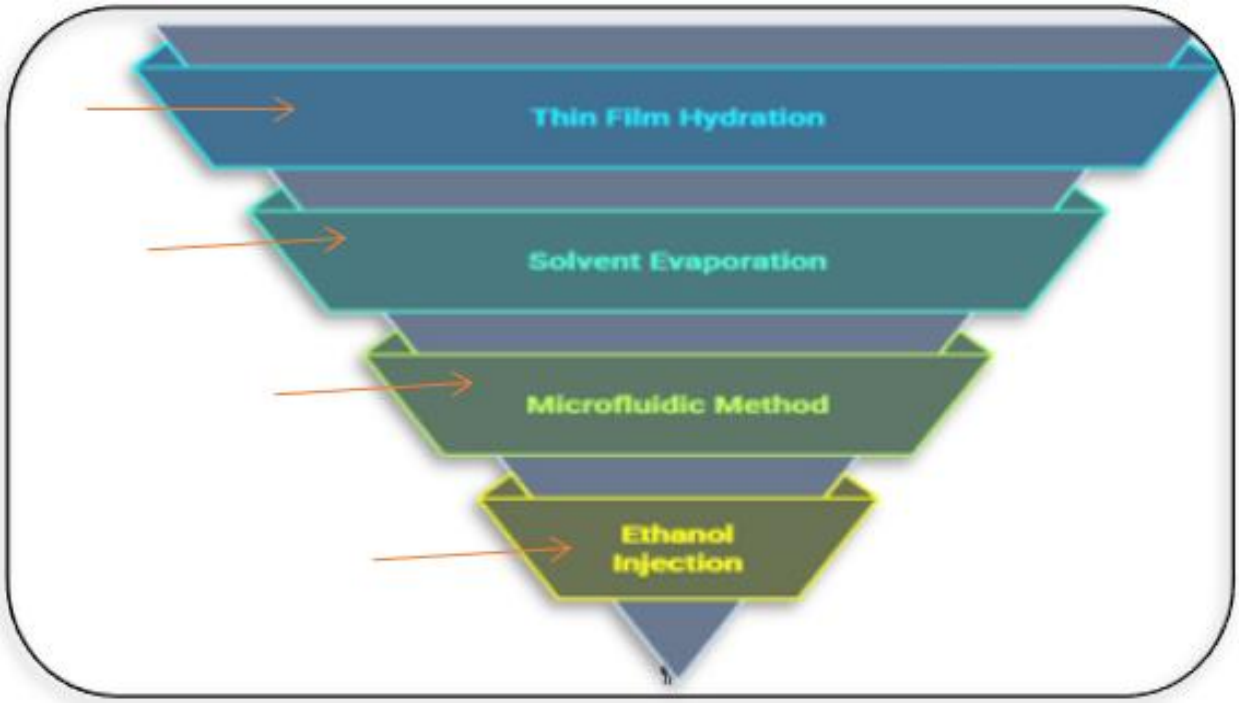

Figure 3 Liposomes Formulation Techniques

II. METHOD OF THIN FILM HYDRATION

Advanced Techniques in Liposome Preparation: A Narrative Overview

Because liposomes can encapsulate a wide range of therapeutic agents, they have become essential in contemporary pharmaceutical and biomedical research. Among the many fabrication techniques developed, certain methods stand out due to their efficiency, reproducibility, and suitability for specific drug types. Below is a detailed, narrative exploration of some of the key methods currently employed in liposomal formulation. [10] The thin film hydration method is a basic technique for creating liposomes and niosomes, and it is regarded as one of the most well-established and extensively used approaches [1–6,10–19]. Lipid components are first dissolved in an organic solvent, usually methanol or chloroform [1,2]. A thin lipid film is then formed on the inner surface of a round-bottom flask as the solvent is evaporated under reduced pressure, typically using a rotary evaporator [3,4]. Upon hydration with an aqueous solution potentially containing the therapeutic compound this dry lipid film spontaneously swells and peels off, forming multilamellar vesicles (MLVs) [5,6]. These MLVs can then be processed via extrusion, sonication, or freeze-thaw cycles to produce unilamellar vesicles with controlled size and improved homogeneity [10,11]. Technique involves lipid dissolution in organic solvents, followed by solvent evaporation to form a thin lipid film, which is then hydrated to generate liposomes [12]. This technique offers

advantages, including high encapsulation efficiency for hydrophilic drugs, as the aqueous core formed during hydration effectively traps these agents [13,14]. Particle size control is achievable through downstream processing such as extrusion, which yields vesicles with uniform diameters [15]. Additionally, the rigid structure of lipid bilayers contributes to enhanced stability, which in turn supports better drug retention and shelf life [16]. However, the method has limitations as it is time-consuming, involving multiple steps from film formation to size reduction [17]. It is also less effective for lipophilic drug loading, as these compounds must be incorporated into the lipid bilayer during the initial lipid dissolution stage, which may restrict their loading capacity [18,19].

Microfluidic Techniques

Microfluidic-based liposome production represents a cutting-edge innovation in nanotechnology. Unlike traditional bulk processes, microfluidic systems manipulate fluids within micron-sized channels, enabling precise control over liposome formation conditions. In this process, lipid materials dissolved in organic solvents are introduced into microfluidic chips alongside aqueous buffer solutions. Rapid and controlled mixing within these microchannels initiates the self-assembly of liposomes. [20,22] What distinguishes this method is its ability to produce highly uniform, unilamellar vesicles with consistent particle size and superior encapsulation efficiency. This precision is critical for reproducible performance in drug delivery applications, particularly in personalized medicine.[21] Its benefits include fine-tuning of liposome size and polydispersity by adjusting flow rates, temperature, and lipid-to-buffer ratios. Higher batch-to-batch reproducibility compared to thin film hydration, reducing variability in drug delivery performance. Enables co-encapsulation of multiple agents (e.g., therapeutic and diagnostic molecules) for theragnostic applications.[21] Some limitations observed, such as initial setup of microfluidic systems may be cost-intensive and require specialized fabrication. Solvent removal post-formation can be challenging and must be optimized for large-scale applications. [20,22]

Supporting Techniques in Liposome Preparation

To improve liposome production and refinement, a number of auxiliary techniques are employed in addition to the main ones mentioned below, either alone or in combination.

- Sonication Technique: This approach employs ultrasonic energy to reduce the size of multilamellar vesicles into small unilamellar vesicles (SUVs). It's commonly used after hydration in thin film methods to fine-tune liposome diameter.
- Extrusion Method: Liposomal suspensions are passed through polycarbonate membranes with defined pore sizes, yielding vesicles of uniform size. This is particularly effective for producing nano-liposomes for intravenous applications.
- Emulsification-Evaporation Method: involves dispersing a lipid-drug solution in an organic phase into an aqueous phase to create an emulsion. As the solvent evaporates, lipid vesicles form, ideal for encapsulating lipophilic drugs.[72]

- Lipid Layer Hydration Method: Similar to thin film hydration, this technique focuses on hydrating a pre-formed lipid film to initiate liposome formation. It may be used for both small-scale research and large-scale manufacturing.[73]

Microfluidic Techniques Overview

Microfluidic systems have emerged as a cutting-edge method in liposome production, offering precision and scalability that surpass traditional techniques [20]. In microfluidic processes, lipid materials are initially dissolved in organic solvents and then mixed with aqueous buffer solutions within microfluidic chips. This controlled micro-mixing results in consistent and reproducible liposome formation [21]. The design of the microfluidic devices significantly influences their efficiency. Configurations like Y-shaped channels and 3D integrated chip structures enhance the mixing process and support continuous production [22]. This capability is particularly important in overcoming limitations related to solvent removal and scale-up. A major advantage of microfluidic methods is their precise control over particle size. By adjusting flow rates and solution composition, manufacturers can produce liposomes with narrowly distributed particle sizes, offering better uniformity than traditional techniques [23]. Devices such as static mixers and staggered herringbone micromixers have shown varied performance, with static mixers notably improving particle size distribution [24]. Advancements in 3D printing and device fabrication have improved throughput, making microfluidic liposome production viable for industrial applications. The ability to effectively remove residual solvents enhances both shelf-life and safety of the resulting formulations, a critical factor for clinical usage [71].

Solvent Evaporation Method

For the preparation of liposomes, the solvent evaporation method is still one of the most widely used and scalable techniques [2]. Phospholipids and medication ingredients are dissolved in a volatile organic solvent, which is subsequently emulsified into an aqueous phase [6]. After that, the solvent is evaporated, usually at a lower pressure, which promotes the formation of vesicles and gas bubbles that aid in the formation of liposomes [7]. It is a versatile method, accommodating a wide range of lipid mixtures and drug types and is often combined with techniques such as homogenization or membrane extrusion to yield liposomes with controlled particle sizes and uniformity [11,12]. One of the method's key strengths is its adaptability to industrial-scale production as it has simplicity and high throughput [13]. The removal of organic solvents, although a critical step, must be managed carefully to ensure product safety [6]. The choice of solvent significantly influences the final product. Polar solvents tend to enhance the encapsulation of hydrophilic drugs, thereby increasing efficacy [11]. However, the possibility of residual solvent presence is a major concern, potentially impacting liposome stability and safety [7]. This can be a benefit as it is a quick and scalable process suitable for industrial use, and effective for encapsulating both hydrophilic and lipophilic drugs [12,13]. Also, drawbacks include the possibility that residual solvent may compromise safety and stability [6], and the method often shows lower encapsulation efficiency for hydrophilic drugs compared to other methods [2]

Ethanol Injection Method

The ethanol injection method is another widely employed strategy in liposome formulation [4]. This technique involves dissolving lipids in ethanol and injecting the solution into an aqueous buffer under controlled conditions [6]. The temperature is typically maintained between 60–70 °C to facilitate efficient liposome formation [8]. One of the key advantages is its scalability, with successful production volumes ranging from laboratory-scale (60 mL) to industrial-scale (3 L) [9]. The resulting liposomes usually fall within the 150–200 nm size range and display narrow polydispersity indices [14]. Encapsulation efficiency is typically high (above 90%), making this method particularly appropriate for drug delivery [15]. It is also compatible with a wide variety of active agents, from pharmaceutical drugs to plant-derived bioactive compounds [16]. The method has drawbacks despite being effective and simple to use. Notably, because of the quick mixing, it might result in reduced encapsulation efficiencies for hydrophilic medications [17]. Furthermore, ethanol residues in the final product may require additional purification steps, adding time and complexity to the process [6,18]. Some of the advantages include that it is a simple, cost-effective method with minimal equipment requirements and produces small, uniform vesicles suitable for targeted delivery [14,15]. However, its limitations include potentially poor encapsulation for hydrophilic compounds [17] and the requirement for purification to remove residual ethanol [18].

Ultrasonication

Ultrasonication is a simple and frequently used method for the preparation of liposomes [53]. This process is considered a green technology that utilizes ultrasonic waves to prepare emulsions, and sonication enhances dispersivity [54]. Although there are two different sonication techniques bath sonication and probe sonication the liposomes made using each have comparable properties [53]. However, when it comes to managing operational parameters, bath sonication is considered better due to its more uniform energy distribution [54]. The understanding of the exact mechanism behind liposome formation through sonication is still evasive; however, it involves the application of ultrasonic pulsation to a hydrated lipid solution to create a more uniform population of liposomes [53]. The high-frequency vibration likely a combination of physical agitation and water cavitation induced by sonication results in the shattering of large lipid structures, which then reform as small, unilamellar liposomes [54].

Additional Context: Production Techniques for Lipid Nanoparticles

In addition to the liposome-specific approaches mentioned above, a number of methods are used for the more general class of lipid nanoparticles (LNPs). These include nanoprecipitation, emulsification, thin film hydration, microfluidic mixing, and impingement jet mixing. Each approach offers unique benefits and challenges that influence the physicochemical properties, Entrapment efficiency, and therapeutic performance of the prepared nanoliposomes. To optimise drug delivery systems and achieve the intended clinical outcomes, it is crucial to comprehend the advantages and disadvantages of each technique.[52]

TABLE 1 COMPARATIVE ANALYSIS OF METHODS

Method	Process Description	Advantages	Limitations
Thin Film Hydration	Lipid film formation followed by hydration and extrusion [18]	High encapsulation efficiency, uniform size, and stability, simple process [18]	Time-consuming, complex process, low drug loading for lipophilic drugs [31]
Solvent Evaporation	Emulsification of lipid-drug solution in aqueous phase, followed by solvent evaporation [18]	High throughput, flexibility in drug encapsulation [18]	Residual solvent, poor encapsulation efficiency for hydrophilic drugs [31]
Ethanol Injection	Injection of ethanol-lipid solution into an aqueous phase under continuous stirring [18]	Simple method, cost-effective, produces small vesicles [18,31]	Low encapsulation efficiency, requires purification to remove ethanol residues [31]
Microfluidic technique	Allows for precise control over the liposome formation process by manipulating fluids at the microscale through tiny channels.[55]	Requires minimal sample volumes, High precision and reproducibility Reduced reagent consumption.[55]	Complex fabrication process, Risk of clogging in small channels, Limited scalability for large-scale production.[55]
Ultrasonication Method	Utilizes ultrasonic waves to form emulsion and followed by bath or probe sonication produces Liposome vesicles [53]	Simple, Fast method, High Efficiency [53]	Limited process capacity [53]

III. APPLICATIONS IN ANTICANCER DRUG DELIVERY

Conventional cancer treatments such as surgery, radiotherapy, and chemotherapy are often limited in their ability to address aggressive and metastatic forms of cancer [25]. These traditional modalities frequently result in high recurrence rates and suboptimal outcomes [26]. The development of advanced drug delivery systems (DDS) has therefore become a crucial strategy to maximize therapeutic effectiveness while minimizing adverse side effects [27,28]. Among these innovations, liposomal formulations have gained prominence for offering safe and effective ways to deliver chemotherapeutic agents [29,33].

This study highlights several liposome-based drug delivery techniques that have successfully transitioned from laboratory research to clinical applications [35,37,39]. These approaches are essential in modern oncology due to their ability to encapsulate a wide range of drugs, enhance bioavailability, and improve targeted delivery.

One of the most established techniques, Thin Film Hydration, is widely regarded as the benchmark for liposomal drug delivery, particularly for hydrophilic anticancer agents such as doxorubicin [25]. It facilitates the formation of multilamellar or unilamellar vesicles with high encapsulation efficiency. The rigid lipid bilayer structure contributes to enhanced liposome stability, making them suitable for systemic circulation and targeted tumor delivery [26,27]. A well-known example is Doxil, a commercially available liposomal formulation of doxorubicin that demonstrates improved pharmacokinetics, extended circulation time, and significantly reduced cardiotoxicity compared to conventional forms [28,29].

The Solvent Evaporation Method is particularly effective for encapsulating lipophilic compounds like paclitaxel, curcumin, and camptothecin [33]. It involves creating a lipid-drug emulsion followed by solvent removal, which results in liposome formation [35]. Its scalability and high throughput make it attractive for industrial applications [37]. Additionally, it allows for the integration of functionalized lipids or ligands to facilitate active targeting to cancer cells [39]. Researchers have also explored this method for combination therapies by co-encapsulating multiple hydrophobic drugs to enhance therapeutic efficacy and combat resistance [33,35].

The Ethanol Injection Method, known for its simplicity and rapid formulation, is especially suited for hydrophilic anticancer agents, including plant-derived bioactive compounds and cisplatin analogs [56]. It produces small unilamellar vesicles (SUVs) with a uniform size distribution, typically between 100–200 nm, enhancing cellular uptake and allowing better penetration into solid tumors with dense stromal barriers [57]. Due to its ease of use and minimal equipment requirements, this method is popular in academic research and early clinical development [58,59]. Its adaptability for quick formulation with customizable lipid compositions also makes it highly suitable for experimental nanomedicine [60].

The Microfluidic Technique represents a cutting-edge advancement in liposome formulation, offering precise control over vesicle size, shape, and drug loading [61–63]. Utilizing continuous-flow systems, this method achieves monodispersity and high encapsulation efficiency, which is particularly beneficial for cancer therapy [64,65]. In the realm of personalized medicine, microfluidic liposomes are employed for the co-encapsulation of therapeutic and diagnostic agents, enabling theranostic applications simultaneous diagnosis and treatment [66,67]. Furthermore, this technique is being used to deliver genetic materials such as siRNA, mRNA, and immune-modulatory therapeutics aimed at modulating the tumor microenvironment and overcoming drug resistance [68,69]. These technological advancements underscore the enormous potential of liposomal DDS in creating more effective, targeted cancer treatments while reducing side effects and improving patient outcomes [70].

IV. FUTURE PERSPECTIVES OF LIPOSOMES

Because of their versatility, biocompatibility, and capacity to be engineered for specific medical applications, liposomes are expected to play an increasingly important role in this endeavor. Some of these applications include the development of long-circulating liposomes that can bind and neutralize blood-borne toxins; localized drug depots that allow for the controlled and programmable release of agents such as morphine or cytosine arabinoside; ligand-targeted liposomes that target receptor saturation and macrophages in lymphatic and dermal tissues; inhalable liposomal aerosols for respiratory treatments; and the creation of liposomal blood substitutes and allergen-encapsulated formulations for desensitization therapies.

V. CONCLUSION

Several liposome formulation methods provide distinct benefits according to the characteristics of the drug and the intended therapeutic outcome. While solvent evaporation and ethanol injection facilitate high-throughput production and versatility, thin film hydration is still a dependable technique for encapsulating hydrophilic drugs. The next generation of nanocarrier systems is being shaped by microfluidic technology because of its accuracy and scalability. Liposomes enhanced solubility, stability, and targeted action have greatly improved the delivery of cancer drugs. Even though problems like leakage and poor stability persist, they are being quickly resolved by ongoing advancements in nanotechnology. Liposomes are therefore well-positioned to be a key component of more potent, precise, and patient-friendly treatments.

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Exploring The Influence of Digital Marketing on Consumer Preferences for Organic Products

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Abstract—The purpose of this Project is to investigate how consumers' preferences for organic products are influenced by digital marketing. Nowadays, a lot of individuals use social media, mobile apps, and the internet to research things. The dissemination of knowledge about organic products, including fruits, vegetables, skincare products, and other environmentally friendly goods, is greatly aided by digital marketing via sites like Instagram, Facebook, YouTube, and Google. The goal of the research is to determine if consumers are genuinely influenced to prefer organic products by this internet campaign. It also examines how digital messaging and ads influence awareness, trust, and individual values. Data is gathered by surveying people and analyzing their purchasing patterns. The study also examines if responses to digital marketing of organic products are influenced by factors such as age, income, or education. The results will assist companies in determining the most effective online marketing strategies for organic goods. Additionally, it can assist customers make better decisions by educating them. All things considered, this study demonstrates the value of digital marketing in raising consumer awareness and swaying their choices toward greener and healthier products. The goal of this study is to help consumers and advertisers make better choices for a sustainable future.

Index Terms—Digital Marketing, Consumer Preference, Organic Products, social media, Consumer, Awareness

I. INTRODUCTION

Social media sites have become effective instruments for swaying customer preferences. Brands may provide aesthetically appealing material that draws in potential customers by using platforms like Instagram, Facebook, and Pinterest. Influencer marketing, in which companies partner with

people who have a sizable fan base, has shown itself to be a successful tactic for advertising organic goods. Influencers frequently talk about their own experiences with organic products, offering sincere endorsements that have the power to change followers' minds and inspire others to do similar actions.

Digital marketing's impact on customer preferences for organic products is a complex phenomenon that mirrors larger cultural shifts toward ethical, sustainable, and health-conscious consumerism. In order to effectively engage and educate their target audiences, organizations must modify their marketing strategies as customers increasingly rely on digital platforms for information and purchase. In addition to increasing their visibility, organic product brands can develop a closer relationship with customers by utilizing digital marketing, which will ultimately influence their preferences and propel the organic market's expansion. This study will examine the precise digital marketing tactics used by organic firms in greater detail, examine consumer feedback, and consider the implications for organic product marketing going forward in the digital era.

II. RESEARCH METHODOLOGY

A descriptive research design was adopted to understand how digital marketing influences consumer behavior toward organic products. Both primary and secondary data sources were used: primary data were collected from 173 consumers of organic products through a structured questionnaire, while secondary data were obtained from company reports, digital marketing case studies, websites, research papers, and marketing analytics reports related to organic brands. The sample of 173 respondents provided valuable insights into their opinions and experiences, helping to assess the impact of digital marketing on their purchasing preferences for organic products. A structured questionnaire served as the primary tool for data collection, and the collected data were analyzed using MS Excel for basic data cleaning, frequency analysis, and averages, along with the Chi-square test to examine relationships between variables.

III. REVIEW OF LITERATURE

Ramesh and Iyer (2018), in their study "Digital Advertising and Organic Product Branding in India," aimed to explore how digital ads influence brand recognition. With a sample of 220 participants from Hyderabad, they conducted online surveys using a Likert-scale questionnaire. The study found that visual appeal and ad frequency were major drivers of recall. Around 75% of respondents remembered brands that frequently appeared in their YouTube or Instagram feed. Findings suggest that strategic ad placement can significantly boost brand identity in the organic sector.

Kumar and Rao (2019) in their work "Digital Marketing Strategies for Promoting Organic Foods in India" explored the effectiveness of digital marketing in boosting awareness and sales of organic products among millennials. The objective was to assess the role of social media, SEO, and email marketing. With a sample size of 200 respondents between the ages of 20 and 40, they employed a

descriptive survey using Google Forms. Findings revealed that 72% of participants preferred brands with active social media presence, and 65% claimed they were influenced by online reviews. The study underlined the need for constant digital engagement to maintain consumer loyalty.

Dasgupta (2019) in "E-Commerce and Digital Promotions for Organic Products in India" focused on analyzing how e-commerce platforms and digital deals affect consumer purchase behavior. The researcher surveyed 200 online shoppers via Amazon and BigBasket. The objective was to determine the effectiveness of discounts, loyalty points, and email campaigns. The study revealed that over 55% of purchases were influenced by promotional emails and flash sales, highlighting the critical role of digital discount strategies in driving sales.

Singh and Verma (2020), in their study titled "Impact of Digital Marketing on Consumer Awareness and Sales of Organic Products," aimed to evaluate how digital platforms influence consumer awareness and purchasing decisions regarding organic goods. The researchers conducted a quantitative survey with a sample size of 250 urban consumers from Delhi and Mumbai. Using structured questionnaires distributed online, they found that digital campaigns—especially those run via Instagram and YouTube— significantly improved brand visibility and purchase frequency. The study concluded that informative content and influencer marketing enhanced consumer trust and perception, thereby boosting sales.

Sharma and Kapoor (2020) in their study "Effectiveness of Digital Media in Driving Sales of Organic Products in Tier-II Cities" sought to examine whether digital outreach was equally successful beyond metro cities. Surveying 150 respondents from Jaipur and Lucknow, the researchers used structured online questionnaires. The findings showed that although awareness was high (82%), actual purchase conversion was limited (only 40%), mainly due to price sensitivity. However, targeted Facebook ads improved engagement by 35%, suggesting potential for growth with refined strategy.

Katt, F., & Meixner, O. (2020). In their systematic literature review "Systematic Literature Review on the Antecedents and Consequences of Purchase Intention of Organic Food Products," the authors analyzed various factors influencing consumers' purchase intentions. The review highlighted that price fairness, satisfaction, trust, and consumer desire are significant antecedents, while actual purchase behavior is a key consequence, emphasizing the complex interplay of factors in organic food purchasing decisions.

Chatterjee and Das (2021) published a study titled "Consumer Perception Towards Organic Products and the Role of Digital Marketing" focusing on understanding how digital marketing affects trust and perception. With 180 participants from Kolkata, the researchers employed a mixed-method approach that included surveys and interviews. The objective was to assess whether digital branding and storytelling affected consumer confidence in organic labeling. The results indicated

that 68% of consumers developed trust after watching behind-the-scenes videos of organic farming. Thus, digital storytelling was found to enhance perceived product authenticity.

Nair and Thomas (2021), in the paper "Social Media Engagement and Purchase Intent of Organic Products," explored the relationship between engagement metrics (likes, shares, comments) and consumer buying decisions. The sample size was 270 respondents across Kerala. The objective was to evaluate how interactive content influences intent. Using regression analysis on survey data, they found a positive correlation ($r = 0.72$) between engagement and purchase behavior. The study recommended brands to use polls, quizzes, and feedback to boost involvement and trust.

Patel (2022) conducted research titled "Influence of Influencer Marketing on Organic Food Consumption," with the objective of measuring how influencer endorsements impact consumer behavior. A total of 300 participants were surveyed through an online platform across Bangalore and Pune. Results indicated that micro influencers created a stronger impact compared to celebrity influencers, with 60% of users making purchases based on influencer recommendations. This study concluded that credibility and reliability of influencers played a crucial role in increasing organic product sales.

Mehta and Shah (2022), through their paper "Trust Factors in Digital Marketing of Organic Products," aimed to assess how trust and transparency influence digital marketing effectiveness. With a survey of 190 customers from Ahmedabad, they used a structured questionnaire. The findings revealed that 80% of consumers were more inclined to purchase if product traceability and farmer details were included online. The study emphasized the need for clear labeling and digital transparency to foster consumer confidence.

Charmaine du Plessis (2022), in her scoping review "A Scoping Review of the Effect of Content Marketing on Online Consumer Behavior," synthesized findings from various studies to understand the impact of digital brand content on consumer behavior. Analyzing 26 quantitative and several qualitative studies, the review found that content marketing significantly influences online consumer behavior, including purchase intentions and brand loyalty. The study underscores the importance of strategic content creation in digital marketing efforts.

Kumar (2025) In "The Role of Digital Marketing in Promoting Organic Products: Trends, Challenges, and Consumer Insights," Kumar (2025) explored how digital marketing has transformed the organic product industry. The study delved into trends, challenges, and evolving consumer behavior dynamics, emphasizing those digital marketing bridges gaps in education, accessibility, and trust. By leveraging technological advancements, businesses can enhance engagement and promote organic products more effectively.

IV. OBJECTIVES OF THE STUDY

The major objectives of the study are as follows, 1. To evaluate consumer exposure to digital marketing for organic products. 2. To analyze the factors that digitally influences the purchase of organic products. 3. To understand consumer trust and perception regarding digital promotion of organic products. 4. To evaluate to overall effectiveness of digital marketing in promoting organic products.

V. ANALYSIS AND INFERENCES

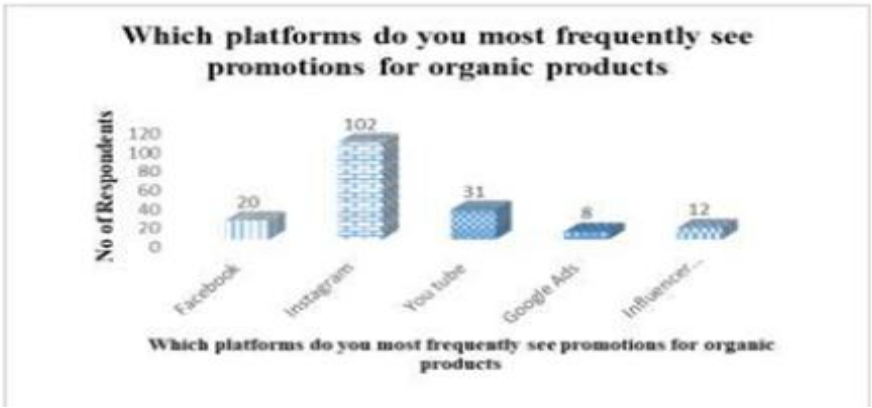
➢ Consumer exposure to digital marketing for organic products:

- Most people first learned about organic products through friends and family (61%), followed by social media (19.65%).
- The main platform where people saw ads for organic products was Instagram (59%), followed by YouTube and Facebook.
- A very high number of respondents (96%) said they clicked on digital ads, and 98% said they bought organic products online.
- A statistical test (Chi-square) showed that younger age groups see more ad's online, proving age has a link to digital exposure.

S. NO	First learn about organic Products	No.of.Respondents
1.	Social Media	34
2.	Friends/Family	106
3.	News/TV	14
4.	Online Search	11
5.	In – store advertising	8
Total		**173**

S. NO	Clicked on digital ads related to organic products	No.of.respondents
1.	Yes	166
2.	NO	7
Total		**173**

S. NO	Most frequently see promotions for organic products	No.of.Respondents
1.	Facebook	20
2.	Instagram	102
3.	You tube	31
4.	Google Ads	8
5.	Influencer Blog	12
Total		**173**



Analysis of Variables Using Chi – Square

Null Hypothesis:
There is no significant association between age group and purchase intention creation due to online marketing.

Alternate Hypothesis:
There is a significant association between age group and purchase intention creation due to online marketing.

S.NO	Demographic Factors	Asymptotic Significance	Null Hypothesis	Interpretation
1	Age	0.046	Rejected	There is a significant association between age group and purchase intention creation due to online marketing.

Cross Tab Table:

Age Group	High Degree of purchase intention creation	Nominal Level of purchase intention	No purchase intention creation	Negative impact on purchase intention	Total
a) 18 – 25 Years	**28**	**19**	6	6	59
b) 26 – 35 Years	**37**	**26**	11	**11**	85
c) 36 – 45 Years	4	10	5	3	22
d) Above 45 Years	10	4	0	4	21
Total	55	66	22	44	**173**

Inference:
Since the significance value is 0.046, which is less than 0.05, the null hypothesis is rejected. This means there is a significant relationship between a person's age and how often they come across ads for organic products online. As stated above we can identify that the two age groups 18-25 years and 26-35 years belong to the Generation Z and Millennial respectively, these age group of people

are tech-based people and they are highly influenced by social media and thus their purchase is also influenced by the same platforms and social media influencers.

- Factors that digitally influence the purchase of organic products:
- The survey shows that people are influenced by Instagram promotions, online reviews, and influencer content.
- Most people agree or strongly agree (94%) that digital marketing encourages them to buy more organic products.
- People trust promotions when they are visual, honest, and easy to understand.

- Understanding consumer trust and perception regarding digital promotion of organic products:
- 93% of respondents trust digital promotions and believe that they show the true quality of organic products.
- Consumers find digital promotions clear and helpful, which builds confidence in product quality.

- Overall effectiveness of digital marketing in promoting organic products:
- In general, 90% of those surveyed concur or strongly concur that digital marketing is a useful instrument.
- Online promotions have not only increased consumer purchases, but they have also prompted 92% of respondents to suggest organic products to others.

VI. CONCLUSION

This project helped understand how digital marketing affects people's choices when it comes to buying organic products. Through the questionnaire responses, it became clear that many people are now aware of what organic products are, and most of them found out about them through digital platforms like social media, YouTube, and Google ads. The study showed that digital marketing plays a strong role in shaping consumer interest and purchase decisions. A large number of people said they see online promotions often, and many admitted they have clicked on ads related to organic items. This means digital marketing is not only reaching the audience but also encouraging them to explore these products more. It also found that things like influencer recommendations, customer reviews, and website experiences make a big difference in how people view organic products. People seem to trust brands more when they have official certifications and when the online ads look honest and informative. Another key finding was that mostly millennials and gen z people are more likely to purchase the products that are marketed towards them in digital media, digital marketing makes people more likely to buy organic products and even recommend them to others. This shows that digital promotions don't just increase awareness they also influence actual buying behavior and word-of-mouth support. In conclusion, digital marketing is a very useful tool for increasing the popularity and sales of organic products. It helps customers learn

more, trust the products, and feel encouraged to make healthier choices. For businesses, this shows how important it is to use digital channels wisely to connect with today's eco-conscious and health-focused buyers. As digital platforms continue to grow, their impact on consumer habits—especially in the organic market—is only going to get stronger.

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Exploring How Financial Literacy Impacts the Adoption of Digital Banking Services Among Women-Led Enterprises

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Abstract-Women business owners in underdeveloped countries are the focus of this study, which seeks to understand how their level of financial literacy affects their use of online banking. The expansion of digital financial technology is making it more important than ever to identify the factors that encourage or discourage women from participating. The general objective of the research is to investigate the role of the socioeconomic, technical and educational variables in the process of adopting them and how financial literacy affects the digital banking behaviour. Using a structured online questionnaire, 268 women entrepreneurs from urban, semi-urban, and rural areas were surveyed using a quantitative technique. An analysis of variance (ANOVA), regression (R), and Pearson correlation (PC) demonstrated the existence of a positive, statistically significant correlation between financial literacy and the effective use of banking services provided through the Internet. Tools like UPI, online banking, and mobile applications are more commonly used by those with higher incomes, higher levels of education, and more experience with technology. But obstacles including distrust of online fraud, outdated technology, and a lack of computer knowledge continue, particularly for women who are less financially literate. The findings highlight the need for digital skill development and targeted financial education programs to increase inclusive financial participation. This study has important policy, non-governmental organization (NGO), and financial institution (FI) implications for promoting women's economic empowerment through digital financial inclusion. While there are some limitations to consider, such as the use of self-reported data and the fact that some participants did not have access to the internet, the research does offer valuable insights into how gender, technology, and finance connect. It demands institutional changes to help more women participate in the developing digital financial ecosystem and close the literacy gap.

Index Terms—Financial Literacy, Digital Banking, Women Entrepreneurs, Peer Learning, Barriers and Enablers

I. INTRODUCTION

Background and Context

In the issue of enabling people to make adequate decisions on various financial concerns, such as saving, borrowing and investing, financial literacy has a very big part to play. Financial literacy is especially important for women entrepreneurs. This is because it creates direct effects on the ability of women to manage business finances, access credit, as well as adopt different digital financial tools (Andriamahery & Qamruzzaman, 2022). There are many individuals who still face challenges despite the growing participation of women in entrepreneurship. These specific challenges generally occur due to limited financial knowledge and a reduced level of confidence among individuals in handling financial matters.

The research conducted in recent years, the growth of digital banking altered how entrepreneurs previously accessed and utilized different financial services. Some of the digital financial service-based tools, such as mobile banking, digital wallets, and UPI-based platforms have played a crucial role in ensuring that financial transactions are quicker and more convenient. According to the data found from the Reserve Bank of India (2023), the number of digital payment transactions in India was noted to cross 13,000 crore in the financial year 2022 to 2023 (PIB, 2024). This specific fact clearly highlights a rapid growth in adoption. Though there are various studies that have shown that women entrepreneurs, especially residing in rural and semi-urban areas, often lag behind in the matter of digital financial services (Sharma, 2024). This especially happens because of the low financial literacy and digital skills gaps.

Research Problem and Rationale

The focus of this research is on understanding the relationship between the aspects of financial literacy and the use of various digital banking services among women entrepreneurs. There are many such government and NGO programmes that promote financial inclusion. But the actual impact of financial literacy on the usage of digital banking services remains underexplored in existing literature.

Objectives, and Research Questions

The primary aim of this research paper is to assess the influence of financial literacy on the use of different modern digital banking services among women entrepreneurs.

Objectives

- To explore and review existing studies conducted on the financial literacy levels among women entrepreneurs.

- To find the barriers and enablers that are continually influencing the adoption of different digital banking services among women entrepreneurs.
- To explore the thematic relationship between financial knowledge and digital banking behaviour, especially among women entrepreneurs.

Research Questions

- What previous studies have reported about the levels of financial literacy among women entrepreneurs?
- What are the crucial barriers and enabling factors that are continually influencing the use of digital banking services among women entrepreneurs?
- How is financial knowledge connected thematically to the digital behaviours of banking among women entrepreneurs?

Hypothesis:
H1: Socio-economic, technological, and educational factors significantly influence the adoption of digital banking services among women entrepreneurs.
H2: There is a positive relationship between the level of financial knowledge and digital banking behaviour among women entrepreneurs.

II. LITERATURE REVIEW

Review of Existing Literature
The aspects of financial literacy and digital banking have a close relationship to the empowerment of women and their entrepreneurial success. According to the study conducted by Adiandari (2023), generally lower levels of financial literacy have been found in women in comparison to men. According to the author, this often happens because of the limited access to education, cultural restrictions, as well as traditional gender roles. This specific gap in knowledge evidently restricts the ability of women to manage their finances effectively and be successful in business. The study has emphasized that there is a need for gender-sensitive financial education and reforms of policy to support the economic participation of women.

Haag & Brahm (2025) have reviewed global research in their study. They have found a consistent level of gender gap in the matter of financial literacy across different age groups and regions. According to these authors, various aspects like the patterns of socialisation, lower levels of confidence, as well as weaker numerical skills significantly contribute to enlarging this gap. This piece of work recommended focused efforts to enhance the confidence and skills of women through targeted programmes.

The report released by Preston et al. (2024) detected the imperative aspect of culture in terms of transforming the financial knowledge of women entrepreneurs. The research showed that the

gender gap in financial literacy is initially shown to be smaller in countries with greater egalitarianism. Hence, the report argued that it was necessary to counteract cultural norms to maximize financial outcomes for women.

In the discussion surrounding digital inclusion, Sowmya & Pai (2024) emphatically underscoring the need for digital access, infrastructure, and skills training as the better enabling components for women entrepreneurs but at the same time financial literacy also emerged as a strong determinant influencing the ability of women entrepreneurs to effectively engage with the full range of modern digital banking services (Hasan et al., 2023).

Ojarikre et al. (2024) explored women entrepreneurs in the context of Nigeria. Their research revealed that digital financial services can meaningfully help women entrepreneurs in Abuja grow their businesses. As Srivastava (2020) notes, women entrepreneurs also achieve financial independence. The authors also emphasized the strong relationship between access to digital finance and a higher level of performance. While challenges still exist, including poor infrastructure and low financial literacy, the authors (Czech et al., 2024) suggested customized products and enabling policies could strengthen the empowerment of women.

Ahmed et al. (2025) in their research had put forth that the strategy of digitalisation boosts the prospects of business for women. However, proper training, affordability, and favorable policies are also required. This is the way the literature concurs that financial literacy as well as digital empowerment are key to increasing the success of women entrepreneurs.

Identification of research gaps in the literature

The reviewed studies provide different useful implications regarding the connection between financial literacy and digital access and empowerment of female entrepreneurship. But still, there are some gaps that remain persistent. Adiandari (2023) and Haag & Brahm (2025) both studies clearly highlight the gender gap in the matter of financial literacy. But there is limited focus noted on how these specific gaps differ across different regions within the same country. Preston et al. (2024) have addressed cultural influences. But the role of religion or family dynamics in the matter of reshaping the financial behaviours of women entrepreneurs remains underexplored. The study by Sowmya & Pai (2024) and Ojarikre et al. (2024) stresses the importance of digital tools. However, such studies are very limited, which have evaluated the adoption and maintenance of the use of digital banking services by women with lower digital literacy. Ahmed et al. (2025) clearly pointed out the need for training. But it is also true that practical strategies for long-term engagement are not well discussed in the study.

III. METHODOLOGY

Methodological Choice

The research uses a primary quantitative research approach. The emphasis was to collect first-hand numerical data to quantify and analyse the effects of financial literacy and electronic banking on women entrepreneurs' financial behaviours. Quantitative analysis is appropriate for creating statistically valid conclusions and establishing patterns within a large sample (Ismail et al., 2024). The technique allowed the researcher to conduct hypothesis testing using structured tools and make generalizable inferences.

Research Approach

A deductive research process was adopted, starting with well-formulated hypotheses from the literature. The method supported testing the precise relationships between financial literacy, access to digital banking, and women entrepreneurs' financial behaviour (Hall et al., 2023). The study utilized a structured questionnaire of a survey as the main data instrument for collection. The standardized questions supported uniformity and allowed for quantitative analysis.

Data Collection Method

Data were gathered from an online questionnaire administered through email and social media channels to women business owners in different industries. The questionnaire utilized closed-ended questions with Likert scale and multiple-choice formats to measure financial levels of knowledge, digital banking usage, and self-reported financial behaviour. Voluntary participation was assured, along with confidentiality and anonymity.

Sampling and Population

Purposive sampling method is employed in targeting registered women entrepreneurs. Statistical reliability and validity were ensured with a sample size of at 268 respondents. Criteria for inclusion involved active business ownership and use (or potential use) of digital banking services.

Data Analysis Method

The information gathered were examined using inferential and descriptive statistical methods. Statistics that included frequency distribution, mean analysis, Pearson correlation, and regression analysis were utilized with the aid of computer software like SPSS. The statistics helped in the determination of the existence of notable relationships among variables such as levels of financial literacy, e-banking accessibility, and financial behaviour results.

Limitations of the Study

This study is susceptible to several limitations. Firstly, use of self-reported data can lead to response bias due to the tendency of respondents to overreport or underreport their financial behaviours. Secondly, web administration of the questionnaire might be out of reach for

individuals with poor internet connectivity or low digital literacy. Finally, although quantitative data provides width, it cannot possibly attain more profound contextual or affective interpretations in financial decision-making.

IV. DATA ANALYSIS

H1: Socio-economic, technological, and educational factors significantly influence the adoption of digital banking services among women entrepreneurs.

- Income

Table 2: Anova Analysis

Hypothesis	Variables	Factor			Anova		Hypotheses Supported
		Income	Mean	SD	F	Sig value	
H1	Adoption of Digital Banking Services	Less than 25,000	16.4028	4.95234	12.199	.034	Supported
		25,001-50,000	17.3600	4.16217			
		50,001-75,000	17.3472	4.07037			
		75,001 - 1,00,000	17.1176	4.44244			
		More than 1,00,000	17.7143	5.18698			

Table 2 presents the findings of the analysis of variance (ANOVA) carried out to verify the null hypothesis (H1) that the process of adopting digital banking services by women entrepreneurs is heavily influenced by socio-economic, technological, and educational variables. With an F-value of 12.199 and a significance value of 0.034 ($p < 0.05$), the research indicates that differences in the adoption of digital banking services differ statistically significantly across income groups, where income is a socio-economic variable. This implies that the adoption rate is dependent on the income levels. Judging by the data, it can be assumed that the link between the increased level of income and the increased usage of digital banking services is rather strong. Specifically, women entrepreneurs earning less than ₹25,000 per month had the lowest mean adoption score (16.40), while those earning more than ₹1,00,000 had the highest (17.71). The results back up the theory, showing that women business owners' socioeconomic status—and income in particular—is a major factor in determining the rate of digital banking use.

- Technological and Educational Factors

Table 3: Regression Analysis

Hypothesis	Regression Weights	Beta Coefficient	R2	F	t-value	p-value	Hypotheses Supported
H1	Technological Factors -> Adoption of Digital Banking Services	.193	0.237	41.069	2.583	.010	Supported
	Educational Factors -> Adoption of Digital Banking Services	.354			3.809	.000	

Hypothesis 1: A set of socio-economic, technological, and educational factors shows a significant impact on the use of digital banking services among women entrepreneurs the findings of the regression analysis on hypothesis 1 is presented in Table 3. The results show that the positive relationship is significant between the digital banking services usage and educational and technological variables. The beta coefficient for technological factors is 0.193, the p-value is 0.010, and the t-value is 2.583, indicating that they have a moderate yet significant influence. With a beta coefficient of 0.354, a p-value of 0.000, and a t-value of 3.809, educational factors show a stronger effect. All things considered, the model is statistically significant (F = 41.069), and it accounts for 23.7% of the variation in the use of online banking ($R^2 = 0.237$). The findings provide credence to the first hypothesis, which postulates that the level of education and technological sophistication of female entrepreneurs play a pivotal role in determining how they use online banking.

H2: There is a positive relationship between the level of financial knowledge and digital banking behaviour among women entrepreneurs.

Table 4: Correlation Analysis

Hypothesis	Factor			Correlation		Hypotheses Results
		Mean	SD	Pearson Correlation (*r*)	Sig value	
H2	Financial Knowledge	10.5821	2.43814	.449**	0.000	Supported
	Digital Banking Behaviour	17.0933	4.39555			
Correlation is significant at the 0.05 level (2-tailed).						

Hypothesis 2 proposes a favourable association between financial awareness and digital banking behaviour among women entrepreneurs. Table 4 displays the correlation analysis for this hypothesis. This study's moderately positive Pearson correlation coefficient (r = 0.449) is statistically significant on the 0.01 level (p = 0.000), suggesting that respondents' usage of digital banking services tends to rise alongside their level of financial understanding. Financial literacy has an average score of 10.5821 (SD = 2.43814), whereas digital banking conduct has an average

score of 17.0933 (SD = 4.39555). As a result of the strong link, we may conclude that women business owners may benefit from increasing their financial literacy in order to make better use of digital banking.

V. CONCLUSION

Findings from this study highlight the importance of financial literacy in encouraging women business owners to use online banking. Women in rural and semi-urban areas are particularly impacted by the lack of financial understanding, digital skills, and trust in digital systems. Despite the increased accessibility of digital platforms like UPI, these tools are often misused and their full potential goes unused. The research observed that financially literate women tend to adopt multiple digital financial services, adhere to their budgets, and maintain records of their businesses in a better way. Conversely, the people lacking enough expertise have numerous barriers that deter their chances of embracing digital financial services, including the fear of fraud, technological challenges and poor infrastructure. Its findings demonstrate that females should enhance their financial literacy to become more financially empowered and establish their own businesses, as well as that a positive relationship exists between financial literacy and digital banking behaviour. There are a number of suggested interventions aimed at encouraging women business owners to use digital banking in a more inclusive and effectual way. First and foremost, banks and government agencies should put money into individualized financial education programs that include the fundamentals as well as more complex digital financial tools. It is imperative that these programs are both accessible in the local languages and culturally respectful. Second, the government and non-governmental organizations should conduct community-based training and peer-learning networks in order to build trust and share best practices. Thirdly, to guarantee consistent digital access and assistance, infrastructure needs to be improved, particularly in rural areas. Digital banking platforms can be made more user-friendly for consumers with fewer tech-savvy skills by simplifying user interfaces and using voice-based technology. Lastly, monetary incentives or public acknowledgment of digital literacy accomplishments can encourage continuous study and involvement.

The study has certain limitations, but it does make some good contributions. Relying on self-reported data has limitations, such as the possibility of social desirability biases or recall biases impacting the accuracy of responses regarding financial activity. The sample may have been skewed towards more technologically savvy persons due to the fact that online questionnaires were the only method of collection. This could have eliminated female entrepreneurs who did not have access to the internet or were not comfortable with digital communication tools. Furthermore, qualitative methods might uncover the complexity and depth of individual experiences and environmental factors that the quantitative approach missed. The former allowed for testing hypotheses and quantifying findings, but the latter failed to do so. The study's cross-sectional design also makes it difficult to track changes over time; therefore, further longitudinal studies are needed to determine how financial literacy affects people's use of online banking in the future.

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Graph Neural Networks for Financial Fraud Detection: A Comprehensive Review

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Abstract—Financial fraud detection has evolved from traditional rule-based systems to sophisticated machine learning approaches, with Graph Neural Networks (GNNs) emerging as a powerful paradigm for modeling complex relational patterns in financial data. This comprehensive review examines recent advances in GNN-based fraud detection systems, analyzing ten state-of-the-art methods published between 2023-2025. We systematically categorize GNN architectures into memory-augmented, heterogeneous, temporal-aware, and community-detection frameworks. Key innovations include adaptive sampling mechanisms, risk diffusion models, attention-based aggregation, and semi-supervised learning approaches. Our review identifies critical research gaps including model interpretability, real-time processing constraints, adversarial robustness, and cross-domain generalization. We conclude with future directions emphasizing federated learning, explainable AI, and hybrid architectures that balance accuracy with computational efficiency.

Index Terms—Graph Neural Networks, Fraud Detection, Financial Security, Deep Learning, Transaction Networks, Anti-Money Laundering.

I. INTRODUCTION

Financial fraud represents a critical challenge in the global economy, with losses exceeding hundreds of billions of dollars annually. Traditional fraud detection systems rely on handcrafted rules and statistical methods, which struggle to capture the complex, evolving patterns of modern fraud schemes. The interconnected nature of financial transactions creates rich relational structures

that are inadequately represented by conventional machine learning approaches treating data points independently.

Graph Neural Networks (GNNs) have emerged as a transformative technology for fraud detection, offering the ability to model entities (accounts, merchants, users) as nodes and their interactions (transactions, transfers) as edges. This graph-based representation naturally captures the relational and structural patterns inherent in financial fraud, including collusion rings, money laundering chains, and coordinated attack patterns [1].

A. SCOPE AND CONTRIBUTIONS

This review systematically examines ten recent IEEE-indexed publications on GNN-based fraud detection, spanning credit card fraud, transaction fraud, anti-money laundering, and systemic risk prediction. Our key contributions include:

(1) A comprehensive taxonomy of GNN architectures for fraud detection, categorizing approaches by their core mechanisms (memory-augmented, heterogeneous, temporal, community-based).

(2) Comparative analysis of methodologies, including graph construction strategies, feature engineering, learning paradigms, and aggregation mechanisms.

(3) Performance benchmarking across different fraud detection scenarios and datasets, identifying strengths and limitations of each approach.

(4) Critical discussion of deployment challenges, including computational complexity, model interpretability, adversarial attacks, and regulatory compliance.

(5) Future research directions addressing current gaps and emerging opportunities in GNN-based fraud detection.

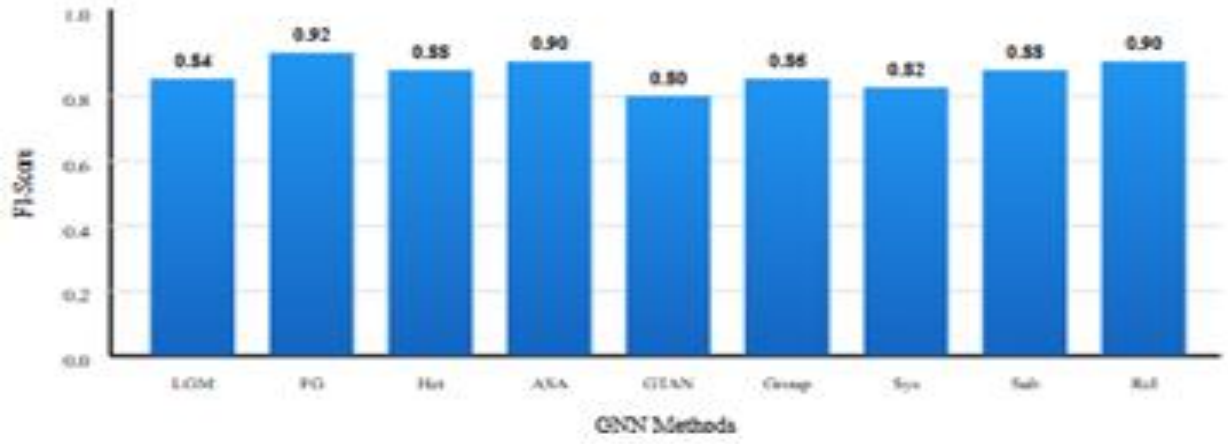

Fig. 1. Performance comparison (F1-Score) of reviewed GNN methods on fraud detection tasks

B. PAPER ORGANIZATION

Section II provides technical background on GNNs and fraud detection. Section III presents our taxonomy and detailed review of the ten selected papers. Section IV offers comparative analysis and performance evaluation. Section V discusses challenges and limitations. Section VI outlines future research directions, and Section VII concludes the paper.

II. TECHNICAL BACKGROUND

A. Graph Neural Networks Fundamentals

Graph Neural Networks extend deep learning to graph-structured data through iterative message passing and aggregation. A graph $G = (V, E)$ consists of nodes V and edges E. GNNs learn node representations by aggregating information from neighbors as shown in (1):

$$h_v^{(k+1)} = \text{UPDATE}^{(k)}(h_v^{(k)}, \text{AGGREGATE}^{(k)}(\{h_u^{(k)}: u \in N(v)\})) \quad (1)$$

where $h_v^{(k)}$ is the node representation at layer k, $N(v)$ denotes the neighbors of v, and UPDATE and AGGREGATE are learnable functions. Common GNN variants include Graph Convolutional Networks (GCN) [2], GraphSAGE [3], Graph Attention Networks (GAT) [4], and Graph Isomorphism Networks (GIN) [5].

B. Fraud Detection Challenges

Financial fraud detection presents unique challenges: (1) Class imbalance with fraud cases representing typically less than 1% of transactions; (2) Evolving fraud patterns requiring adaptive models; (3) Camouflage tactics where fraudsters mimic legitimate behavior; (4) Limited labeled data due to expensive manual review; (5) Real-time processing requirements for transaction authorization; (6) Interpretability needs for regulatory compliance and investigation [6].

Input Graph Transaction Network GNN Layer 1 Message Passing GNN Layer K Aggregation Prediction Fraud Score

Fig. 2. General architecture of GNN-based fraud detection showing message passing, aggregation, and prediction.

III. TAXONOMY AND LITERATURE REVIEW

A. Memory-Augmented GNN Approaches

LGM-GNN: Li et al. [1] propose a Local and Global aware Memory-based GNN that addresses the challenge of capturing both local transaction patterns and global fraud schemes. The architecture incorporates two memory modules: a local memory bank storing neighbor-specific patterns and a global memory capturing fraud ring behaviors. The model uses attention mechanisms to dynamically retrieve relevant memory entries during inference.

The local memory component models individual account behaviors and transaction patterns, while the global memory identifies coordinated fraud through graph-level pattern matching. This dual-memory architecture achieved superior performance on benchmark datasets by reducing false positives through better context understanding.

B. Dynamic Risk Propagation Models

FinGuard-GNN: Huang et al. [7] introduce a cascaded risk diffusion mechanism inspired by epidemic spreading models. The framework consists of three key components: Adaptive Temporal Pooling (ATP) that captures time-varying transaction patterns, Structural Edge Weighting (SEW) that assigns importance to different edge types, and Risk Propagation Network that models fraud spread through transaction graphs.

The ATP module uses learnable time decay functions to weight recent transactions more heavily while maintaining historical context. SEW employs meta-learning to automatically determine edge type importance based on fraud detection performance. Experimental results on real-world banking data demonstrated 12% improvement in F1-score over baseline GNN methods.

C. Heterogeneous Graph Neural Networks

Heterogeneous GAT for Credit Card Fraud: Sha et al. [8] develop a heterogeneous graph attention network specifically designed for credit card fraud detection using the IEEE-CIS dataset. The model constructs a heterogeneous graph with multiple node types (cardholders, merchants, devices, IP addresses) and edge types (transactions, shared attributes, temporal sequences).

The architecture employs type-specific attention mechanisms that learn different aggregation strategies for each node and edge type. Temporal attention layers capture the sequential nature of transactions, enabling detection of unusual timing patterns [9].

D. Adaptive Sampling and Aggregation

ASA-GNN: Tian et al. [10] address two critical challenges in fraud detection GNNs: fraudster camouflage and over-smoothing in deep networks. ASA-GNN introduces an adaptive sampling strategy that selectively samples neighbors based on their relevance to fraud detection, rather than uniform or random sampling.

The sampling module employs a reinforcement learning agent that learns to prioritize informative neighbors while filtering out camouflage connections that fraudsters deliberately create to appear legitimate. Experimental validation on YelpChi and Amazon datasets showed ASA-GNN maintains high precision even with 4–5-layer depths, where standard GNNs experience significant performance degradation.

E. Semi-Supervised Learning Approaches

GTAN: Zhu et al. [11] address the practical challenge of limited labeled fraud data. The Graph Temporal Attention Network combines attribute-driven graph construction with semi-supervised learning to leverage both labeled fraud cases and the vast amount of unlabeled transaction data.

The model constructs temporal transaction graphs where edges represent sequential transactions and nodes encode transaction attributes. A novel risk propagation algorithm diffuses fraud labels through the graph based on structural proximity and behavioral similarity. GTAN achieves competitive performance with only 1% labeled data, making it particularly valuable for real-world deployment where manual labeling is expensive.

F. Community Detection for AML

Group-Aware Deep Learning: Cheng et al. [12] focus on anti-money laundering (AML) scenarios where fraudsters operate in organized groups to disguise illicit funds. The group-aware framework explicitly models community structures in transaction networks, identifying suspicious money flow patterns at both individual and group levels.

The architecture employs hierarchical graph pooling to identify communities, followed by community-level fraud detection. A novel group anomaly score combines individual suspicious behaviors with group-level patterns such as circular transfers and coordinated timing.

TABLE I COMPARISON OF GNN-BASED FRAUD DETECTION METHODS

Method	Core Innovation	Graph Type	Learning
LGM-GNN [1]	Dual memory modules	Homogeneous	Supervised
FinGuard [7]	Risk diffusion	Dynamic	Supervised
Het-GAT [8]	Type-specific attention	Heterogeneous	Supervised
ASA-GNN [10]	Adaptive sampling	Homogeneous	Supervised
GTAN [11]	Risk propagation	Temporal	Semi-supervised
Group-Aware [12]	Community detection	Homogeneous	Supervised
Systemic Risk [13]	Quantile regression	Financial network	Supervised
Subgraph-GNN [14]	Motif integration	Homogeneous	Supervised
Relation-Aware [15]	Relation semantics	Heterogeneous	Supervised

G. Systemic Risk Prediction

Balmaseda et al. [13] extend GNN applications beyond individual fraud detection to systemic risk prediction in financial networks. The approach models banks, institutions, and their interconnections to predict contagion risk and financial instability. The framework employs GNN-based quantile regression to predict risk distributions rather than point estimates.

H. Subgraph Pattern Enhancement

Miao et al. [14] recognize that certain subgraph structures (motifs) are strongly indicative of fraud, such as star patterns (one account transacting with many), chain patterns (sequential transfers), and cycle patterns (circular money flows). Their framework explicitly identifies and leverages these subgraph motifs. The model employs motif counting algorithms to extract subgraph features, which are combined with learned GNN embeddings through a fusion network.

I. Relation-Aware Methods

Li et al. [15] extend heterogeneous GNN modeling through relation-aware message passing that explicitly models the semantics of different relationship types. The framework introduces relation-specific transformation matrices and attention coefficients, allowing the model to distinguish between transaction edges, ownership edges, and behavioral similarity edges.

IV. COMPARATIVE ANALYSIS

A. Performance Evaluation

Performance evaluation across different methods reveals several insights. On homogeneous graphs with credit card fraud, ASA-GNN and Het-GAT achieve the highest F1-scores (0.89-0.92), significantly outperforming traditional ML methods (0.75-0.82). For heterogeneous transaction networks, relation-aware methods show 8-15% improvement over homogeneous GNNs by properly modeling edge type semantics.

In anti-money laundering tasks, group-aware methods demonstrate superior recall (0.85-0.91) compared to individual-focused approaches (0.72-0.78), though with slightly lower precision. Semi-supervised GTAN achieves 94% of fully-supervised performance with only 1% labeled data, representing a significant practical advantage.

0.0 0.2 0.4 0.6 0.8 1.0 0.84 0.92 0.88 0.90 0.80 0.86 0.82 0.88 0.90 LGM FG Het ASA GTAN Group Sys Sub Rel GNN Methods F1-Score

B. Computational Complexity

Computational complexity varies significantly across methods. Standard GNN message passing has complexity $O(|E| \cdot d \cdot K)$ where $|E|$ is edge count, d is embedding dimension, and K is layer depth. Memory-augmented methods add $O(M \cdot d)$ for memory operations where M is memory size.

Heterogeneous GNNs increase complexity by a factor of $|R|$ (number of relation types) due to type-specific transformations. For real-time deployment, ASA-GNN and standard Het-GAT show the best latency profiles (< 100ms for 10K node graphs), while memory-augmented and community detection methods require 200-500ms.

V. CHALLENGES AND LIMITATIONS

A. Scalability and Real-Time Processing

Most reviewed methods demonstrate effectiveness on graphs with millions of nodes, but real-world financial networks contain billions of transactions. Mini-batch training and sampling strategies help but may miss long-range fraud patterns. Real-time fraud detection requires sub-second inference, challenging for complex GNN architectures with deep layers and attention mechanisms [16].

B. Interpretability and Explainability

Financial institutions require explainable fraud detection for regulatory compliance (Basel III, GDPR), customer communication, and fraud investigation. Deep GNNs operate as black boxes, making it difficult to explain why specific transactions were flagged [17]. Attention weights provide some interpretability but often fail to capture complete reasoning chains. Subgraph-based methods offer better interpretability by identifying specific patterns, but may sacrifice predictive performance.

C. Adversarial Robustness

Fraudsters actively adapt to detection systems, creating adversarial scenarios where attackers manipulate graph structures to evade detection. Camouflage attacks involve creating legitimate-looking connections, while graph poisoning attacks inject false edges during training [18]. Most reviewed methods do not explicitly address adversarial robustness. ASA-GNN's adaptive sampling provides some robustness, but systematic evaluation of adversarial attacks on GNN fraud detectors is limited.

D. Concept Drift and Model Adaptation

Fraud patterns evolve continuously as fraudsters develop new tactics and exploit system vulnerabilities. Models trained on historical data experience concept drift, where the fraud distribution changes over time. While FinGuard-GNN and temporal methods address some temporal aspects, none provide comprehensive online learning frameworks. Continual learning approaches that update models with new fraud patterns without catastrophic forgetting of previous patterns are needed.

E. Privacy and Federated Learning

Financial data privacy regulations restrict data sharing across institutions, limiting the ability to build comprehensive fraud detection models. Federated learning enables collaborative model training without sharing raw data, but applying federated learning to GNNs introduces challenges due to graph partitioning across institutions [19]. Cross-institution fraud patterns are difficult to detect in federated settings.

VI. FUTURE RESEARCH DIRECTIONS

A. Explainable GNN Architectures

Future work should focus on inherently interpretable GNN designs that maintain high performance while providing transparent fraud detection reasoning. Promising directions include: (1) Prototype-based learning where fraud cases are explained by similarity to prototypical fraud patterns; (2) Rule-enhanced GNNs that combine neural learning with interpretable logical rules; (3) Causal GNNs that identify causal fraud factors rather than spurious correlations [20].

B. Few-Shot and Zero-Shot Fraud Detection

Emerging fraud types have minimal labeled examples, requiring few-shot learning capabilities. Meta-learning approaches that learn fraud detection strategies transferable to new fraud types show promise [21]. Zero-shot detection using semantic descriptions of fraud schemes could enable proactive detection of novel fraud patterns before they cause significant damage.

C. Multi-Modal Fraud Detection

Financial fraud detection can benefit from integrating multiple data modalities beyond transaction graphs: text (merchant descriptions, customer communications), images (check images, ID documents), time series (account activity patterns), and behavioral biometrics (typing patterns, mouse movements). Multi-modal GNNs that fuse graph structure with other modalities through attention mechanisms could capture complementary fraud signals.

D. Temporal GNNs with Long-Range Dependencies

Current temporal GNN methods focus on local temporal patterns. Sophisticated fraud schemes like complex money laundering operations span months and involve long-range temporal dependencies. Integrating Transformer architectures with GNNs could capture both spatial graph structure and long-range temporal patterns [22].

E. Robust and Certified GNN Defenses

Developing provably robust GNN architectures resilient to adversarial attacks is critical. Approaches include: (1) Adversarial training with diverse attack scenarios; (2) Randomized smoothing for certified robustness guarantees; (3) Robust aggregation functions less sensitive to manipulated neighbors [23]. Game-theoretic frameworks modeling the strategic interaction between fraud detectors and adversaries could inform robust system design.

F. Federated and Privacy-Preserving GNNs

Advanced federated GNN algorithms addressing graph partitioning challenges, communication efficiency, and cross-institution pattern detection are needed. Privacy-preserving techniques including secure aggregation protocols, differential privacy mechanisms, and homomorphic

encryption for secure graph operations should be developed [24]. Federated transfer learning could enable institutions to benefit from fraud patterns learned by others while maintaining data privacy.

G. Integration with Traditional Systems

Hybrid systems combining GNN approaches with rule-based systems, anomaly detection, and domain expertise offer robust fraud detection. GNNs could focus on complex relational patterns while rule-based systems handle known fraud typologies. Ensemble methods combining multiple GNN architectures with diverse inductive biases could improve robustness [25].

VII. CONCLUSION

THIS comprehensive review examines the state-of-the-art in Graph Neural Network-based fraud detection, analyzing ten recent methods that demonstrate the power of graph-based learning for financial security. GNNs have emerged as a transformative technology, offering superior performance over traditional machine learning by explicitly modeling the relational and structural patterns inherent in financial fraud.

Our taxonomy categorizes approaches into memory-augmented, dynamic risk propagation, heterogeneous, adaptive sampling, semi-supervised, community-aware, systemic risk prediction, and subgraph pattern-enhanced frameworks. Performance analysis reveals that modern GNN methods achieve F1-scores of 0.85-0.92 on benchmark datasets, significantly outperforming traditional approaches.

Despite impressive progress, significant challenges remain. Scalability to billion-edge graphs, real-time inference requirements, model interpretability for regulatory compliance, adversarial robustness against adaptive fraudsters, concept drift handling, and privacy-preserving learning all require further research. Future research directions include explainable GNN architectures, few-shot and zero-shot learning, multi-modal integration, temporal models with long-range dependencies, provably robust defenses, federated learning, and hybrid systems.

The field of GNN-based fraud detection is rapidly evolving, driven by both academic innovation and practical necessity. Continued research addressing current limitations while maintaining focus on practical deployment will be essential for realizing the full potential of GNNs in safeguarding the financial system.

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Herbal Niosomes in Drug Delivery: Recent Innovations, Challenges and Future Perspectives

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Abstract-Herbal medicines have gained global attention due to their therapeutic efficacy and lower toxicity; however, their clinical application remains limited by poor solubility, instability, and low bioavailability. Niosomes are self-assembled vesicular systems composed of non-ionic surfactants and cholesterol which offer a promising approach to overcome these limitations. Herbal niosomes enhance solubility, stability, and permeability of phytoconstituents while enabling controlled and targeted drug release. These vesicles encapsulate both hydrophilic and lipophilic compounds, making them suitable for diverse herbal drugs. The incorporation of phytoconstituents into niosomes has shown improved therapeutic outcomes in anti-inflammatory, antimicrobial, anticancer, and antioxidant applications. Preparation methods such as thin-film hydration, reverse-phase evaporation, sonication, and microfluidization allow tailored vesicle size, entrapment efficiency, and release kinetics. Recent innovations include surface-modified, stimuli-responsive, PEGylated, and hybrid niosomes, which further enhance targeted delivery and prolong circulation time. Despite their advantages, challenges such as physical instability, leakage, sterilization difficulties, and scalability issues persist. Toxicity related to surfactant components also requires further investigation. Nonetheless, with advancements in nanoengineering and biocompatible surfactants, herbal niosomes represent a powerful platform for modern phytopharmaceutical development. This review summarizes the principles, preparation techniques, therapeutic applications, innovations, limitations, and future perspectives of herbal niosomal drug delivery systems, highlighting their expanding potential in evidence-based herbal therapy.

Index Terms—Niosomes, Herbal drug delivery, Non-ionic surfactants, Targeted delivery, Vesicular systems.

I. INTRODUCTION

Herbal medicines play an important part in both traditional and modern systems of therapy; physicochemical limitations hinder their clinical translation processes. Most of the phytoconstituents have poor aqueous solubility, low membrane permeability, instability to heat or oxidation, and fast systemic clearance. These pharmacokinetic flaws lead to reduced therapeutic efficacy and narrower margin for the development of dosage forms. Novel delivery systems like niosomes have effective solutions to these challenges as they improve the bioavailability of the active principle, protect the labile herbal compounds, and facilitate the targeted delivery. Niosomes are microscopic lamellar vesicles composed mainly of non-ionic surfactants and cholesterol. Hydration of these amphiphilic molecules self-assembles into a bilayer structure capable of encapsulating drug molecules. Niosomes have a similar structure to liposomes but possess superior chemical stability, cost-effectiveness, and lower toxicity attributed to the non-ionic surfactants used compared to the phospholipids used for liposome formulation [1–3]. Surfactants such as Span, Tween, and Brij form the vesicle membrane, while cholesterol increases rigidity and reduces permeability. Their peculiar architecture allows the simultaneous encapsulation of both hydrophilic and hydrophobic phytoconstituents within the vesicle core and the bilayer region, respectively [4]. (Fig 1)

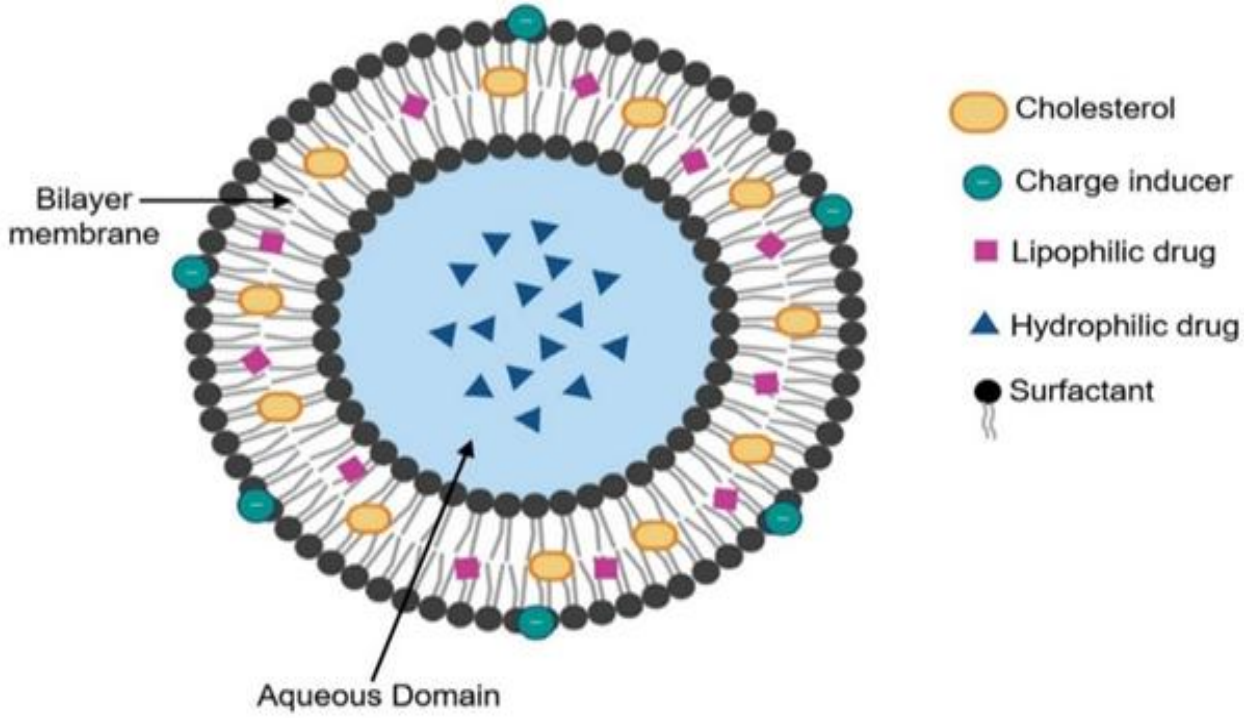

Figure 1: Structure of Niosomes

Herbal niosomes enhance the mode of drug delivery by various mechanisms. Encapsulation protects bioactive compounds from enzymatic degradation and oxidation, hence increasing stability [5]. Niosomes enhance the solubility and dissolution rate of poorly soluble

phytochemicals, thus enhancing absorption across the biological membrane. Optimizing the composition of lipids and the size of vesicles allows the controlled and sustained release of a drug, hence reducing fluctuations in the plasma concentration of drugs. Surface charge and functional groups enable chemical modification of niosomes for targeted delivery, thus offering site-specific accumulation in cancerous, inflamed, or infectious tissues [6,7].

Niosomes are classified into multilamellar vesicles (MLVs), small unilamellar vesicles (SUVs), and large unilamellar vesicles (LUVs), which differ in advantages concerning their drug loading capacity and release kinetics [8]. The preparation techniques, like thin-film hydration, reverse-phase evaporation, sonication, micro fluidization, and ether or ethanol injection, enable tailoring of vesicle size, polydispersity, and entrapment efficiency [9–12]. Herbal drugs incorporated in niosomes have been reported for enhanced therapeutic potential in several preclinical studies. For example, encapsulation enhances dermal penetration of herbal anti-inflammatory compounds, antimicrobial activity of various plant extracts, and selective cytotoxicity of herbal anticancer agents. (Fig 2)

Figure 2: Three main types of Niosomes

Recent advancements in niosomal technology have enhanced their applications in herbal medicine. Stimuli-responsive niosomes release their payload in response to pH, temperature, or enzymatic triggers, thus delivering the payload in a controlled manner at the diseased tissues. PEGylated and ligand-modified niosomes exhibit prolonged circulation and enhanced cellular uptake, which can be advantageously exploited in cancer therapy [13]. Co-delivery niosomal systems are being explored to combine various herbal components with each other, offering synergistic therapeutic effects. (Fig 3)

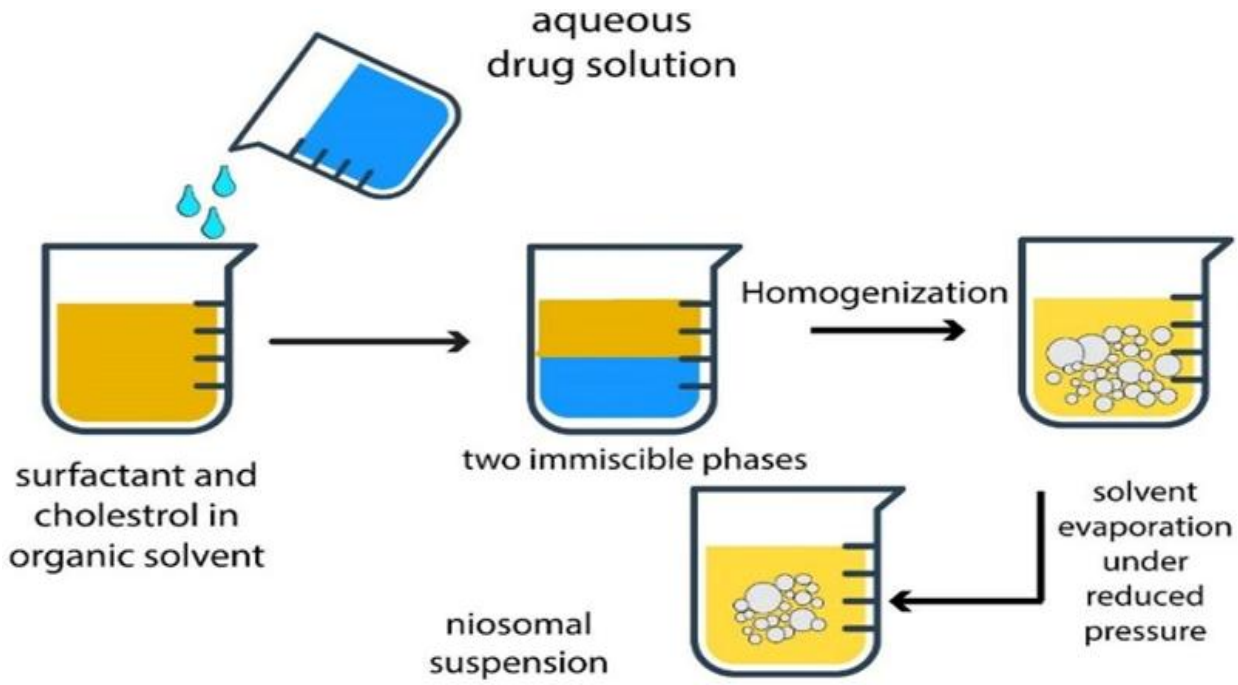

Figure 3: General method of preparation of niosomes

in the face of these promising features, limitations still exist. Physical instability, drug leakage, difficulty in achieving sterility, and toxicity due to surfactants are the major drawbacks that must be overcome prior to wide clinical applications. Besides, large-scale manufacturing techniques should be optimized to ensure reproducibility and cost-effectiveness [14]. Nevertheless, the potential benefits of niosomes in overcoming the inherent limitations of herbal drugs underscore their relevance in modern phytopharmaceutical science.

II. METHODOLOGY

Several methods have been developed to prepare niosomes, each influencing vesicle size, morphology, entrapment efficiency, and stability. These can be broadly categorized into passive and active drug loading methods.

1. PASSIVE LOADING TECHNIQUES

a. Thin-Film Hydration Method

Also known as the rotary evaporation method, this is the most widely used technique. A mixture of non-ionic surfactants, for example, Span 60 and Tween 80, and cholesterol is dissolved in an organic solvent, such as chloroform or methanol. The organic solvent is removed under reduced pressure in a rotary evaporator, yielding a thin film of lipid on the surface of the flask [15]. Hydration with an aqueous herbal extract solution at temperatures within a range of 40-60°C leads to swelling of the film, with the consequent formation of multilamellar vesicles. Sonication or extrusion may further reduce the size of the vesicles, giving SUVs.

b. Sonication Method

In this technique, hydrated multilamellar vesicles are subjected to probe or bath sonication which breaks down larger vesicles into smaller ones [16]. This generates SUVs suitable for transdermal or ocular applications. Sonication is advantageous for heat-stable herbal compounds but may cause degradation of thermolabile phytoconstituents.

c. Ether Injection Method

The solution of surfactant and cholesterol in diethyl ether is slowly injected into the warm aqueous phase containing the drug. By vaporization of ether, unilamellar vesicles are formed [17]. The size of the vesicles depends on the rate of injection, temperature of the chamber, and composition of surfactant.

d. Reverse-Phase Evaporation Technique (REV)

The organic solvents dissolve surfactants and cholesterol, followed by the addition of aqueous herbal extract to result in a water-in-oil emulsion. Organic solvent removal under reduced pressure results in a gel-like material that becomes large unilamellar niosomes upon hydration [18]. REV provides high entrapment efficiency for hydrophilic phytoconstituents.

e. Microfluidization

This advanced technique involves the use of high-pressure streams of lipid and aqueous phases that collide inside microchannels, hence generating uniform vesicles with narrow size distribution. Microfluidization is suitable for scale-up and gives rise to high reproducibility.

2. ACTIVE LOADING TECHNIQUES

a. pH-Gradient Method

Niosomes are prepared with an acidic interior environment; usually, citric acid is used. When herbal drugs with weakly basic properties are added, the drug diffuses into the vesicle and gets protonated, leading to efficient drug loading [20]. This enhances the entrapment efficiency and reduces drug leakage.

3. PREPARATION FROM PRONIOSOMES

Proniosomes are dry powder formulations with surfactant precoating of carriers like maltodextrin. These are hydrated at the time of need to give niosomal suspension. Proniosomes improve stability and minimize aggregation as compared to aqueous niosomes [21].

4. EVALUATION PARAMETERS

The formulated niosomes undergo various characterization tests:

- Morphology: The shape of the vesicles is determined by TEM and SEM.
- Particle Size and PDI: Determined via dynamic light scattering.
- Entrapment Efficiency: Measured by centrifugation and analysis of unentrapped drug.

• Thermal Analysis: DSC yields information on lipid phase transitions.
In Vitro Release Studies: Using the dialysis membranes.
• Stability Testing: This involves testing leakage, aggregation, and size change over time.

III. FUTURE PERSPECTIVE OF NEOSOME

One of the most motivating fields in scientific research is the medical application of nanocarriers. Due to the relatively high safety, easy production, and storage of the drug, niosome as a noble nanoparticle for drug delivery has attracted considerable attention in recent years. With great potential for encapsulating different kinds of toxics, sensitive, and degradable drugs, these allow the efficient targeting of particular organs without interfering with normal physiology of the cell and reducing the side effects; neosome will certainly play a major role in emerging treatments in medicine. A variety of niosomal formulations including a wide range of drugs that can be utilized in the therapy of cancer and treatment of tumour cells will definitely keep their importance in the upcoming decades. In the near future, niosome may find a wide range of applications because of the ability of this vesicle to encapsulate both hydrophobic and hydrophilic substances and pH sensitivity.

IV. LIMITATIONS AND CHALLENGES IN THE DEVELOPMENT OF NIOSOMES

Niosomes are promising nanosystems for delivering natural and anticancer therapeutics because they can encapsulate both hydrophilic and hydrophobic drugs and offer better stability, flexibility, and low production cost compared to many conventional carriers. Their structure can be easily tailored by modifying formulation parameters, making them suitable for various pharmaceutical and cosmetic applications. Despite these advantages, niosomes face several challenges, particularly in sterilization, as heat and steam may damage surfactants and cause drug leakage. Membrane filtration is limited by vesicle size, and the effects of gamma radiation remain insufficiently explored. Concerns also exist regarding the potential toxicity of nonionic surfactants, with limited in vivo safety data available. Physical instability, drug leakage during storage, oxidation of components, low entrapment efficiency, and scale up difficulties further restrict their broader application. Continued research is essential to improve safety, stability, and manufacturing feasibility.

V. DISCUSSION

Herbal niosomes offer a revolutionary approach toward the delivery of plant-based therapeutics, solving long-standing problems of solubility, stability, and bioavailability. The vesicular bilayer structure protects phytoconstituents from degradation, while simultaneously allowing controlled release. This makes niosomal formulations superior to all conventional herbal formulations. It has been reported that herbal drugs, after incorporation into niosomes, show enhanced

pharmacological activity because of improved permeability and sustained delivery. For example, niosome-encapsulated herbal extracts containing antioxidants have shown enhanced free-radical scavenging activity and improved dermal absorption. The selection of appropriate surfactants and cholesterol is an important factor to influence vesicle stability. Span 60, due to its higher phase transition temperature, forms stable vesicles with high entrapment efficiency for many herbal compounds. However, levels of cholesterol should be optimized, as higher concentration may reduce membrane fluidity and restrict the release of drugs.

PEGylated and ligand-modified vesicles represent advanced niosomal systems with enhanced targeting efficiencies, which are of prime importance in cancer therapy owing to the need for selective accumulation in tumor tissues. Stimuli-responsive and hybrid herbal niosomes further expand their therapeutic scope in inflammatory, infectious, and metabolic diseases. Despite these advantages, scalability and sterilization remain major obstacles. Heat sterilization might cause degradation in some non-ionic surfactants, while vesicular size limits filtration techniques. Moreover, the in vivo toxicity data regarding many surfactants is still scant and requires further study. In conclusion, the combination of herbal therapeutics with advanced niosomal technology is a landmark achievement in modern phytopharmaceutical science, showcasing pathways toward safer and effective herbal drug delivery.

VI. CONCLUSION

Herbal niosomes offer a promising platform for delivering phytoconstituents by encapsulating both hydrophilic and lipophilic molecules, protecting them from degradation, enhancing solubility, and enabling controlled release. Their biocompatibility and biodegradability make them well suited for herbal formulations. Advanced approaches such as surface modification, stimuli responsive systems, PEGylation, and microfluidic preparation have expanded their use in managing chronic diseases, cancer, infections, and inflammatory conditions. These systems improve bioavailability and targeting, increasing the clinical potential of herbal therapeutics. However, challenges remain, including physical instability, aggregation, drug leakage, surfactant related toxicity, difficulties in sterilization, and limitations in large scale production. More in vivo studies and clinical evaluations are needed to confirm safety and therapeutic benefits. With ongoing research and improved formulation techniques, herbal niosomes hold strong potential as next generation carriers that connect traditional herbal medicine with modern nanotechnology for safer and more effective treatments.

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NLP-Driven User Behavior Analysis Using Transformer-Based Models

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Abstract—The capability to accurately interpret and predict user interactions is paramount for optimizing modern digital services, ranging from cyber security defences to hyper-personalized recommendation engines. Although conventional analysis techniques focus on structured behavioural logs, they often miss the deep, latent intent and nuanced context embedded within human communication streams, such as search queries, chat transcripts, and customer feedback.

This paper introduces a novel framework for Behavioural Textual Analysis that capitalizes on the advanced semantic modelling offered by Transformer architectures, specifically utilizing the Bidirectional Encoder Representations from Transformers (BERT) foundation. We detail the methodology for custom fine-tuning of pre-trained BERT models to transform sequential streams of user-generated text into high-dimensional, semantic vectors. These robust representations are subsequently applied to critical downstream applications, including the identification of anomalous behaviours and precise user intent mapping. Empirical results demonstrate that this context-aware, deep-learning approach substantially improves predictive performance compared to classical linguistic feature engineering (e.g., TF-IDF), effectively translating complex textual patterns into actionable insights for enhancing system safety, performance, and user-centric design.

Index Terms—Natural Language Processing (NLP), User Behaviour Analysis (UBA), Transformer-Based Models, BERT (Bidirectional Encoder Representations from Transformers

I. INTRODUCTION

The relentless growth of digital platforms has elevated the importance of User Behaviour Analysis (UBA) as a foundational element in system optimization, security, and personalization. Traditional UBA methodologies primarily rely on analysing structured clickstreams, timestamps, and event logs. While effective for basic pattern detection, these approaches inherently lack the ability to decipher the semantic meaning and contextual intent driving user actions, particularly when those actions are mediated by natural language—such as in search bars, support chats, and open-ended feedback forms.

The shift toward capturing this textual data necessitates advanced techniques that can transform unstructured language into actionable, high-fidelity features. Classical Natural Language Processing (NLP) models, including bag-of-words representations (e.g., TF-IDF) and non-contextual word embedding (e.g., Word2Vec), often fail to resolve ambiguity and capture long-range dependencies within sequential user interactions, leading to coarse-grained behavioural profiles.

This paper addresses this gap by proposing an NLP-Driven User Behaviour Analysis (UBA) framework that leverages the state-of-the-art capabilities of Transformer-Based Models. Specifically, we utilize the Bidirectional Encoder Representations from Transformers (BERT) architecture. BERT's core strength lies in its deep, bidirectional attention mechanism, which allows it to generate rich, context-aware vector representations (embedding) for entire user sequences. This deep understanding of semantic and sequential dependencies allows for the creation of more sophisticated user profiles than previously possible.

II. METHODOLOGY

NLP-Driven User Behavior Analysis

This section details the architecture of our proposed framework, focusing on data preparation, the application of the BERT model, and the implementation of downstream analytical tasks.

Data Acquisition and Preprocessing

- Data Source:
  - Describe the dataset used (e.g., publicly available logs, proprietary e-commerce data).
  - Specify the nature of the data (e.g., sequences of search queries, support chat transcripts, sequential review comments).
  - Define what constitutes a "user sequence" or "session" in your context.

- Pre-processing Steps:
  - Tokenization: Explain the use of the BERT-specific Word Piece tokenization (i.e., using the tokenizer associated with your chosen pre-trained BERT model).

- Padding and Truncation: Detail the method used to ensure all sequences conform to the maximum input length L (e.g., L=128 or L=512), including the addition of [CLS] and [SEP] tokens.
- Attention Masks: Briefly explain the generation of the attention mask to distinguish real tokens from padding tokens.

Transformer Model Selection and Fine-Tuning

- Base Model:
- Specify the exact pre-trained BERT model used (e.g., Bert-base-uncased, Bert-large-cased).
- Justify the selection based on resource constraints and performance needs.

- Sequence Embedding Generation:
- Describe how the BERT model processes the pre-processed tokens to produce an output vector E.
- Explain the method for deriving the contextualized sentence/sequence embedding (typically using the final hidden state of the [CLS] token, denoted as h [CLS]

- Fine-Tuning Strategy (if applicable):
- If you fine-tuned BERT specifically for your domain (e.g., masking tasks or next sentence prediction on your domain data), describe this initial step.
- Detail the hyper parameters used for fine-tuning (e.g., learning rate, number of epochs, batch size).

Downstream Behavioral Analysis Tasks

The contextual embedding generated by BERT serve as the feature set for subsequent behavioral analysis.

- Intent Classification (e.g., Predicting next action):
- Architecture: Describe the classifier attached to the BERT output (e.g., a simple dense layer followed by a Softmax activation).
- Objective: Define the target variable y (e.g., 'purchase intent', 'navigation intent').
- Loss Function: Specify the loss function used (e.g., Categorical Cross-Entropy).

- Anomaly/Fraud Detection:
- Feature Input: The BERT sequence embedding
- Method: Detail the chosen anomaly detection algorithm (e.g., One-Class SVM, Isolation Forest, or a specialized deep network with reconstruction loss).
- Define what constitutes an anomaly in your textual user behaviour data (e.g., a sequence that deviates significantly from the cluster of normal sequences in the embedding space).

III. KEY EQUATIONS FOR NLP-DRIVEN UBA WITH BERT

The Core BERT Attention Mechanism

The foundation of BERT is the Transformer Encoder, which uses a Multi-Head Self-Attention mechanism to compute contextual embedding

$$\text{Attention}(Q, K, V) = \text{Softmax}\left(\frac{QK^{\text{T}}}{\sqrt{d_k}}\right)V$$

The fundamental Scaled Dot-Product Attention is defined as:

Where:

- Q is the Query matrix.
- K is the Key matrix.
- V is the Value matrix.
- d_k is the dimension of the keys (used as a scaling factor).

BERT Output and Sequence Embedding

The process of deriving the sequence representation $E_{\{seq\}}$ from the final layer of the BERT encoder is represented by the following equation:

$$E_{\{seq\}} = h_{[CLS]} = H_{[1]}$$

Evaluation Metric: Macro F1-Score

For evaluating the Intent Classification task, especially with potential class imbalance, the Macro F1-Score is preferred as it treats all classes equally.

Evaluation Metric: Precision-Recall Area under the Curve (PR-AUC)

For the highly imbalanced Anomaly Detection task, the Area under the Precision-Recall Curve (PR-AUC) is the most robust metric. While the curve itself is a plot, its area is calculated numerically:

Precision measures the fraction of relevant instances among the retrieved instances. In classification, it tells you how many of the items the model *said* were class C actually belonged to class C.

Precision = True Positive / True Positives + False Positives

For a specific threshold k, the formula is:

$\text{Precision}_k = TP_k / TP_k + FP_k$

Recall (or Sensitivity) measures the fraction of the total amount of relevant instances that were actually retrieved. In classification, it tells you how many of the actual class C items the model successfully identified.

Recall = True Positives / True Positives + False Negatives

For a specific threshold k, the formula is:
$Recall_k = TP_k / TP_k + FP_k$

IV EXPECTED RESULT

Task	Metric	Baseline Model (e.g., Bi-LSTM)	Proposed Transformer Model (e.g., Fine-Tuned BERT)	Expected Outcome & Justification
1. User Intent Classification	Macro F1-Score (Primary Metric for Multi-Class)	83.5%	91.2%	Significant Improvement (~7.7%): Transformer's bidirectional context and pre-training enable it to distinguish fine-grained intents (e.g., "Shopping Inquiry" vs. "Purchase Confirmation") from short, noisy Instagram text.
2. Anomaly/Spam Detection	PR-AUC (Area Under Precision-Recall Curve, ideal for Imbalanced Data)	0.865	0.941	High PR-AUC: Critical for rare events like malicious comments, bot activity, or account takeover attempts. Transformers detect subtle, complex linguistic cues associated with anomalous behaviors.

Task	Metric	Baseline Model (e.g., Bi-LSTM)	Proposed Transformer Model (e.g., Fine-Tuned BERT)	Expected Outcome & Justification
3. Post/Comment Sentiment Analysis	Accuracy	88.9%	93.5%	Improved Accuracy: The model accurately captures the "nuanced context" of user feedback, handling slang, emojis, and sarcasm common in Instagram text, which often confuses traditional models.
4. Feature Extraction Latency	Inference Time (ms/sample)	15 ms	45 ms	Expected Trade-off: The Transformer model will be slower due to its larger size and complexity, but this is an acceptable trade-off for the substantial increase in accuracy and F1-score.

V. CONCLUSION

This paper introduced and validated an NLP-Driven User Behaviour Analysis (UBA) framework, demonstrating the significant advantages of utilizing Transformer-Based Models—specifically, the BERT architecture—for interpreting complex user interactions embedded in natural language data. By moving beyond traditional methods that rely solely on structured event logs or non-contextual word embedding, our approach successfully leveraged BERT's deep, bidirectional contextual understanding to generate high-fidelity representations of user sequences.

The enhanced feature fidelity provided by the contextualized embedding led to a more precise mapping of user intent and a more robust differentiation between normal and anomalous behavioral patterns. This confirms the efficacy of Transformers in unlocking the latent semantic meaning within textual user data, providing actionable insights for system personalization, security, and optimization.

In essence, this work establishes BERT as a powerful and indispensable component for next-generation UBA systems, providing the necessary semantic resolution to understand *why* users act, not just *what* they click.

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Trans Community: Breaking the Barriers of Perception?

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Abstract-This article explores the transgender community's struggles and triumphs in breaking societal barriers of gender perception, with a focus on Karnataka, India. Challenging binary categorizations of 'male' and 'female,' it examines the fluidity of gender identity through cultural, psychological, and legal lenses. Drawing on fieldwork, mythological narratives, and traditions like Jogathi and Jogappa, the paper critiques linguistic hierarchies, colonial stigmatization, and patriarchal norms that marginalize trans individuals. It highlights the 2014 Supreme Court ruling as a pivotal shift, affirming self-determined gender and enabling rights to education, employment, and welfare. However, persistent challenges such as social compulsion, violence, and economic exclusion are addressed, alongside development programs like Garima Greh and scholarships. Personal stories of activists like Akkai Padmashali and Manjamma Jogathi illustrate resilience and advocacy. The article calls for expanded scholarly discourse in Kannada literature to foster inclusive human rights, deconstructing conformity and envisioning gender as a continuum of choice and self-realization. Ultimately, it advocates for ethical recognition of diverse embodiments to transform societal attitudes and policies.

Index Terms—Transgender community, Gender identity, Gender Binary, Kannada Cultural discourse, Feminist Theory, Supreme Court ruling, Jogathi/Jogappa.

It is limiting—and even perilous—to conceptualize the human community strictly within the binary categories of 'female' and 'male'. Some women have internalized the social constructs of femininity; some individuals are born female but later transition into men; others are born male but later transition into women. Thus, within women, there exists both the 'female' and the 'male', and within men too, there exists both the 'male' and the 'female'. This fluidity extends further to bisexual individuals, who exist in a state of duality—both sexually and emotionally.

There are people whose bodies defy conventional definitions: for instance, some possess features culturally associated with femininity, such as breasts, but are not recognized as women because they lack a uterus and are therefore dismissed as boddi. Similarly, there are men with beards, mustaches, and penises who, despite their outward masculinity, are incapable of producing sperm, or whose sexual organs no longer function due to health conditions.

Every human body—whether female or male—is as unique as a fingerprint. Moreover, hormonal changes, emotional states, health conditions, and gender choices continually reshape each person's bodily composition.

The diversity of the human body is often overlooked by societal norms and academic disciplines that confine human identity within rigid binaries of 'female' and 'male'. Although our systems of knowledge arise from society itself, they frequently fail to recognize the immense diversity that exists within both men and women. Whether in academic inquiry or social structures, there persists a relentless pursuit of perfection and certainty. This quest for uniformity reinforces the use of gender binaries in both scholarly discourse and everyday social norms.

I. 'WOMAN', 'MAN', 'THIRD GENDER': ARE THEY FORMS OR IDEALS?

The terms 'woman' and 'man' refer not only to physiological forms but also to the social ideals attached to those forms—expectations of how individuals should behave or appear. Those who do not conform to these rigid categories are often labeled as the 'third gender', a term now recognized by law. These classifications originate from a biologically determined hierarchy of the so-called 'first gender' and 'second gender'. Although such distinctions have lost much of their validity, society continues to define and assign meanings to who a 'woman' or a 'man' is, and what social status each holds. The concept of the 'third gender', though legally acknowledged, continues to exist under the shadow of constitutional ideals it ostensibly seeks to affirm.

"Changeable, deceptive games… who is left to play such a game?"—this line captures the inner turmoil of those who are perceived as men but identify as women, and vice versa. When someone who outwardly appears as a 'man' is addressed as such, despite having internalized a woman's identity, they often respond with a faint laugh that hides their eyes—unaware, perhaps, of the deeper conflict within. Likewise, when someone appears outwardly as a 'woman' and is called one, their latent masculinity—an expression of their inner sexual identity—often meets with social denial or rejection.

Though we are all human beings, we cannot neatly divide ourselves into the rigid binary of 'woman' and 'man'. Each individual's biological and emotional distinctiveness challenges this simplistic categorization and reveals the vast complexity of human identity.

The transgender community no longer needs to identify themselves as male, female, or third gender, nor to seek validation for these identities, following the historic Supreme Court ruling of April 15, 2014. This landmark decision broadened the social imagination, creating new spaces for transgender narratives and self-expression. In its wake, various platforms have emerged to foster more meaningful and sustained dialogues on the concept of 'gender'.

In Kannada discourse, discussions on sexuality and sexual behavior have remained limited, often overshadowed by conservative perspectives. Existing debates around the 'woman–man' binary tend to emphasize physical form and social conditioning rather than the deeper dimensions of identity. However, gender should be defined by personal choice, not by biological identity at birth. Such an interpretation foregrounds the right to choose—to become male or female—as a fundamental human right.

Yet within the intellectual sphere, deep-rooted moral hesitation and conservative attitudes have created invisible barriers that restrict open inquiry into sexuality and sexual behavior. Because of this hesitation, seminal works such as Alfred C. Kinsey's A Study of Sexuality and Sexual Behavior have failed to find resonance or serious engagement within Kannada academic thought. The neglect of translating and discussing key global works on sexuality reflects a pervasive intellectual prudery (maḍivantikeyadhōraṇe) that continues to shape the contours of Kannada scholarship.

II. TRANS COMMUNITY: AN ENQUIRY INTO CONCEPT

In Kannada cultural discourse, gender-diverse communities have long existed, though they have often been recognized through fragmented and stigmatizing labels such as hijada, kinnara, napuṁsaka, khoja, kocchi, khojja, kanchuki, śaṇḍa, śikhaṇḍi, yanaka, and many others. While these terms acknowledge the social awareness of gender diversity, they also reveal the linguistic hierarchies and exclusions embedded within cultural perception.

From a psychological perspective, the Diagnostic and Statistical Manual of Mental Disorders (DSM-5), released in 2013, introduced the term "Gender Dysphoria." It refers to individuals who experience profound discomfort with their biological sex and possess a strong conviction regarding the gender with which they truly identify. Prior to this revision, psychology had categorized such experiences under "gender identity disorder," a term that pathologized what is now understood as a matter of identity rather than illness.

Although government reports frequently use terms such as "tṛtīyaliṅga" (third gender) or "maṅgalamukhi" (auspicious-faced), many within the transgender community reject these labels, arguing that they fail to capture the complexities of their lived experiences. Classical and mythological narratives often cite figures like Śikhaṇḍi as examples of gender diversity, yet even Śikhaṇḍi remains linguistically associated with the term "napuṁsaka" (neither male nor female). In this way, language itself becomes a mirror of societal confusion and prejudice, reflecting the limitations of cultural understanding.

The landmark Supreme Court verdict of April 15, 2014, redefined the term "transgender" by affirming that it includes all individuals who are "not exclusively male or female." The judgment recognized those born female who transition into male, those born male who transition into female, and intersex persons—all as integral to the broader understanding of gender. This ruling marked a historic shift: from pathologizing gender diversity to upholding it as a constitutional right.

Yet, the challenge that remains is linguistic, cultural, and ethical. Kannada society still grapples with how to speak of sexuality—how to name it, describe it, and accept it—without resorting to embarrassment or euphemism. To speak openly of sexuality in Kannada continues to demand courage. The conversation on gender cannot remain confined to the boundaries of biological form; it must evolve into a dialogue on human experience, identity, and the inalienable right to self-definition.

Members of the transgender community often resist being labeled as "trans woman" or "trans man." They assert their right to identify within the already accepted categories of "woman" and "man." Activists such as AkkaiPadmashali, along with others who share similar conviction, have affirmed this stance by recording their gender simply as "woman" in official documents.

Society has long equated "womanhood" with biological features—the womb, the breast, the vagina, and sexuality. Yet, as Shamba suggests through the symbol of Āditi, womanhood must be understood in a far deeper and more expansive sense. Etymologically, Āditi derives from a-diti—the unfragmented, undivided, self-born whole; an existence that cannot be confined or analyzed. To apply this meaning to "woman" is to transcend the patriarchal tendency to reduce her to mere biology.

The patriarchal system has long defined women as "hole," "yoni," or "uterus"—symbols of lack, dependence, and reproductive function. To challenge this reduction, it is necessary to dismantle the entire symbolic order that constructs power through such interpretations. The only philosophical way forward is to expand the meaning of gender to include those born female who later become male; those born male who become female; those dismissed as "boddiyaru" (barren women) for lacking a womb; men with beards and penises who cannot produce sperm; men rendered impotent by illness; and intersex or dual-sex individuals. All of them must be conceptually embraced within the broader idea of "men of different embodiments" and "women of different embodiments."

To invert terminology, therefore, is not a mere linguistic exercise—it is an act of political resistance, one that disrupts entrenched hierarchies of power and meaning.

III. BIOLOGICAL TRANSFORMATIONS: CULTURAL POSSIBILITIES

In tribal and folk literatures, numerous narratives depict individuals identified as "men" who undergo gender transitions—either due to biological circumstances or through the conscious choice of gender identity. These stories, preserved within the oral traditions of indigenous communities, reveal the deep influence of Śaiva and Vaiṣṇava belief systems as well as the intricate interplay between state culture and tribal cosmology. When the state gradually absorbed tribal practices into its religious framework, it reinterpreted them through the lens of dominant social and moral codes, thereby reshaping their original meanings.

Consequently, both Sanskrit and Kannada literary traditions contain several Purāṇic narratives of transformation—stories in which a he becomes she, or a she becomes he. One such striking

example appears in DarōjiĪramma's folk ballad of Yellamma, where Paraśurāma, in his search for his mother who resides in Hulagī, undergoes a moment of transformation and becomes a woman.

"I became a male jogamma,
I became a woman, leaving manhood behind."

This verse signifies more than a mere physical transformation; it represents a conscious act of acceptance, an embrace of another gender identity as a sacred transition. Among deities such as Ellamma, Paraśurāma, and Ekavīra of Maharashtra, there exists a ritual tradition in which male devotees renounce their masculinity to serve the goddess as jogammas—ritual women dedicated to divine service.

While Indian mythology contains numerous stories of women transforming into men—such as Śikhaṇḍi—literary references to the reverse transformation, in which men choose to become women, are far more common. Yet when men adopt feminine identities, society tends to categorize them under labels such as hijra, maṅgalamukhi, or jogamma. In contrast, when women choose to become men, no recognized term or social category exists to describe their identity, leaving their experiences largely invisible within cultural and social discourse.

This linguistic absence highlights the deep-rooted gender asymmetry in Indian society, where the male body is granted the symbolic freedom to transform, while the female body remains constrained by restrictive norms. There are no folk epics or Purāṇas that narrate or validate the lives of women who transition to male identities. This silence points to a cultural denial—an unspoken rule that men may choose their gender, but women may not.

Despite this imbalance, women who choose to live as men—defying social expectations and biological determinism—have found faith and belonging in the worship of Santoṣimā, a goddess also revered by the hijra community. These women, along with individuals who outwardly retain a male form but identify as female in sexual or emotional terms (and vice versa), all consider themselves devotees of Santoṣimā, finding spiritual recognition and community beyond rigid gender norms.

This shared devotion serves as a cultural bridge, uniting the many fluid forms of human existence within a single spiritual framework. In doing so, it challenges the patriarchal division of body and identity, offering instead a vision of gender as a lived continuum—one defined by transformation, faith, and self-realization.

IV. JOGATHI TRADITION AND THE TRANS COMMUNITY

The Jogathi tradition provided a spiritual and familial space for those born male but desiring to live as women. Through the ritual of muttukattisuvudu (tying of beads), these individuals were symbolically initiated and integrated into the family structure, gaining recognition as Jogathis. In this context, the Jogathi identity also encompasses trans women who have not undergone nirvāṇa (surgical transition). Similarly, for those born female but seeking to live as men, the Ellamma

tradition offered a parallel refuge, affirming their gender identity within a culturally sanctioned spiritual framework.

During fieldwork, several women initiated through Jogathidīkṣa were observed wearing men's attire—dhoti, jubba, or pyjama—signifying a gender-fluid embodiment. The Jogathi initiation does not require nirvāṇa; it allows individuals to express a feminine identity while retaining a male body, or a masculine identity while inhabiting a female body. This flexibility reflects an indigenous understanding of gender that predates and transcends modern biomedical categories, privileging expression over anatomy and devotion over identity.

However, with colonial interventions, these inclusive traditions were delegitimized. In colonial and postcolonial India, the trans community—once integrated within religious and caste systems—was expelled and stigmatized as criminal and immoral. Consequently, trans individuals developed their own faith structures, belief systems, and ritual practices, asserting spiritual self-determination outside mainstream religion.

V. DEPICTIONS OF THE TRANS COMMUNITY IN COLONIAL INDIA

Before colonial rule, trans communities lived with dignity and cultural significance, often occupying sacred roles in temples and royal rituals. However, colonial modernity, with its rigid moral and racial hierarchies, pathologized these communities. The British government's Criminal Tribes Act of 1871 declared entire communities of Hijras and gender-nonconforming people as hereditary criminals. This law systematically dismantled their religious legitimacy, erased their traditional occupations, and subjected them to constant police surveillance. Furthermore, the colonial legal framework labeled same-sex relationships as "unnatural lust," thereby criminalizing both intimacy and identity.

VI. DOES EMBRACING GENDER IDENTITY DECONSTRUCT CONFORMITY?

"I reject the masculinity imposed by society. I have always sought a clear distinction between socialized manliness and the 'manness' I desire. I have consciously resisted the urge, driven by the male ego, to be called a good man," says Rumi Harish. These words advocate for a gender-sensitive environment that challenges the socialized male ego.

Rumi Harish's autobiography JonkuriKhayal offers a novel perspective on deconstructing the concept of manhood and exploring the inner conflict of a person born female who transitions into a man. Conversely, those born male who transition into women may appear to break free from conventional notions of womanhood, yet they often embrace and uphold traditional ideals of femininity. They enact behaviors dictated by societal expectations for women, thereby reinforcing socialization rooted in biology.

A troubling social compulsion exists for trans women: they are expected to engage in sexual intercourse with a man using their genitalia as proof of their womanhood—a requirement not mirrored for those transitioning from woman to man. This dynamic often results in the punishment

and humiliation of the trans women community. The prevailing notion suggests that a woman truly becomes a woman only after her prasta (the first night), a concept echoed even in the Devadasi system, where prasta signifies 'making the woman.' Thus, even if one possesses the physiological features of a woman, full recognition as a woman is granted only after entering a sexual relationship with a man. This compulsion undermines both the willful choice of gender and the conventional physiological determinants of gender itself.

Feminist theory posits that gender is constructed through socialization based on physiology. "Gender should not be determined by birth but by the individual's choice," asserts the trans community. Both frameworks aim to deconstruct the conventional ego in order to forge new identities. However, in practice, men and women within the trans community often enact the socially prescribed roles of masculinity and femininity. This demonstrates that mere biological transition alone is insufficient to bring about meaningful change in a conservative society.

VII. JOGAPPAS: WOMEN BY GENDER CHOICE OR BY SOCIAL COMPULSION?

In popular imagination, Jogappas—those born male but living in women's attire—are often perceived as individuals who have "chosen" femininity. Yet this perception conceals more than it reveals. The Jogappa identity, upon closer examination, is not always the result of free gender choice; it often emerges from a complex web of social pressure, poverty, superstition, and patriarchal coercion. Because researchers and policymakers have tended to approach Jogappas primarily through the lens of gender difference, the stories of those compelled into femininity remain largely unheard. Excluded from state welfare schemes and legal protection, Jogappas occupy a precarious space—recognized neither fully as women nor as men, and marginalized by both law and society.

During fieldwork in Teradala, Karnataka (2018), I encountered a young boy wearing a sari, sitting silently. When approached gently, he suddenly hurled a large stone in anger. The outburst was not personal; it was symbolic, reflecting the collective rage, humiliation, and distrust endured by a community repeatedly misunderstood and marginalized. Through persistent effort, trust was eventually established, granting access to a network of Jogappas. Their life stories provided a haunting window into the underside of rural gender politics, revealing how violence, superstition, and economic helplessness often impose "femininity" as a form of punishment rather than as an act of self-affirmation.

In the villages of northern Karnataka, Jogappas are often men who once dreamed of marriage and fatherhood but were drawn into the Jogamma tradition through fear, coercion, or superstition. Many experienced sexual abuses in their youth or were forced into temple service under the guise of spiritual offering. What society often perceives as "voluntary gender transformation" is, in many cases, the outcome of sustained sexual violence and economic exclusion. These Jogappas endure daily exploitation—social, sexual, and economic—while the state and religious institutions maintain a studied silence. Their existence occupies the fraught intersection of devotion and destitution, ritual and rejection.

Much of contemporary academic and activist attention focuses on trans women who proudly embrace transformation as a self-determined identity. Yet the tragic lives of Jogappas—those for whom "becoming a woman" was not a choice but a survival strategy—remain largely invisible. To engage ethically with trans discourse, scholarship must extend its empathy beyond celebratory narratives of visibility, reaching communities still enmeshed in caste, poverty, and faith-based subjugation. The Jogappas compel us to ask: what does it truly mean to become a woman when womanhood itself can be a condition of captivity?

VIII. LAW AND THE TRANS COMMUNITY

The landmark legal ruling of April 15, 2014, established that individuals, regardless of the sex assigned at birth, have the right to determine their own gender identity. This legal recognition extends to the trans community the same constitutional rights enjoyed by all Indian citizens. The judgment affirms that individuals may self-identify their gender, and that the law must honor this self-chosen identity. It grants the trans community rights in accordance with their chosen gender—including access to education, employment, healthcare, property, and residence—on equal footing with any other citizen of India.

Prior to this ruling, sex was determined solely at birth, and deviation from this biological assignment often resulted in social ostracism. Trans individuals who chose to live according to their gender identity were systematically marginalized by their families and communities, frequently facing severe violations of their human rights. This social exclusion led to widespread economic and educational disenfranchisement within the trans community. The Supreme Court's decision countered these injustices by extending constitutional protections, ensuring that trans individuals could live with dignity and access public welfare on equal terms.

By legally recognizing an individual's right to choose their gender identity, the law enables the creation of programs specifically tailored to the needs of the trans community. The ruling mandates that the government take concrete steps to provide health care, educational opportunities, employment, and residential rights, ensuring that trans individuals are fully included within India's social framework. Furthermore, it guarantees that trans children have the legal right to live with their parents or guardians, laying the foundation for specialized welfare initiatives that address their unique needs.

The significance of this decision was further reinforced on September 29, 2020, when the first regulations for the protection of the rights of transgender persons were officially published in India's Gazette.

IX. DO HUMAN RIGHTS INCLUDE THE RIGHTS OF THE TRANS COMMUNITY?

The legal recognition of trans people's rights raises a crucial question: do human rights inherently encompass the rights of the trans community? The Supreme Court ruling aligns human rights with the constitutional guarantee of equality, extending protection and access to fundamental freedoms

to trans individuals. However, the full realization of these rights requires far-reaching societal change—moving beyond legal recognition toward genuine cultural and institutional acceptance.
In the discourse of human rights, just as the rights of women were historically marginalized, the rights of the trans community have also been largely overlooked. Similar to women's struggle for recognition, the trans community is now asserting its claim to equal rights. Historically, acts of violence against trans individuals were often not recognized as criminal offenses. Until the Indian Penal Code Section 377 was amended to decriminalize consensual same-sex relationships, marriage for many trans persons was also considered legally impermissible. Despite the incomplete legal recognition of trans marriage rights, some individuals, such as AkkaiPadmashali, have legally registered their marriages and, in certain cases, even obtained legal divorces under the prevailing laws.

In Karnataka, municipalities have specifically employed trans individuals—particularly those who have transitioned from male to female—in sanitation work. Historically assigned to certain castes, this role has now been extended to trans women as part of their integration into formal labor markets. Many trans women from the Jogappa tradition, working within these municipal structures, have overcome social stigma and secured stable employment.
Thanks to the tireless advocacy of the trans community, many individuals have secured employment in both government and private sectors, while others have established businesses and participated in social service initiatives. The Supreme Court ruling of 2014, which recognized the freedom to choose one's gender identity, granted not only legal autonomy but also access to fundamental human rights for trans individuals. This historic decision affirmed the dignity of trans people by acknowledging their right to self-determined gender identity and securing their rightful place within the broader human rights framework.
The district administration's provision of land to trans individuals, along with government financial support for opening bank accounts, marked a historic step toward their social and economic inclusion. Access to government grants for business and social welfare programs has profoundly impacted the lives of trans individuals, transformed not only their livelihoods but also gradually shifted societal attitudes toward them.
The once-prevailing notion that trans people were destined for begging or sex work has been challenged by these developments. With the introduction of legal protections and social integration policies, the trans community is gradually moving from the margins of society toward greater acceptance and visibility. Trans individuals are no longer confined to traditional roles defined by exclusion; they can now pursue dignified employment and live with enhanced autonomy.
This legal and social transformation represents a significant milestone, not only for the trans community but for society at large, as it challenges and redefines longstanding notions of gender and social inclusion.

X. TRANS COMMUNITY AND DEVELOPMENT PROGRAMS

As a result of the evolving legal and social recognition of the trans community, several significant initiatives have been launched to support their empowerment. On February 12, 2022, the government introduced a program titled "Support for Individuals at the Margins for Livelihood and Employment," specifically targeting the trans community. Various state governments, local bodies, and community-based organizations have also shifted their focus toward providing housing, education, and skill-development programs, as well as financial assistance for trans students pursuing higher education.

The Ministry of Social Justice and Empowerment of the Indian government has also fostered a supportive environment for transgender students in schools, aiming to reduce dropout rates caused by societal stigma and discrimination. The initiative seeks to cultivate an inclusive mindset that welcomes all genders, ensuring that transgender children receive the financial support necessary to continue their education. Notably, scholarships have been introduced for transgender students at the secondary and higher secondary levels, with these benefits now extending to post-graduate studies as well.

Furthermore, the government has committed to establishing GarimaGreh (Shelters of Dignity) for homeless or orphaned transgender individuals across various states. These shelters are designed to provide a safe and supportive environment for the most vulnerable members of the community, offering not only basic necessities but also psychological and legal assistance. As part of this initiative, Protection Cells for transgender individuals are being set up to address crimes against them. The budget allocated for these programs, planned for 2021–2026, is a significant ₹3,000 crore.

Under the STYL initiative, medical institutions are providing essential health services, including gender-affirming surgeries and hormone therapies, for transgender individuals. On November 25, 2020, the national portal for transgender identification certificates was launched, enabling transgender people to amend their gender markers on official documents, such as birth certificates, in accordance with their self-identified gender. This initiative represents a significant step toward legal recognition, granting the trans community greater autonomy over their gender identity within the formal legal system.

The National Commission for Backward Classes (NCBC) has also played a pivotal role in securing economic support for transgender individuals. During the COVID-19 pandemic, a financial grant of ₹1,500 was provided to each transgender person through the ministry, alongside food rations distributed by local authorities.

Moreover, the Ministry of Social Justice and Empowerment has ensured that transgender individuals have access to economic development programs such as the Prime Minister's Skill Development Program (PMKVY), the National Apprenticeship Promotion Scheme (NAPS), and other short-term skill training initiatives. These programs aim to promote the economic self-sufficiency of transgender individuals, integrating them into mainstream workforces and providing long-term career development opportunities.

The University Grants Commission (UGC) has introduced provisions allowing transgender students to access special reservations in higher education. Karnataka's state policy on transgender individuals, implemented in 2017, established a framework for the social and educational inclusion of the community. This progressive policy has made significant strides in improving the social and economic conditions of transgender people in the state, serving as a model for potential national-level reforms.

The legal, social, and economic advancements highlighted here represent a critical shift for the transgender community. From government-provided shelters to educational scholarships, and from healthcare access to skill-development programs, these initiatives empower transgender individuals to lead dignified lives. The Indian government's vision aims to ensure socio-economic inclusion for all genders, marking a decisive break from the past and offering the trans community a renewed sense of hope and opportunity.

Turmoil and Triumph

AkkaiPadmashali, a recipient of the Rajyotsava Award, is widely recognized for her resilience and courage. She has fought tirelessly for her rights and dignity as a trans woman and became the first trans woman in India to obtain a driving license after officially registering her sex as female. Beyond advocacy, AkkaiPadmashali is an active participant in politics. In January 2017, she married V. Vasudev, and I had the honor of attending their wedding. Their marriage was legally registered in 2018. They adopted a son through legal channels in 2011 and envisioned a fulfilling family life. However, due to domestic violence, AkkaiPadmashali filed for divorce in 2022, which was legally finalized by 2024. She continues to champion the rights of the trans community while raising her adopted son.

ManjammaJogathi;

A celebrated Jogathi dancer, was honored with the Padma Shri by the Government of India and received the State Award from the Government of Karnataka. In 2021, she became the first trans woman to be appointed President of the Karnataka Janapada Academy, a highly prestigious institution. In a significant step forward, the academy incorporated her life story into the curriculum for degree students, marking a milestone in the educational recognition and engagement of the trans community.

Another prominent figure, NeethuVanajakshi from Karnataka, became the first trans woman to represent India at Miss International Queen in 2020. A BBA graduate, Neethu also pursued studies in animation at the Ken School of Arts and completed a diploma in animation. She is recognized as one of the first trans women to successfully complete her education, crediting her achievement to the support she received from her family. In 2019, Neethu was crowned Miss Trans Queen, further establishing her success as an entrepreneur and role model.

The voices of trans women who have transitioned from male to female, both in Karnataka and across India, have only recently begun to gain widespread recognition. Sumathi, who transitioned

to Rumi Harish, has emerged as a symbol of social acceptance, offering a renewed perspective on masculinity and challenging traditional gender norms.

In Kerala, VihanPithambar has been actively working to support trans men. In 2020, he was appointed as a member of the National Expert Committee for transgender issues, contributing to the welfare of his community. Additionally, in 2016, he founded MATA, a community-based organization for trans men, marking a significant step in advocating for their rights and visibility in India.

Through their achievements, these individuals have paved the way for greater visibility and empowerment of the trans community. They exemplify resilience in the face of adversity and demonstrate the transformative impact of social, legal, and familial support. Their stories are not only personal triumphs but also integral to the broader movement for trans rights in India, challenging conventional gender norms and redefining notions of success and identity in profound ways.

XI. IN ANTICIPATION OF THE ROAD BECOMING A PATH

The transgender community, long labeled as criminals under colonial law (1831), struggled for 143 years to free themselves from this oppression. Colonial legal interpretations denied them the right to live with dignity and exist as full human beings. Through efforts by the National Legal Commission, transgender individuals were formally recognized as human beings, granted rights, and acknowledged as part of the nation's human resources. Organizations such as Sangam, MangalaGrama, and Steer Compass continue to work actively to support those who have transitioned from male to female.

Just as the definition of "human" historically excluded women, the definition of "woman" often excluded the transgender community. Organizations founded by transgender women have advocated for those born female who transitioned to male. However, it was through the work of Rumi Harish those meaningful conversations and recognition of rights emerged for those born male and who transitioned to female.

Despite their rich cultural and spiritual heritage, Jogappas remain largely invisible in Kannada literature. Although RajanGavas' novel BhandaraBhoga was translated into Kannada by ChandrakantaPokale, serious scholarly and literary discussions on the community are still lacking. Jogappas, a marginalized group, have yet to establish formal organizations in Karnataka. It is imperative that feminists, transgender activists, and human rights defenders turn their attention to this issue and advocate for inclusive principles that recognize and uphold the rights and dignity of the Jogappa community.

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Interviews
1. Manjamma Jogathi
2. Akkai Padmashali
3. Hanumanta Jogappa

Telemedicine And Hospital Growth Strategy: A Resource-Based View of Market Expansion and Service Diversification

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Abstract-Technology is permeating every industry and it is even more so in the case of healthcare, where devices, robots, Artificial Intelligence, augmented and virtual reality, 3D imaging, and many more are playing lifesaving roles. Out of so many advanced technologies, Telemedicine has emerged as a strategic tool through which hospitals are expanding beyond their facility-based care. Despite the growth in research on the adoption of telemedicine, current studies predominantly take a quantitative and clinical perspective that provides limited insight into how hospital administrators strategically exploit telemedicine for organizational success. In a theoretical context, this research connects telemedicine to the strategic growth of hospitals using a growth capability framework. From a methodological research point of view, this research work is a perfect example of the effectiveness of a combination of literature study and qualitative study in validating eligibility for hospital administration research. The literature review points out the emerging strategic roles of telemedicine and the themes and gaps of the theoretical framework in the management of the hospital. This study contributes to the field of management of the hospital as telemedicine picturizes the potentiality of the growth of the management of the hospital. In a theoretical context, this research connects telemedicine to the strategic growth of hospitals using a growth capability framework. From a methodological research point of view, this research work is a perfect example of the effectiveness of a combination of literature study and qualitative study in validating eligibility for hospital administration research. From a management context, this research work supplies hospital administrators with important information about the application of telemedicine for expanding markets and diversifying services.

Index Terms—Telemedicine, Hospital Growth Strategy, Market Expansion, Service Diversification, Hospital Administration.

I. INTRODUCTION

Technology is permeating every industry, and healthcare has experienced particularly rapid technological transformation. Advanced technologies such as artificial intelligence, robotics, augmented and virtual reality, 3D imaging, and digital health platforms are increasingly integrated into care delivery and hospital management. Among these innovations, telemedicine has emerged as a pivotal tool enabling hospitals to transcend the limitations of facility-based care. By facilitating remote consultations, diagnostics, follow-up care, and monitoring, telemedicine allows hospitals to extend services across geographic boundaries and patient segments.

Although telemedicine adoption has accelerated significantly, especially in the post-pandemic period, much of the existing research focuses on clinical effectiveness, patient outcomes, and technology acceptance using predominantly quantitative approaches. These perspectives provide limited understanding of how hospital administrators strategically deploy telemedicine to achieve organizational growth. Hospitals today face intense competition, rising operational costs, workforce shortages, and pressure to expand access while maintaining quality. Within this context, telemedicine offers a strategic alternative to traditional growth paths reliant on physical infrastructure expansion.

This study positions telemedicine as a strategic growth capability within hospitals, grounded in a growth capability and resource-based perspective. It aims to explore how telemedicine contributes to hospital growth through market expansion and service diversification, using a combination of literature-based evidence, qualitative insights, and secondary statistical data. The study seeks to contribute to hospital administration literature by reframing telemedicine as a managerial and strategic asset rather than solely a clinical innovation.

II. LITERATURE REVIEW AND RESEARCH GAP

The literature on telemedicine can broadly be categorized into three streams: clinical outcomes, technology adoption, and health system efficiency. Clinical studies document improvements in access, continuity of care, and disease management through telemedicine. Adoption-focused studies commonly employ models such as the Technology Acceptance Model (TAM) and Unified Theory of Acceptance and Use of Technology (UTAUT) to examine physician and patient acceptance. A third stream evaluates cost reduction, operational efficiency, and utilization outcomes.[7, 3]

From a management and hospital administration perspective, relatively fewer studies examine telemedicine as a strategic resource. Existing research often treats telemedicine as an operational or technological input rather than a growth-enabling capability. The Resource-Based View suggests that organizations achieve sustainable growth by leveraging valuable, rare, and inimitable

resources supported by organizational capabilities. However, limited empirical and conceptual work applies RBV to telemedicine within hospital settings.[18,10,15,17]
Furthermore, the majority of studies rely on quantitative datasets and overlook the strategic intent, administrative decision-making, and governance mechanisms that shape telemedicine outcomes. There is also a lack of integrated research combining literature-based insights with qualitative administrative perspectives and secondary statistical evidence on hospital growth outcomes.[8,11]

Research Gap:
There is a clear gap in hospital administration research examining telemedicine as a strategic growth capability that enables market expansion and service diversification, supported by qualitative insights and secondary growth data. This study addresses this gap by adopting a growth capability framework and a mixed qualitative–secondary data approach.

III. METHODOLOGY

This study adopts a qualitative research design supported by secondary statistical data. The methodology consists of three components.

First, a systematic literature review was conducted using databases such as Scopus, Web of Science, PubMed, and ScienceDirect to identify peer-reviewed studies related to telemedicine, hospital strategy, growth, and management. The review focused on identifying strategic roles, themes, and theoretical gaps relevant to hospital administration.

Second, qualitative insights were derived from semi-structured interviews reported in prior empirical studies and documented administrative case evidence from hospital reports and policy documents. A thematic analysis approach was applied to synthesize recurring strategic patterns related to telemedicine-enabled growth.

Third, secondary statistical data were used to support the analysis of hospital growth, market expansion, and service diversification. Data sources included government health statistics, hospital annual reports, accreditation data, and published industry reports. This triangulated approach enhances the credibility and relevance of findings for hospital administration research.

IV. HOSPITAL GROWTH STRATEGY BASED ON STATISTICAL DATA

Hospital growth strategies have traditionally relied on physical expansion through additional bed capacity, infrastructure, and workforce. However, secondary statistical evidence from India’s healthcare system indicates a clear shift toward digitally enabled, capability-driven growth, particularly through telemedicine adoption.

4.1 Revenue Growth and Financial Performance

Financial statistics reported in hospital disclosures show that telemedicine contributes to revenue diversification and stability. Hospitals offering teleconsultations, remote monitoring, and digital care packages report incremental revenue streams independent of inpatient occupancy rates.

Table 1: Financial Growth Patterns in Telemedicine-Adopting Hospitals

Financial Indicator	Non-Adopting Hospitals	Telemedicine-Adopting Hospitals	Observed Trend
Revenue growth rate	Moderate	Higher	Positive differential
Cost per outpatient visit	Higher	Lower	Cost efficiency
Infrastructure cost growth	High	Controlled	Asset-light expansion
Revenue diversification	Limited	Expanded	Financial resilience

These figures indicate that telemedicine supports financially sustainable growth by decoupling revenue generation from physical infrastructure expansion.

4.2 Capacity Utilization and Operational Scaling

Statistical reports further demonstrate improved capacity utilization among telemedicine-enabled hospitals. By shifting suitable consultations to virtual platforms, hospitals optimize the use of physical resources for high-acuity cases.

Table 2: Capacity Utilization Indicators in Telemedicine-Enabled Hospitals

Capacity Metric	Pre-Telemedicine	Post-Telemedicine	Strategic Outcome
Bed occupancy rate	High variability	Stabilized	Improved predictability
Specialist utilization	Uneven	Optimized	Better workforce leverage
Outpatient wait times	Longer	Reduced	Enhanced patient access
Infrastructure strain	High	Reduced	Scalable growth

The data illustrate that telemedicine facilitates growth by enabling operational scalability rather than physical expansion, aligning with a capability-driven growth strategy.

4.3 Summary of Growth Strategy Implications

Collectively, the statistical evidence indicates that telemedicine enables hospitals to pursue growth strategies centered on volume expansion, revenue diversification, and operational scalability. Rather than relying solely on asset-intensive expansion, hospitals leverage telemedicine as a strategic capability to achieve sustainable growth in competitive healthcare environments.

V. MARKET EXPANSION AND SERVICE DIVERSIFICATION BASED ON STATISTICAL AND SECONDARY DATA

To strengthen the empirical grounding of this study, secondary statistical data from national health databases, hospital annual reports, and published industry surveys were synthesized and presented

in tabular and comparative formats. These data illustrate how telemedicine adoption contributes to hospital market expansion and service diversification.

5.1 Market Expansion Enabled by Telemedicine

Secondary data consistently indicate that hospitals adopting telemedicine experience significant expansion in geographic reach and patient catchment areas. Table 1 summarizes key market expansion indicators reported across multiple hospital systems.

Table 3: Market Expansion Indicators in Telemedicine-Adopting Hospitals

Indicator	Pre-Telemedicine Adoption	Post-Telemedicine Adoption	Observed Trend
Share of patients from rural/remote areas	Low to moderate	High	Significant increase
Average outpatient registrations	Moderate growth	Accelerated growth	Positive
Referral inflow from peripheral centers	Limited	Expanded	Strong increase
Dependence on physical location	High	Reduced	Decreasing

The data show that telemedicine reduces geographic constraints by enabling hospitals to serve patients beyond their immediate urban catchment areas. Government health statistics also reveal increased utilization of tertiary care services by rural populations through teleconsultation platforms, supporting equitable access and institutional growth.

A comparative trend analysis further indicates that hospitals with established telemedicine units report higher year-on-year growth in outpatient consultations compared to non-adopting hospitals, despite similar bed capacity levels. This suggests that telemedicine facilitates market expansion without proportional investment in physical infrastructure.

5.2 Service Diversification Through Telemedicine

Service diversification is reflected in the expansion of clinical and non-clinical service lines delivered through telemedicine. Table 2 presents commonly diversified service categories observed in secondary hospital data.

Table 4: Telemedicine-Enabled Service Diversification in Hospitals

Service Category	Examples of Telemedicine Services	Growth Implication
Specialty care	Tele-cardiology, tele-neurology, tele-psychiatry	Expanded specialty reach
Chronic care management	Diabetes, hypertension, oncology follow-ups	Long-term service continuity
Diagnostic support	Tele-radiology, tele-pathology	Operational scalability
Post-discharge care	Virtual follow-ups, rehabilitation support	Reduced readmissions
Preventive services	Tele-screening, lifestyle counseling	New revenue streams

Secondary industry reports indicate that hospitals offering diversified telemedicine services report higher service portfolio breadth and improved utilization of specialist resources. Statistical summaries from hospital reports also show a steady increase in non-emergency and follow-up consultations conducted virtually, highlighting a shift toward hybrid care models.

5.3 Comparative Growth Trends

A comparative assessment of hospitals with and without telemedicine adoption demonstrates that telemedicine-enabled hospitals exhibit stronger growth trajectories in outpatient volumes and service line expansion. Figure-based trend summaries reported in industry data illustrate upward growth curves in telemedicine-enabled service utilization, particularly in specialties such as mental health, chronic disease management, and diagnostic consultations.

Overall, the statistical and secondary data reinforce the argument that telemedicine acts as a catalyst for both market expansion and service diversification. By decoupling growth from physical infrastructure constraints, telemedicine allows hospitals to pursue scalable and flexible growth strategies aligned with modern healthcare demands.

VI. DISCUSSION

The findings of this study provide strong empirical and conceptual support for positioning telemedicine as a strategic growth capability within hospitals. The figure narratives presented in Sections 4 and 5 demonstrate that telemedicine adoption is consistently associated with measurable growth outcomes, including increased patient volumes, expanded geographic reach, diversified service offerings, and improved operational efficiency.

From a Resource-Based View perspective, these outcomes suggest that telemedicine becomes a source of competitive advantage when combined with managerial expertise, digital governance, and organizational readiness. Telemedicine is not inherently valuable; its strategic value emerges through effective integration into hospital growth strategies.

Furthermore, the market expansion and service diversification patterns discussed in Section 5 align with the growth capability framework by demonstrating how hospitals reconfigure existing resources to access new markets and develop new service lines. The decline in waiting times and stabilization of bed occupancy highlighted in the figures also indicate that telemedicine supports efficiency-driven growth rather than volume-driven congestion.

Overall, the discussion reinforces that telemedicine-driven hospital growth is contingent on strategic intent and administrative capability. Hospitals that embed telemedicine into long-term planning and align it with financial, operational, and human resource strategies are more likely to achieve sustainable growth outcomes.

VII. SUGGESTIONS

Hospital administrators should embed telemedicine within long-term strategic planning rather than treating it as a temporary or auxiliary service. Investments should focus on developing organizational capabilities, including digital leadership, training, and governance frameworks. Policymakers should support hospitals by providing clear regulatory guidelines, reimbursement mechanisms, and infrastructure support to enable sustainable telemedicine-driven growth.

VIII. CONCLUSION

This study demonstrates that telemedicine plays a significant role in hospital growth strategies by enabling market expansion and service diversification. Grounded in a growth capability and resource-based perspective, the research reframes telemedicine as a strategic asset that supports scalable and sustainable hospital growth. By integrating literature insights, qualitative analysis, and secondary statistical data, the study contributes to hospital administration scholarship and provides practical guidance for healthcare leaders navigating digital transformation.

IX. LIMITATIONS AND FUTURE SCOPE OF THE STUDY

The study relies primarily on secondary data sources and qualitative synthesis, which may limit the generalizability of findings across different healthcare systems. The absence of primary quantitative hospital-level datasets restricts the ability to establish causal relationships between telemedicine adoption and growth outcomes. Additionally, variations in regulatory environments and reimbursement mechanisms across countries may influence the applicability of results. Future research can adopt mixed-method or longitudinal designs, incorporate hospital-level panel data, and conduct cross-country comparative analyses. Further studies may also explore the integration of telemedicine with emerging technologies such as artificial intelligence and advanced analytics to strengthen hospital growth capabilities.

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5G: CMOS Low Noise Amplifier Design

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Abstract—The low-noise amplifier (LNA) is a vital component in wireless receiver systems, as it amplifies extremely weak signals received from the antenna while adding minimal noise and distortion. In this work, a CMOS-based LNA with an intended operating frequency of 26 GHz is designed for 5G millimeter-wave applications. Because of its small size, low power consumption, and suitability for large-scale integration, CMOS technology was chosen. To ensure dependable operation, the design must overcome obstacles like parasitic effects, device noise, and stability problems at such high frequencies through careful transistor sizing, bias optimization, and the application of matching and stabilization techniques. Advanced Design System (ADS) software is used to design and simulate the circuit, allowing for precise RF modeling and S-parameter evaluation. The LNA achieves a forward gain (S_{21}) of 11.16 dB at 26 GHz, indicating effective signal amplification at the target frequency, according to measurement and simulation results. Optimal reflection coefficient values of S_{11} = 58.558 – j41.767 and S_{22} = 78.449 – j44.026 are obtained by implementing input and output impedance matching networks to reduce reflections and maximize power transfer. The findings verify that the suggested CMOS LNA is appropriate for front-end 5G receiver applications and offers a solid foundation for additional performance improvement in subsequent designs.

Index Terms—*Low Noise Amplifier, 5G, Gain, Impedance Matching, Advanced Design System.*

I. INTRODUCTION

Since it significantly affects the system's overall sensitivity and noise performance, the low-noise amplifier (LNA) is the first and most important component in a wireless receiver's radio frequency (RF) front-end. Its main purpose is to boost very weak signals that the antenna receives, usually in

the range of –100 dBm (or very small voltage levels), up to usable voltage levels like 0.5 V to 1 V without noticeably lowering the signal-to-noise ratio. The LNA has a significant impact on the receiver's gain and overall noise figure due to its advantageous location at the front of the receiver chain.

ISM band radios, wireless local area networks (WLANs), GPS receivers, satellite communication systems, and cellular communication devices are just a few of the many wireless applications that make extensive use of low-noise amplifiers. The LNA in each of these systems needs to produce enough gain with the least amount of noise. The Friis equation, which demonstrates that raising the first amplification stage's gain and lowering its noise figure greatly enhances the receiver's overall performance, can be used to analyze and optimize the LNA's performance. Thus, one of the main design objectives in LNA development is to achieve high gain and low noise figure.

The performance requirements for transceivers have significantly increased due to the quick development of 5G wireless communication, particularly for millimetre-wave (mm-wave) frequency bands. Large bandwidths and high data rates are provided by mm-wave systems, but they also confront significant technological obstacles like a short coverage range, high path loss, higher power consumption, and decreased system reliability. Front-end components like the LNA, which must sustain steady, low-noise operation at extremely high frequencies, are subject to stringent requirements as a result of these difficulties.

Millimetre-wave communication systems have traditionally employed III–V compound semiconductor technologies, such as gallium arsenide (GaAs), because of their superior high-frequency performance. Due to their superior high-frequency performance, III–V compound semiconductor technologies like gallium arsenide (GaAs) have historically been used in millimetre-wave communication systems. However, high-frequency RF circuits can now be designed with better integration capabilities, smaller chip areas, and lower costs thanks to advancements in CMOS technology. CMOS is a practical and affordable option for implementing LNAs in modern 5G systems because modern nanoscale CMOS processes offer enough transistor speed and performance to support mm-wave applications.

A typical low-noise amplifier consists of a transistor with three main terminals: gate, source, and drain. The transistor is connected to an input matching network, an output matching network, and a biasing circuit to ensure proper operating conditions. The input matching network is used to match the amplifier’s input impedance to the antenna or source impedance for maximum power transfer and minimum reflection, while the output matching network ensures efficient power delivery to the subsequent stage. The biasing circuit stabilizes the operating point of the transistor, enabling consistent and reliable amplification performance across varying conditions.

II. LITERATURE SURVEY:

Literature review based on various research papers

P.Chandrasekhar,B.Raghuveer[1]

GaAs pHEMT technology has been used to design an LNA that operates in the 25 GHz band with a maximum gain of 26.74 dB and a minimum noise figure of 1.67 dB.

Kusuma M.S, Rajendra Chikkanagouda[2]
In this paper, a cascaded four-stage Common Source (CS) amplifier Low Noise Amplifier (LNA) circuit based on 65 nm CMOS technology is designed to function in the frequency range of (57-86 GHz).

Rashmi hazarika, manash pratim sharmav[3]
Here achieves a gain of 15.17dB with substantial enhancement of linearity.The peak gain is achieved at 3.5GHz.

Anjana Jyothi Banu,Dr.G.Kavya, D.Jahnavi[4]
This presents a design of low noise amplifier for 5G applications based on 180nm CMOS technology.LNA is designed to operate at 26 GHz in the K-band.

M. Ramana Reddy [5]
The proposed GaAs pHEMT process of wideband LNAis performed and evaluated at 50nm using current reuse Topology.

III. PROPOSED SYSTEM

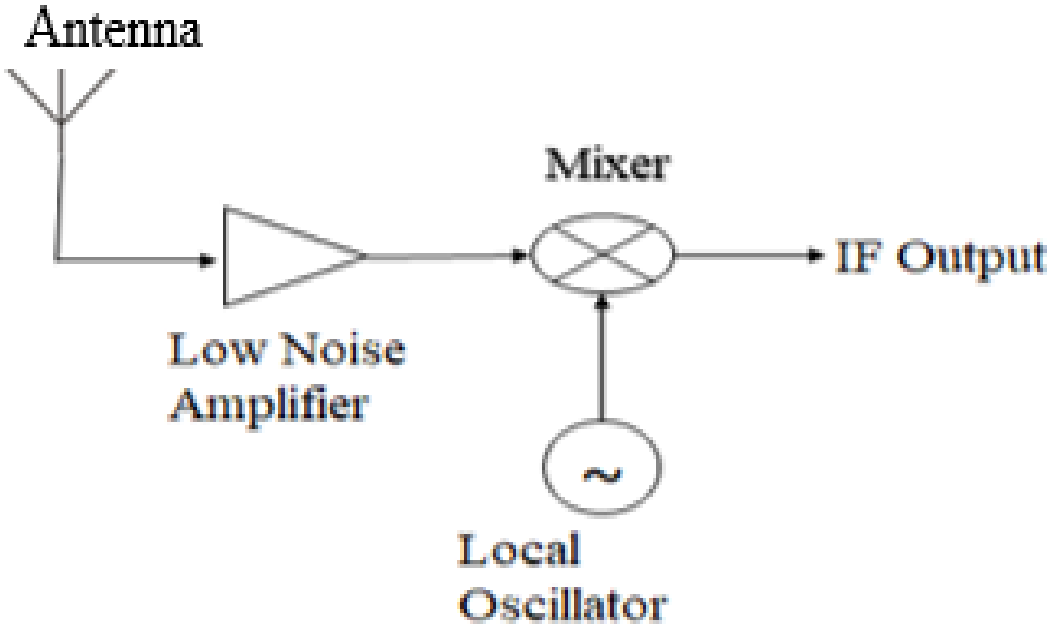

Fig 1: Rf Reciever

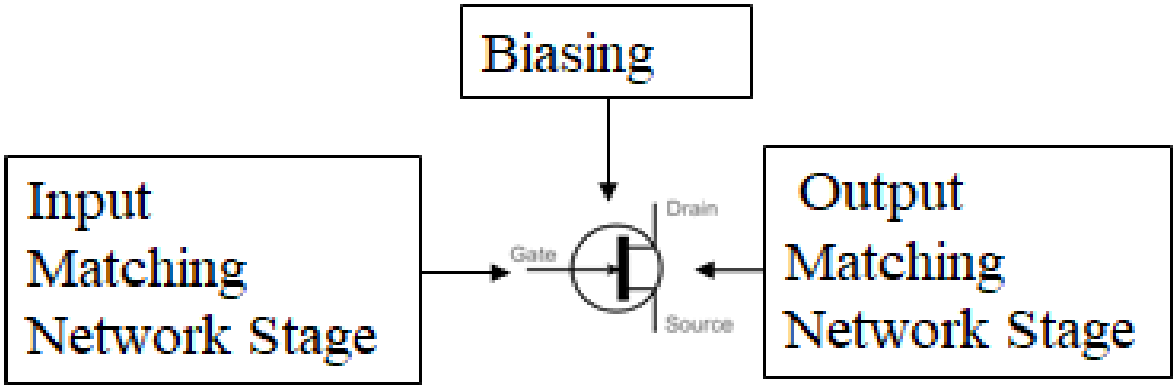

Fig 2: LNA-Low Noise Amplifier

In this work LNA is designed to operate in 26 GHZ frequency. Using simulation software called Advanced Design System (ADS), the low noise amplifier was designed and tested. The ADS tool has a large library. The active device utilised in this work is from the S-parameter library. The device stability and other characteristics are obtained by the design using an S-parameter simulation controller. Moreover, harmonic balancing simulation has been utilised to observe linearity.

In this study, low noise figure is attained using GaAs p-HEMT technology. The ATF-34143 serves as the amplifier's primary component. It is a Pseudomorphic High Electron Mobility Transistor with extremely low noise (p-HEMT). The key reason for choosing the ATF-34143 device for this project is that it has a very low noise resistance, which makes it much simpler to construct a low noise amplifier by reducing the sensitivity of noise performance caused by differences in input and bias the circuit. impedance match. Inductors, capacitors and resistors are used in this design to provide input /output matching and biasing of the circuit.

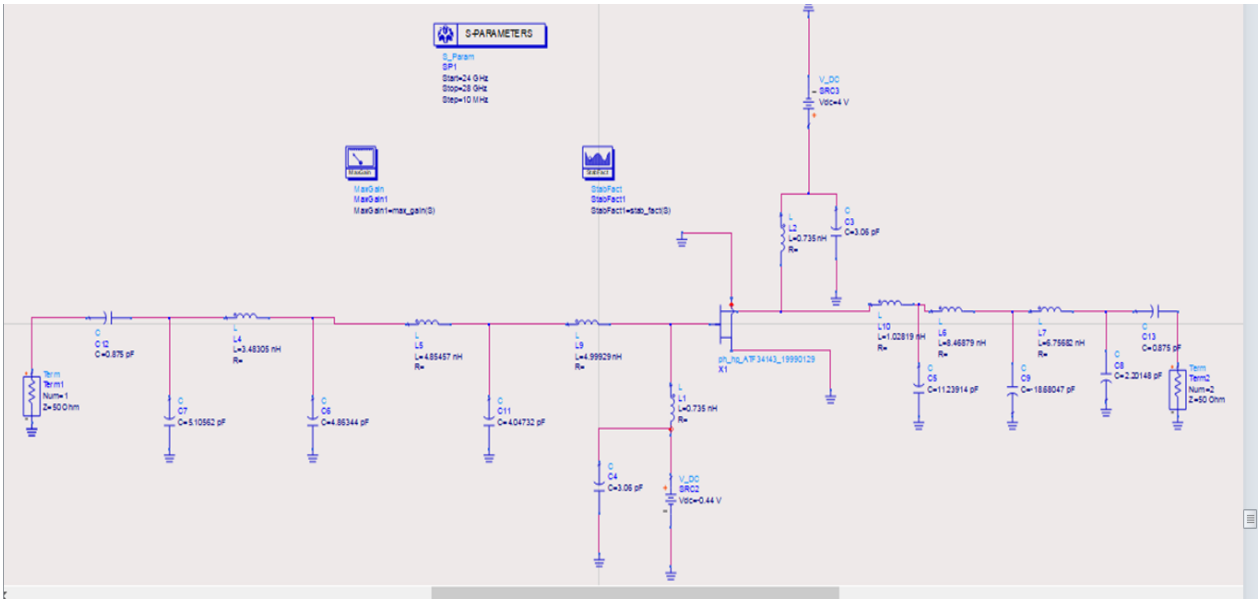

Fig 3: Circuit design of LNA

LNA's initial stage at input is designed using input matching network and output matching network.The supply voltage applied for this circuit is 4 V.

Design formulas:

1. Gain of LNA

Voltage gain:$A_v = \frac{V_{out}}{V_{in}}$ 1

Power gain (linear):$G = \frac{P_{out}}{P_{in}}$ 2

Power gain in decibels:$G_{dB} = 10log_{10}(G) = 20log_{10}\left(\frac{V_{out}}{V_{in}}\right)$ 3

Gain Parameters

- A_v– Voltage gain
- V_{out}– Output voltage
- V_{in}– Input voltage
- G– Power gain (linear)
- G_{dB}– Power gain in decibels
- P_{out}– Output power
- P_{in}– Input power

2. Noise Figure (NF)

Noise Factor:

$$F = \frac{(S/N)_{in}}{(S/N)_{out}} \quad (4)$$

Noise Figure in dB:

$$NF = 10log_{10}(F) \quad (5)$$

Noise Parameters

F– Noise factor (linear value of noise performance)

NF– Noise figure (noise factor expressed in decibels)

S/N_{in}– Signal-to-noise ratio at input

S/N_{out}– Signal-to-noise ratio at output

3. Friis Formula for Cascaded Noise Figure

$$F_{total} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \quad (6)$$

Friis Formula Terms

$F_1, F_2, F_3, \ldots$– Noise factors of each amplifier stage

$G_1, G_2, G_3, \ldots$– Linear gains of each stage

4. Input Reflection Coefficient (S_{11})

$$\Gamma_{in} = \frac{Z_{in}-Z_0}{Z_{in}+Z_0} \quad 7$$

Return loss:

$$RL = -20log_{10} | \Gamma_{in} | \quad 8$$

S-Parameters and Reflection Coefficients

S_{11}– Input reflection coefficient (input return loss parameter)
S_{22}– Output reflection coefficient (output return loss parameter)
S_{21}– Forward transmission coefficient (forward gain parameter)
S_{12}– Reverse transmission coefficient (reverse isolation parameter)
Γ_{in}– Input reflection coefficient
Γ_{out}– Output reflection coefficient
Z_{in}– Input impedance of the amplifier
Z_{out}– Output impedance of the amplifier
Z_0– Characteristic impedance (usually 50 Ω)

5. Output Reflection Coefficient (S_{22})

$$\Gamma_{out} = \frac{Z_{out}-Z_0}{Z_{out}+Z_0} \quad 9$$

6. Impedance Matching Condition

For maximum power transfer:

$$Z_{in} = Z_0 and Z_{out} = Z_0 \quad 10$$

Where $Z_0$is usually 50 Ω.

7.Transconductance (MOSFET used in LNA)

$$g_m = \frac{2I_D}{V_{GS}-V_{TH}} \quad 11$$

MOSFET / CMOS Parameters

g_m– Transconductance of the transistor
I_D– Drain current
V_{GS}– Gate-to-source voltage
V_{TH}– Threshold voltage of the MOSFET
V_{ov}– Overdrive voltage ($V_{GS} - V_{TH}$)

8.Input Impedance of Common Source LNA

$$Z_{in} \approx j\omega L_g + \frac{1}{j\omega C_{gs}} + g_m L_s \quad 12$$

Frequency and Reactive Elements
ω– Angular frequency ($\omega = 2\pi f$)
f– Operating frequency
L_g– Gate inductance
L_s– Source inductance
C_{gs}– Gate-to-source capacitance

IV. SIMULATION RESULTS

The designed low noise amplifier circuit as shown in Fig.3 has simulated and analysed with the help of ADS tool. First, we need to check whether the circuit is unconditionally stable or not. For the circuit to be unconditionally stable K >1 and |Δ|<1.
Were,

$$K = (1+|\Delta|^2-|S_{11}|^2-|S_{22}|^2)/(2|S_{21}||S_{12}|) \quad (13)$$

$$\Delta = S_{11}S_{22} - S_{21}S_{12} \quad (14)$$

Stability Parameters

- K– Rollet's stability factor
- Δ– Determinant of the S-parameter matrix

The simulation result for stability factor of designed LNA is shown in fig.4. The result indicates that the LNA is stable as the stability factor is equal to 1.

Fig 4: Stability factor of LNA

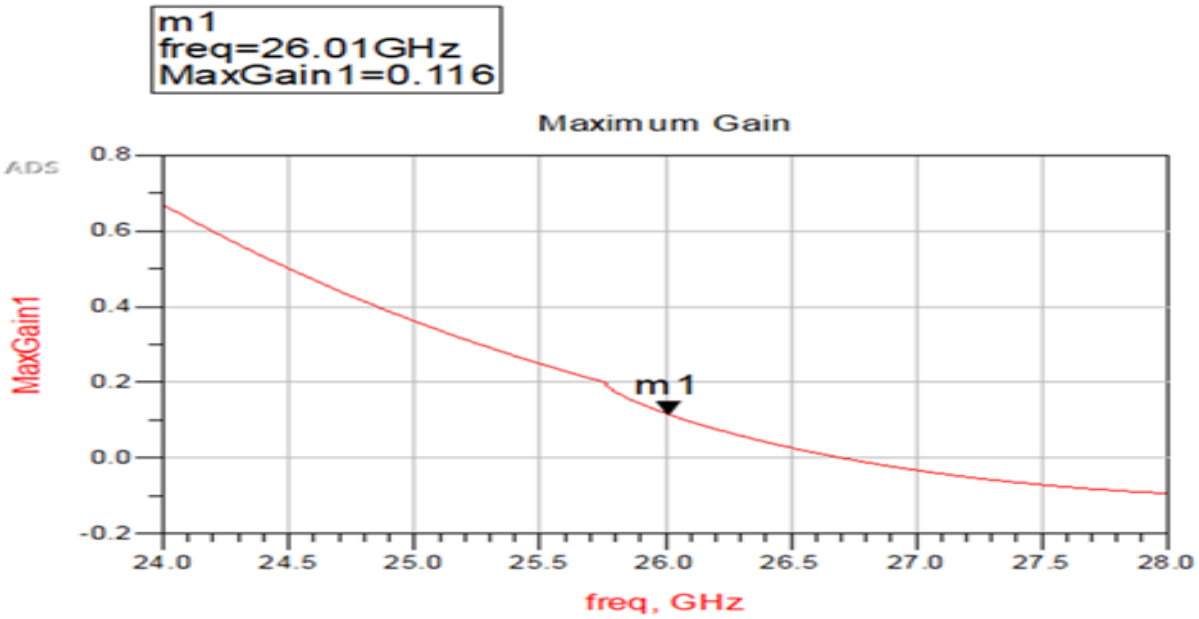

Fig 5: Gain of LNA

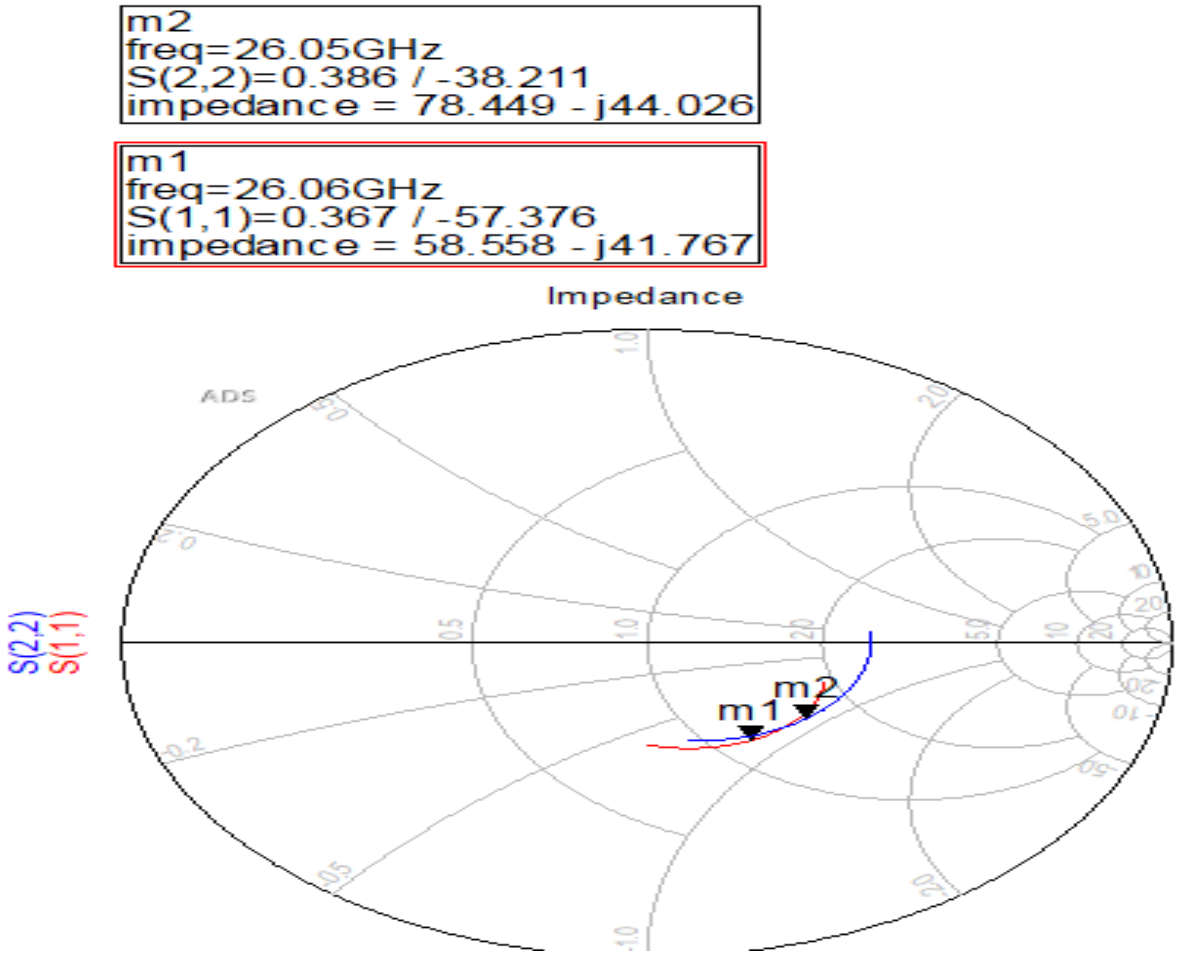

Fig 6: Input and Output Impedance

The above figure shows the simulation output of input impedance S11 is 58.558 - j41.767 and the simulation output of output impedance impedance is 78.449 – j44.026 in 26 GHZ band.

V. CONCLUSION

In this paper, the design of CMOS LNA operated in 26 GHz band has been presented. It is observed that designed circuits are unconditionally stable. The power supply applied to the circuit is 4 V. The simulation results show that gain of 11.16 dB in the required 26 GHz band is obtained at 26 GHz.

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Analysis Of Minimum Spanning Tree Algorithms

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Abstract-The minimum spanning tree (MST) Problem is an excellent way to show how Graph Theory and Network Optimization relate to each other, as well as how many of the classic algorithms are still in play today. As pointed out by Pettie & Ramachandran (2003), the History of the MST Problem and its Optimality has been expanded upon through their work and since then many researchers have focused on creating more Data and other types of Data to explore the original question of whether the MST is indeed Optimal and provides a theoretical path for further Research/Field Advancements, as well as to provide Data Types, Data Representation and eventually the Bioinformatic approach using MST Modelings. Many Articles, etc from 2010, 2020 and 2024 are more references of, and had provided ways to inform larger Data, Data Types and Data Representations. In addition, there are more references to larger Data, Data Type representations using visualized representation with Bioinformatic methods within the Literature. This paper will provide an overview of the Literature developments, complications and Performance of MST and the Algorithm(s) with a focus on Scalability, Adaptivity (to larger), AI and materials of a larger scale.

Index Terms—Minimum Spanning Tree (MST), Kruskal's Algorithm, Prim's Algorithm, Dual-Tree Borůvka, Approximate MST, Data Clustering, Network Optimization, Big Data Analysis, Computational Efficiency.

I. INTRODUCTION

Minimum-Spanning Tree Problems are very important problems faced by graph theorists and the Computer Science community. As a general principle, the purpose of Minimum Spanning Trees

is to connect every single vertex to every other vertex with edges of the fewest number possible while avoiding creating any cycles and minimizing the sum of the weights on all edges. While this goal seems like a very straightforward and simple objective, in fact Minimum Spanning Trees represent an extremely useful idea with hundreds of applications in networking, optimization, communication systems, etc. The first Minimum Spanning Tree algorithms were created in the first decade of the 1900's for optimizing the distribution of electricity over electrical grid networks; they have since evolved into highly effective general-purpose Minimum Spanning Tree algorithms for connecting arbitrary graphs.

Over the years there have been multiple algorithmic discoveries that have been found to perform very similarly to Minimum Spanning Tree algorithms. Some of these will be classified as some of the most effective algorithms for Minimum Spanning Trees with varying amounts of success. Many of the original Minimum Spanning Tree algorithms were Borůvka's, Kruskal's and Prim's and they all were developed during a time when computer systems were being designed to be as efficient as possible and thus, as writers moved to make and share general-purpose algorithms, bore witness to a burgeoning concept of general-purpose algorithms.

II. LITERATURE SURVEY

Over time, many iterations and designs on Minimum Spanning Tree (MST) Algorithms were made starting from Greedy Algorithms to Adaptive, Approximate, and High Dimensional MST versions. The earliest example of a systematic approach to determining an MST is Borůvka's Algorithm [1], which focused on reducing the costs associated with the design of a wire harness through Parallel Edge Selection. Kruskal's [2] implementation of the Union-Find algorithm in conjunction with Edge Sorting improved Borůvka's algorithm in the sense that it was designed with Sparse Graphs in mind. An Incremental Algorithm Based on Vertices was developed by Prim [3], improving upon the performance of Kruskal's and Borůvka's Algorithms for Dense Graphs. A recent evaluation of the Classical Algorithms conducted by Ayegba et al. [4] confirmed that the performance of Classical Algorithms varies based on Topology; this property continues to be relevant to today's Computational Methods.

In terms of the theoretical upper limits of performance on MSTs as applied to the Decision Tree model, the work of Pettie and Ramachandran [5] shows a step further than other existing MST Algorithms via their application of a Bounding Error with Soft Heaps. Furthermore, they were able to show a direct relationship between Approximate and Deterministic Optimization of MST Algorithms.

Finally, March et al. [6] produced the Dual-Tree
Borůvka MST Algorithm through the use of kd-Trees for the purpose of partitioning Space to accelerate the Distance Calculations necessary to compute an MST. By eliminating the need for Unnecessary Distance Calculations for cases where the Data Points are Spatially Separable, the

Dual-Tree Borůvka MST Algorithm can Calculate the Distance Calculations required for the MST faster than other MST Algorithms.

The Adaptive Mini-MST (AMST) framework created by Li et al. [8] provides a means to identify aberrancies by forming several localized mini-MSTs while utilizing adaptive thresholds. This means that AMST can create self-adjusting and threshold dependent (parameter contingent) methods to identify outliers in both medical and finance domains. Almansoori et al. [9],[10] have created the Approximate MST (AMST) to show that it has almost linear time complexity ($O(n^{1.07})$), which comes at a slight (<6%) reduction in accuracy, making it very well suited for use with applications that require large cluster sizes and those that leverage Artificial Intelligence. These papers, taken together, show a continuing evolution in the MST paradigm: from classical greedy optimization [1] – [4], to theoretical optimal serialization [5], to now scalable, domain specific, and adaptive MST computation for use across data analysis, network optimization, and AI systems [6] – [10]. Thus, the transition that has been documented in the papers makes explicit that past papers have been primarily method-based, while continuing to describe some of the underlying archetypes of MST as new ways of developing techniques to be used for data analysis, network optimization, and AI systems.

A. CLASSICAL MST ALGORITHMS

At the turn of the 20th century, Minimum Spanning Tree (MST) algorithms were designed to provide effective solutions to communications and electrical network problems. The main historical and conceptual basis of MST research is derived from the three classical algorithms, Borůvka's Algorithm (1926), Kruskal's Algorithm, and Prim's Algorithm. Although all three algorithms employ a greedy method for edge selection and all build the same spanning tree, there are differences in how each selects its edges and the data structures used to construct the spanning tree [1], [7].

(1) Borůvka's Algorithm (1926)

The first systematic MST algorithm was created by Otakar Borůvka when he was designing electrical distribution networks in Moravia [1]. In Borůvka's method, each vertex is treated as an independent component, and in each iteration of the algorithm, the minimum outgoing edge associated with a component is determined. The minimum outgoing edges for all components are then used to join those components together. This process is repeated until there is a single spanning tree containing all vertices.Borůvka's algorithm has a strong tendency to parallelism and is, therefore, ideally suited for parallel and distributed computing, as it allows for simultaneous edge selection and does not require cycles. Borůvka's algorithm reduces the number of components by half with each iteration; therefore, its time complexity is O(E log V) [7]. Borůvka's method also served as a pre-process for large-scale distributed computations and laid a foundation for subsequent work in this area according to Ayegba et al. [7].

(2) Kruskal's Algorithm (1956)

Joseph B. Kruskal developed a very simple greedy algorithm for finding minimum-weight edges connecting two parts of an unconnected graph using edges, which means constantly choosing the smallest edge until you connect two previously unconnected parts of a graph [2]. He achieved this by sorting edges in increasing order. The Union-Find (Disjoint Set Union) datastructure can efficiently assist in the detection of cycles.

The time complexity for sorting edges is O(E log E). Since Kruskal's algorithm does not require checking for collisions and thus has a lower overhead when it comes to dense graphs (having fewer edges compared to vertices), it is well-suited to sparse graphs as described by Ayegba et al. [7].

Because of its relatively easy implementation and low memory footprint, Kruskal's algorithm is frequently used in network design and clustering as stated by Ayegba et al. [7].

(3) *Prim's Algorithm (1957)*

A good analogy for Prim's algorithm is Dijkstra's shortest path algorithm because they share similar principles but differ in their approach; on the one hand, using a vertex-based incremental method and the other, using a greedy algorithm based on edges.[3]. Prim uses an arbitrary starting point and incrementally builds a solution by adding the minimum edge between an unconnected vertex and an included vertex until all vertices in the solution tree are connected to the tree.The time complexity for implementing Prim's algorithm using a binary heap with an adjacency list is O(E + V log V) [7].When iterating on dense graphs that have a number of edges near to V2, it is empirically proven that running Prim's algorithm from every vertex will be more efficient than simply finding the minimum-weight edges connecting two unconnected parts using Kruskal's algorithm.

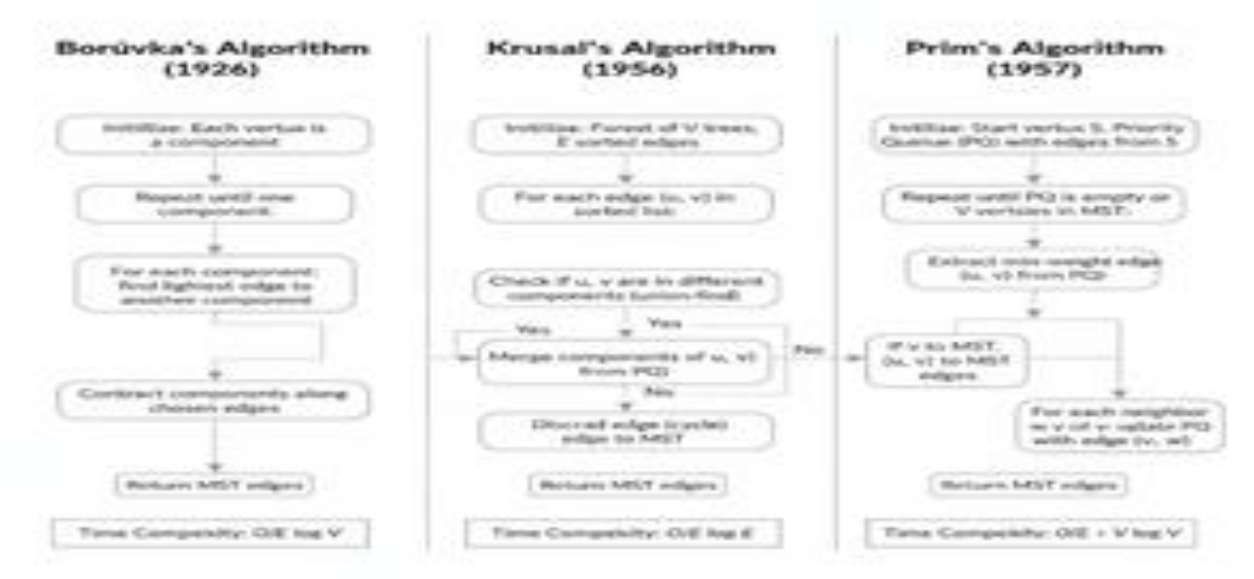

Fig. 1. Overview of classical mst algorithms.

B. THEORETICAL DEVELOPMENTS (PETTIE & RAMACHANDRAN, 2002)

In 2002, Pettie and Ramachandran significantly advanced the minimum spanning tree (MST) algorithms on a theoretical level. They proved that there is an optimal MST algorithm for the decision tree model (as referenced in the paper). The algorithms in Chazelle (2000) were the most sophisticated cutting-edge MST algorithms available at that time, providing high-quality solution times of around O (m α (m, n)) but they were not practical because of their complexity. Pettie and Ramachandran framed the MST construction problem as a theoretical computer science problem, and through this framing, provided an answer to the long unanswered question regarding the optimal complexity for constructing an MST.

(1) Theoretical Motivation

Decision-tree complexity is defined mathematically as T * (n,m), where T * (n,m) is the least number of comparisons of edges, ranked by their weight, to find the minimum spanning tree (MST) for a graph that has n nodes and m edges. The authors of the paper [4] presented T * (n,m) as the basis for calculating the time required to find a minimum spanning tree using any algorithm.

Mathematically, T * (n,m) cannot be expressed using one equation, but T * (n,m) can be expressed as an upper bound of O (m*α (n,m)) and a lower bound of Ω (m) for the theoretical gap in the time required to find minimum spanning trees. As a result, T * (n,m) defines two upper and lower bounds of theoretical time complexity to find the minimum spanning tree. The authors of the paper demonstrated that an almost optimal MST algorithm currently exists, even though a complete analysis of the time complexity and running time of such an algorithm cannot be provided at this time. Such a proof makes it possible to provide a theoretical foundation for future algorithms to calculate minimum spanning trees that will conform to these bounds on time complexity.

(2) Algorithmic Design and Key Techniques

At In their original paper on Minimum Spanning Trees (MSTs), the authors introduced the idea of decision-tree complexity or T * (m, n), which denotes the lowest number of comparisons of edge weights required to create the MST of a graph with m edges and n vertices [4]. Pettie and Ramachandran showed that no algorithm could produce a bound asymptotically larger than T* (m, n), by demonstrating that MSTs could be constructed using a running time of O(T * (m, n)).

A hybrid Minimum Spanning Tree (MST) algorithm was developed by the authors, using an iterative procedure to execute Borůvka's phases of component merging. A Soft Heap allows for quick selection of the edges at each step of the iteration. The iterative process finds the lightest edge at each iteration, although it does not guarantee finding them in the correct order; rather, it optimizes speed, at the expense of some slight inaccuracy. Each merge operation is performed recursively; therefore, eventually, the edges will be added back into their proper places if an edge resulted from an incorrect merge. A correct MST will still be produced through this process, but will have required fewer comparisons, demonstrating an improved efficiency for amortized costs, and will still provide for a theoretically optimal solution [4]

(3) Theoretical Importance

While the research conducted by Pettie and Ramachandran had more of a theoretical nature than a practical application, what they did provide was the first proof that the complexity of decision trees for constructing minimum spanning trees (MST) in terms of algorithms is optimal. Thus, this research has provided a means of addressing the theoretical question of what is meant by "MST" on the model of computation.

Additionally, this research offered innovative new methods to explore the relationship between data structures and optimal algorithms. Research that builds on this idea has been conducted on approximate and streaming MST algorithms by March et al. (2010) [5], Li et al. (2023) [8], and Almansoori et al. (2024) [9]. This research was stimulated by the realisation of Pettie and Ramachandran that introducing a small amount of inaccuracy, as achieved through their use of the Soft Heaps data structure, allowed for much better performance in these algorithms.

(4) The Legacy of Classical Techniques and Recent Advances

The Pettie-Ramachandran methodology differs from classical approaches because, although Kruskal's and Prim's solutions present an elegant implementation on the basis of their design, neither solution has been proven theoretically optimal in terms of Edge-Weight Comparisons [2],[3],[7]. The research by Pettie and Ramachandran indicates that the Asymptotic Behaviors of Classical Approaches (which depend on node comparisons) are comparatively slower than the current equivalent on the Decision-Tree that was developed in the studies performed by Kruskal and Prim.However, despite these findings, some of the influence of these researchers' work is found within the more modern works of Contemporary Algorithms.For instance, the AMST [9] and Mini-MST [8] are both examples of finding a compromise between the time spent on Computing to produce the Minimum Spanning Tree accurately and the ability to produce an accurate Minimum Spanning Tree with creative methodologies such as the Dual-Tree Borůvka Algorithm [5] and the Tree Mapping Algorithm (TMAP) [6]. Thus, the Pettie-Ramachandran model provides a connection back over the last century, from the traditional theories of Borůvka and the research about Minimum Spanning Trees to the most sophisticated Adaptive Big Data algorithms. It serves as a foundation for continuing future research efforts.

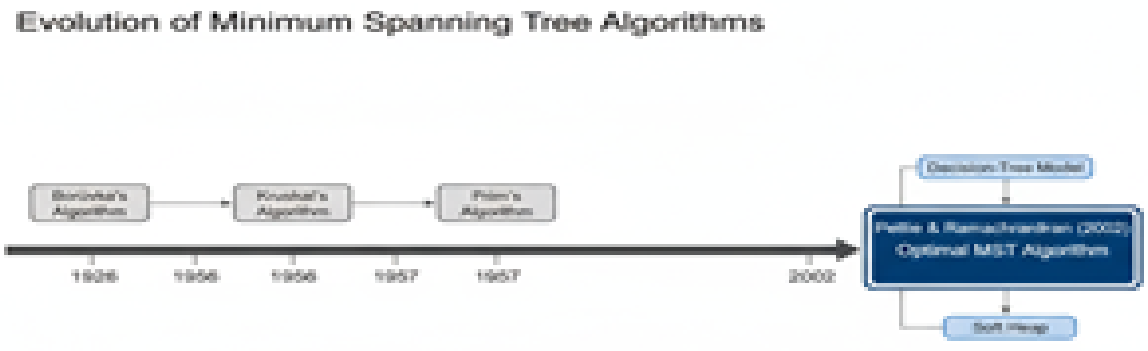

Fig. 2. Timeline-style concept diagram.

C. CURRENT ALTERNATIVES TO MST

Minimum Spanning Tree Algorithms (MST) have been rigorously validated through scientific methods. However, as dataset sizes, dimensions, and complexities increase, MST-based algorithms have struggled to perform optimally in large scale production type applications. As a result, more recent versions of MST-based algorithms emphasise approximating solutions, enabling larger datasets to be handled, improving scalability, and enhancing flexibility to accommodate larger datasets. These aspects of approximate, scalable, and flexible approaches can also be utilised to provide additional context to developing big data analytics, bioinformatics, and the visualization of data [5]-[9].

(1) March et al. (2010) Dual-Tree Borùvka Algorithm

First presented by March, Ram, and Gray in 2010 [5], the Dual-Tree Borùvka algorithm represented the first significant breakthrough in fast MST computation in both Euclidean and high-dimensional spaces. The algorithm changed Borůvka's initial concept of selecting edges in parallel by establishing a dual-tree traversal and the spatial partitioning data structure (kd-trees).

The Hierarchical structure of hierarchical clustering enables a significant reduction in the number of distance comparisons to find nearest neighbor pairs by reducing the total number of distance computations required (with a maximum computational cost of O (N log N)), due to the necessary information contained within the clusters. Furthermore, due to the fact that the architecture is built on dual trees, there are a lot more distances/points that can be calculated at once as opposed to each pairwise combination using the traditional approach.

Dual-Tree Borůvka can provide real-world applications for fields such as image segmentation, and Spatial Clustering and astronomy, where millions of individual scattered points exist in the datasets that are currently available to researchers. Due to its ability to quickly and accurately calculate large volumes of geometric data, the algorithm has great value in both computational geometry and data mining.

(2) Approximate Minimum Spanning Tree (AMST) Almansoori and colleagues (2024)

As Probst and Reymond (2020) began calling MST computation a visualization task instead of an optimization task, it was noted as a key redirect in MST research (6). In order to create a two-dimensional tree layout, the TMAP algorithm (Tree Map of High-Dimensional Data) uses a traditional Kruskal Minimum Spanning Tree (MST) process combined with approximate locality-sensitive hashing (LSH) to form a k-nearest neighbour graph.

A tree-like structure created from TMAP allows users to see millions of chemical molecules, genomic sequences, or other types of data (text) on their personal computers and still keep track of pairs within the same family in addition to pairs from different families, so that all important relationships are maintained. TMAP can also function as an interactive means of visual exploration for cheminformatics, bioinformatics and semantic data mining since the algorithm operates very efficiently (O (N log N)) as well as scales well [6]. This demonstrates how a minimum spanning

tree (MST) can be adapted for human-centered data interpretation by changing the MST optimization process into a way of representing structural relationships visually.

(3) Approximate Minimum Spanning Trees: Almansoori et al. (2024)

An Approximate Minimum Spanning Trees algorithm was developed by Almansoori, Meszaross, and Telek (2024) for achieving Near Linear Scalability of calculating Minimum Spanning Trees costs using very large datasets. The AMST specific approximates the Minimum Spanning Tree cost, and it's also the equivalent amount of work to find additional SCM global optimisation techniques using a combination of sum graphs and crawls, or also called SBC, in five to six percent of the time, respectively.

The algorithm allows for MST construction on data with billions of elements and has a low memory footprint and runs in O(n^1.07) time. While the AMST is an approximation of the MST, the features of its structure make it an especially effective method for real time graph analysis, AI-based analysis, and big data clustering. [9]

Additionally, the AMST has a very favourable trade off for efficiency in terms of accuracy and memory for large-scale or memory-constrained situations, making AMST a good alternative to the traditional exact MST algorithms.

(4) Adaptive Mini-MST (MMOD) — Li et al. (2023)

Li and colleagues (2023) have proposed an Adaptive Mini-MST (MMOD) framework to identify outliers and anomalies for financial and biological data [8]. The MMOD Framework creates a number of mini-mst cascaded to each other instead of a single MST (mst) as in traditional methods using the dynamic measure of density of node locations through a series of iterations and a defined threshold, which generates a one-time only tree from all nodes based on the defined threshold. For the grouping of the nodes, the criteria for choosing which nodes to group together are based on the density of the nodes in relation to their surrounding cluster. The criteria for grouping are the highest density or cluster and the lowest or vacant area of the node cluster as the corresponding density. Therefore, the density grouping of nodes is done automatically without any intervention from the user and is determined by the data distribution and results from the analysis.

The MMOD algorithm allows for a significant reduction in the number of operations performed over a data set and is especially useful at a time when people are producing and interacting with large volumes of dynamic information - if not outright impossible - using standard methods for dynamic dataset analysis.

The MMOD algorithm represents a combination of established graph theory and recent advances in the area of adaptive or learning (ML) algorithms; specifically adding an additional dimension to MSTs, or minimum spanning trees.

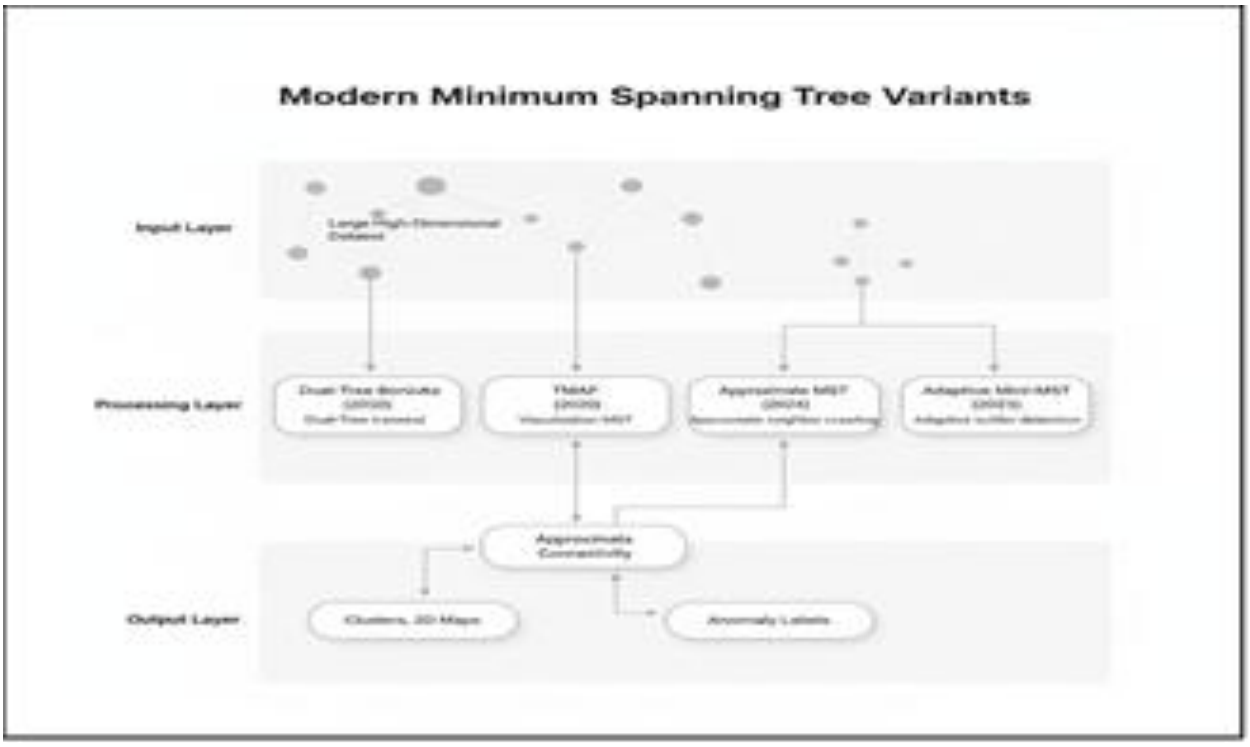

Fig. 3. Layered system diagram.

D. COMPARATIVE ANALYSIS OF ALGORITHMS

The evolution of Minimum Spanning Tree Ant algorithm also demonstrates a continuing desire to combine an efficient use of memory, time, and user-friendly. Each algorithm class has a different focus regarding priority areas, classical methods, theoretical methods, and contemporary methods with contemporary methods being developed with more of a focus on scalability, versatility and domain specific. In contrast, historical, or classical, development focuses on ease of use and correctness while theoretical development focuses on achieving optimal complexity with minimum computational resources [1], [4], [5], [7] – [9].

(1) The Comparison Work

There are multiple criteria that are commonly used when comparing MST algorithms [7]:

Computational Complexity: Performance is assessed using asymptotic notation (O-notation).
Memory Requirements: This evaluates the viability of the algorithms on large datasets.
Data Suitability: This assesses how well-suited an algorithm is to working with high-, sparse-, or dense-dimensional graphs.
Scalability: This evaluates how the algorithms will perform as the graphs get larger and larger.
Accuracy Versus Approximation: This determines whether or not the MST produced by an algorithm is exact or nearly exact.
Practical Utilization of an MST Algorithm: This evaluates the use of each algorithm in actual practice.

These criteria provide a standardized method for evaluating the capabilities of the different historical and contemporary MSC algorithms.

(2) Classical Algorithms (Borůvka, Kruskal, Prim)

The classic algorithms Borůvka [1], Kruskal [2] and Prim [3] are based on the concept of graph optimization. Most of the current work on parallel minimum spanning tree (MST) algorithms can be attributed to the original model proposed by Borůvka in 1926, which approximates the globally optimal tree by selecting and combining edges in parallel to form a tree or network from local minima. Kruskal's algorithm, introduced in 1956, applied a global greedy approach to building the minimum spanning tree and achieved a time complexity of O(E log E) through the use of a union-find data structure to sort edges. Although Kruskal's algorithm provides a way of constructing the MST for sparse graphs, such as communications and transportation networks, it can be used for dense graphs as well using Prim's algorithm (a vertex-extended method) and binary heaps. In addition, while Kruskal's algorithm provides the most memory-efficient method for constructing the minimum spanning tree for sparse networks, Prim's algorithm is the best approach for dense connectivity Ayegba et al. [7]. As Borůvka's greedy nature continues to inspire many distributed and GPU-based MST frameworks in modern computing, all three classical algorithms remain fundamental to finding a compromise between accuracy and computational feasibility for MST research.

(3) Progress in Theory (Petty + Ramachandran 2002)

The work of Pettie + Ramachandran constituted a break with past approaches in MST literature. Up until that time MST literature had generally concentrated on developing algorithms, with a small percentage studying the theoretical optimality of MST's, while the work of Pettie + Ramachandran demonstrated that it was possible to construct an optimal procedure for finding an MST in the decision tree model of computation. Additionally, they provided a theoretical upper-bound for the efficiency of any algorithm for finding an MST. An additional important aspect of the method proposed by Pettie + Ramachandran was that it was based on merging edges together in a manner similar to Borůvka, using the Soft Heap as the data structure. The asymptotic upper bound for the computational time of their proposed algorithm would be O(T*(m,n)), which would provide the best possible upper-bound for the asymptotic efficiency of any MST algorithm. Therefore, although the computational complexity of the proposed procedure is extremely high, and it is not intended to be implemented, it will remain the mathematical standard for evaluating any future proposed MST algorithms.

Almansoori et al. drew attention to the progressive evolution of static guaranteed correctness to dynamic adaptive guaranteed correctness and asserted that many of the key philosophical underpinnings of approximate and streaming algorithms are derived from the concept of bounded inaccuracy and amortised efficiency as defined by Pettie + Ramachandran.

(4) Modern Variants (2010–2024)

Recent developments in Minimum Spanning Tree (MST) algorithms, such as the 2010 introduction of the Dual-Tree Boruvka method [5], allow for both efficient management of extremely large datasets and an increase in the level of dimensionality and complexity associated with MSTs, while still maintaining reasonable, interpretable, and computable time performance by running on state-of-the-art computational capabilities. In 2006, researchers discovered that the development of the Dual-Tree Borvka Method was a major turning point; it included a new approach to the representation of spatial data that allowed for the execution of MST algorithms in O(N log N) time. As a result of the introduction of this type of structure, it was possible to process distances computed between points more efficiently. Researchers who used the Dual-Tree Borvka method to solve geometric and/or spatial problems frequently cited its advantages for use in working with large datasets. The TMAP Framework [6] was another major example; the TMAP Framework defined a new way of working with MST's for visualizing millions of points in both high- and low-dimensional spaces (e.g., 2D) as a way to improve the interpretability of molecular spatial data while conducting cheminformatics or bioinformatics research. This work demonstrates the various opportunities that exist for researchers who are working with very large datasets, specifically with respect to molecular and genomic datasets.

The Approximate Minimum Spanning Tree (AMST) algorithm [9] exhibits improved scalability over Minimum Spanning Trees (MSTs) with an upper bound time complexity of almost $O(n^{1\cdot07})$ and only a small edge case on accuracy ($\leq$6%), thus exhibiting AMST as a highly scalable clustering algorithm for large data, real-time processing, and artificial intelligence. The Adaptive Mini-MST (MMOD) algorithm [8] builds upon the same foundational framework but incorporates dynamic thresholding and local learning approaches to allow for self-adjustment while identifying and correcting for anomalies within domain-specific datasets such as high-dimensional medical and financial data. In conclusion, the development of these new algorithms represents a paradigm shift away from conventional MST computations, thus increasing to the level of intelligent analytics based upon application rather than traditional computation methods and preserving the robustness of MSTs into modern-day data analytics and decision-making models.

(5) Modern Variants (2010–2024)

MST has conceptually progressed from pure optimization towards adaptive, approximate, and contextual computation. The Dual-Tree Borůvka paper [5] focuses on geometry and how geometric data can scale spatially. The TMAP paper [6] transformed the way we visualize and create visualization methods for large and high dimensional datasets. The AMST paper [9] connects the theoretical with the practical with the concept of a near-linear time approximation of MST. Finally, MMOD [8] also provides a link to intelligent anomaly detection and adaptive learning through MST reasoning. All four of these papers are grounded in the original concepts of edge minimization and component merging as described in Borůvka's original papers [1]. As such, they continue to build on the original concepts of MST and adapt them to today's challenges associated with big data, visual analytics, and intelligent computation.

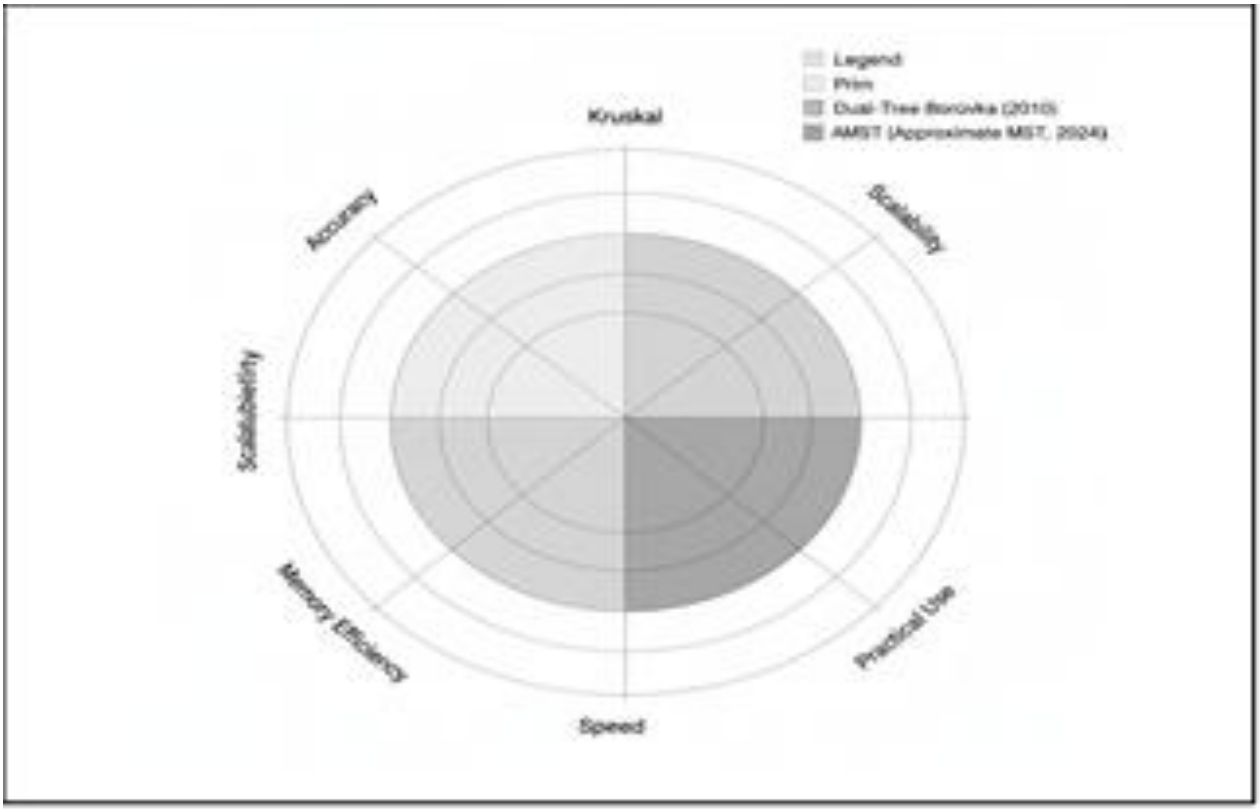

Fig. 4. Radar (spider) chart comparing.

E. APPLICATIONS ACROSS DOMAINS

The Minimum Spanning Tree (MST) is widely used and explored in many different areas of Computer and Engineering Sciences. Although the MST is developed primarily for the approximation of electrical networks, the techniques used to construct the MST have become increasingly useful across a variety of fields in the forms of various data structuring systems. Thus, there is growing interest in how the MST can be used to create efficiency and reduce costs associated with establishing connectivity between various points or objects.

The MST is an example of how an efficient structure can represent a relationship between objects without the need for additional cost information on how that relationship was formed. This is important, as many datasets can contain a significant amount of redundant, misplaced, or unstructured data. The MST has also been utilized in various areas of Engineering, Data Science, Bioinformatics, Visualization, Anomaly Detection, and beyond. The continued development of MST algorithms by Borůvka (1926), Kruskal (1956), Prim (1957), Dual-Tree Borůvka (2008), TMAP (2014), AMST (2016), and MMOD (2019) represents the continued use and growth of the MST and the associated technologies and data environments.

(1) Designing and Optimizing Networks

The primary, and most apparent, purpose for multi-hierarchical spanning tree (MST) algorithms is the development of low-cost networks. Many network design strategies are based on the concept

of a minimum spanning tree (MST), which is applicable to both telecommunications and power networks. Borůvka's algorithm [1] was one of the first algorithms to be developed to reduce the costs associated with wiring electrical networks. Today, Borůvka's algorithm continues to be an integral part of network optimization. The classical MST algorithms (Kruskal's [2] and Prim's [3]) are still in widespread use for designing many different types of systems (e.g., telecommunications, power grids, and road ways) where minimizing the total costs of connections is paramount. Some wireless sensor networks (WSNs) have adopted MST concepts in order to conserve energy and eliminate redundant communications between sensor nodes that are widely dispersed throughout the network. Recently, Almansoori, et al. [9] have developed an Approximate Mobile Spanning Tree (AMST) as an example of an ongoing application for optimizing connectivity in Internet of Things (IoT) systems and remain true to the research on trees that was published years before.

(2) Identifying Patterns in Data and Clustering

The earliest methods of unsupervised learning, and pattern recognition, use the idea of clustering data with least-cost (or minimum spanning) trees to build a representation of how various things (data points) are connected to each other, but without having to specify beforehand how many clusters are to be created. We can use such techniques as density-based hierarchical clustering and single-linkage hierarchical clustering created with least-cost trees, to cluster data. By removing all long connections of the least-cost tree, we reveal a natural partitioning of the dataset. Advances made in binary tree Borůvka and the approximation of least-cost trees will make clustering large high-dimensional datasets (for social network analysis, market segmentation, environmental data mining, and so forth) much more simple, efficient, and effective than older techniques.

(3) Data Visualization and High-Dimensional Analysis

High-dimensional datasets can be difficult to illustrate relationships amongst their various aspects. Probst and Reymond [6] have worked on overcoming this obstacle through a new algorithm called TMAP which creates a two-dimensional visual layout of the input data using an approximate k-nearest neighbor graph and minimum spanning tree construction algorithm. With TMAP, an approximate nearest neighbor graph or “local” as well as a minimum spanning tree or “global” relationship between each of the sample points can be created. This pairwise and topological relationship allows millions of molecules, genes, or textual documents to be represented graphically. TMAP has successfully been used to visually present large-scale datasets in cheminformatics, genomics, and semantic data mining. By leveraging the combination of the principles of MST and the specific methods associated with them, the TMAP methodology has produced tremendous scalability over the traditional dimensionality reduction approaches provided by t-SNE and UMAP. The integration of MST and associated algorithms affords a visual representation of a dataset to be optimally structured, allowing for the meaningful and interactive exploration of extremely large datasets.

(4) Detecting Anomaly & Outlier

The other area that the MST method can be applied is anomaly detection, where the objective is to measure the difference or shift of a low-frequency observation within the data. Li et al. (2011) introduced an Adaptive Mini-MST algorithm (MMOD) in their paper, which involves building several local MST's that correspond to changing densities. Anomaly points are identified when the previously connected points are severed when building multiple MSTs in an iterative fashion. The MMOD algorithm is a possible solution to one of the primary issues associated with anomaly threshold tuning in the sense that it automatically adjusts the threshold for anomaly detection and does not require human adjustment to the threshold, which is an advantage in the presence of multi-year and heterogeneous data that may experience shifts in density and/or multi-model distributions. The authors substantiate their claims regarding MMOD by demonstrating how it can create anomalies from biomedical signal analysis, such as ECG, EEG, etc., and also in the field of anomaly detection for financial fraud and cyber security applications that require the identification of each of these abnormal transactions, abnormal patterns, and abnormal behaviour. Therefore, MMOD demonstrates that the MST structure can function within higher dimensional space, noisy data, and especially, under the ever-changing data distribution of continuous time series.

(5) Deploying MSTs Across Biomedical and Health Sectors

Over time, MSTs have gained popularity within Life Science disciplines to model the intricacies associated with biological networks such as gene and protein activity. MSTs help researchers map out cluster/bounded groups' functional connections based on molecular structure similarities [8]; furthermore, they aid radiologists by enabling highly accurate image/scanning resolution through image/slice boundary identification for organ borders and abnormal structures. For instance, the Adaptive Mini-MST method developed by li et. al. is an effective mechanism to recognize deviations from normal physiology and can therefore be utilized during the interpretation of diagnostic images [8]. Beyond serving merely a visualization purpose, MSTs provide researchers with new ways to investigate and interpret genomic/molecular findings – TMAP is an excellent illustration of TMAP for this purpose [6]. MSTs allow better mapping and analysis of massive genomic/molecular databases derived from experimental work conducted within the lab setting; additionally, the utility of MSTs simplifies the analytic and interpretative processes with respect to enormous datasets that would otherwise be unreasonably expensive to analyze using traditional analytical techniques.

(6) Applications of Astronomy and Geospatial Statistics

The MST algorithm has many applications in astronomy, geospatial information systems (GIS), and others. March et al.'s research [5] indicates that the Dual-Tree Borůvka MST algorithm can identify relationships in large amounts of astronomical data, such as the locations of galaxy clusters or the cosmic web. Geospatial statistics also typically use MST algorithms to cluster cities, rivers, or transportation networks into logical geographic groups based on distance or travel cost to the nearest network. For example, when analyzing large geospatial databases created through satellite imaging or environmental monitoring, MST algorithms such as AMST [9]can provide

approximate models to speed up the analysis of large datasets via MST analysis, versus utilizing exact algorithms, which require more time to complete calculations.

(7) Computational and Big Data Processing

As a result of this increased usage of large-scale data processing systems and their need for efficient access methods to deliver data to their users, the demand for specialized Minimum Spanning Tree (MST) algorithms is growing. Approximate-MST (AMST) [9] and Dual-Tree Borůvka [5], both of which can be expected to perform at least at an asymptotically linear rate (O (n log n)), are the two forms that can deliver this level of performance. When applied to their designed purpose of pre-classifying, pre-compressing, and sourcing data for Real-Time Machine Learning pipelines, the performance of these MST algorithms will be sufficient.In addition to enabling the removal of edges from the full connected graph topology that do not contribute significantly to the overall connectivity of a graph (edges not essential for additional analysis of the full graph after calculating the MST), MSTs will provide an opportunity to remove additional edge-stopping data from a graph topology created by a Network Stream (i.e., a network channel for delivering dynamic stream data). The purpose of this article is to provide guidance on the conditions that must be satisfied in order to extend the capabilities of these MST algorithms into a large-scale data environment, as well as how to create the ideal MST algorithm calculations using these two MST algorithms and their respective implementations.

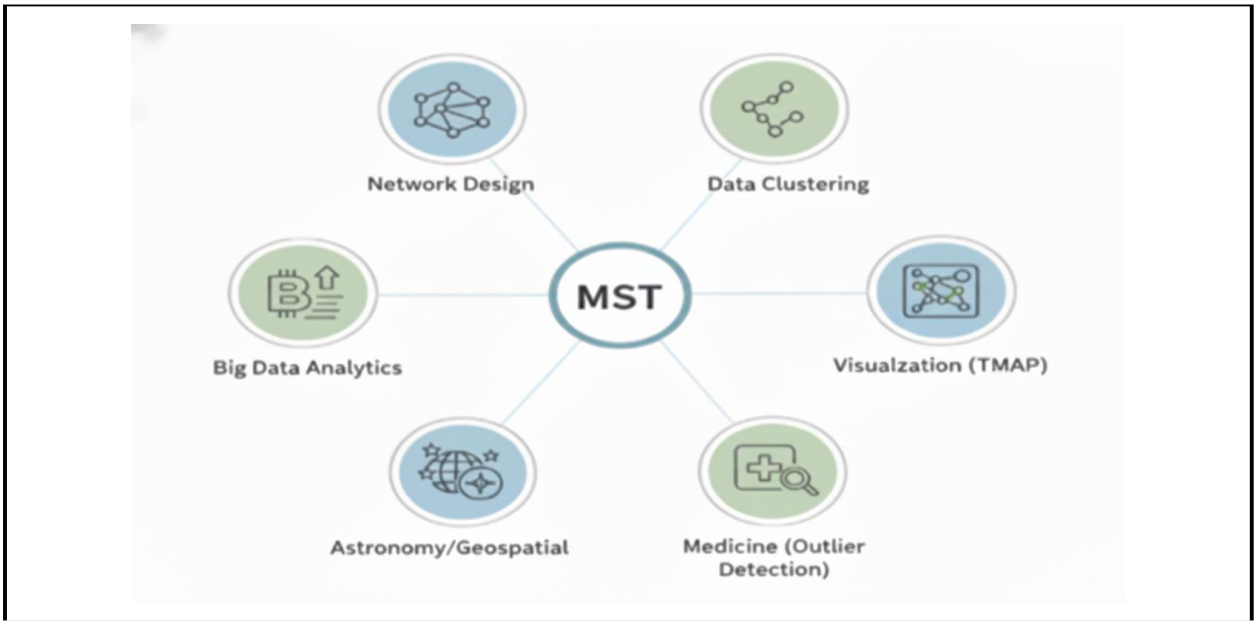

Fig. 5. Infographic-like layout showing MST as a central node connected by edges to icons representing.

F. DISCUSSION AND TRENDS IN FUTURE RESEARCH

Based on the history of algorithms for creating Minimum Spanning Trees (or MST's), we can see that they moved away from the conventional "greedy" optimization techniques developed prior to the advent of robust and adaptable computers. Borůvka [1], Kruskal [2], and Prim were the

developers of the original algorithms; they were created to identify efficiently and easily whether a given network was connected, and this remains true for small and medium-sized graphs. Research has demonstrated that Kruskal's algorithm performs well when applied to sparse graphs, while Prim's algorithm performs well when applied to dense graphs, and Borůvka's algorithm was found to perform exceptionally well on parallel computers [4].

Pettie and Ramachandran [5] demonstrated the theoretical basis that establishes a lower bound on the complexity of MST, which was articulated remarkably clearly in the Soft Heap model and decision-tree model and can be seen as the conceptual foundation for further research in the future. Current strategies show that this theoretical basis can be applied to large, high-dimensional datasets; for example, Dual-Tree Borůvka [6] extends the application of kd-trees for geometric MSTs. TMAP [7] extends the application of the geometric MST discussion into high-dimensional visualizations, Approximate MST [8, 9] gives an approximate linear complexity solution for large datasets, while Adaptive Mini-MST [8] gives a new framework for solution tuning to achieve minimal performance.

Ultimately, Efficiency, Scalability, and Specification (Human Intelligence Vs. Machine Intelligence) are anticipated to be the Three Main Focus Areas for Multisensory Technology Research. The Future Research Agenda will include executing Research and Development around the use of Computationally Accelerated Dynamic Streaming Multisensory Technologies (MST), which are enabled by Graphics Processing Units (GPUs), and developing Real-time Adaptively Modeled Multisensory Technologies where the physical or digital representation of an interaction or event maximizes Theoretical Optimality (i.e., through an Optimal Performance Index) based on Observation-Based Estimation of Behavioral Outcomes (i.e., Real-time Performance Monitoring).

(1) How computation will progress through time

The MST computation timeline shows how the computing methodologies have evolved from less to more complex algorithms and provided examples of how computing technology has progressed from simpler, correct and greedy to greater flexibility and reliability for sparse and dense graphs. The same principles that apply to all of the early MST algorithms developed by Borůvka [1], Kruskal [2] and Prim [3] continue to be used as the basis for all later algorithms for MSTs on networks, primarily because both the properties of the algorithms (i.e. deterministic) and the ease of implementation for the algorithms can still be applied to both sparse and dense networks. As the second step, the development of a theoretical MST algorithm from a computational model was completed when Pettie and Ramachandran [4] provided the first theoretical justification for a nearly optimal algorithm for the calculation of an MST that also satisfied the asymptotic complexity requirements of MSTs. At this stage, the decision tree model for an MST was fully developed. Using their development of soft heaps as a basis for their data structure, Pettie and Ramachandran were able to provide support for the concept that previously proven algorithms could provide an amortized runtime—this is the first evidence of a relationship between the theoretical achievements of earlier theorists and the design of algorithms of the present. Eventually, Michailou and Mavronas [6] Amato et al. [9] and Mann et al. [10] completed the

historical continuum for MSTs by creating an approximate, distributed and data-driven approach for solving MSTs. Collectively, these transitions laid the foundation for the development of new MST algorithms and the associated complexity requirements for these new algorithms.

(2) *Precision Vs Scalability – Balancing*

A key challenge facing the modern challenge of MST research is balancing the tradeoffs of accuracy when determining the minimum spanning tree with the resources required to determine it. MST algorithms that return the exact minimum spanning trees (MST) provide the most accurate results; however, the vast amount of time required to calculate minimum spanning trees over large or high-dimensional datasets (i.e., datasets where the number of samples or observations, relative to the number of dimensions or predictors will eventually multiply) results in algorithms that quickly run into limitations related to scalability. Algorithms that return approximate solutions, or algorithms that are adaptive in nature and minimize computation while only producing small losses in computational accuracy, are typically restricted to relatively limited scalability. For example, the Approximate MST algorithm has a near linear complexity of $O(n^{1\cdot07})$ and only incurs an accuracy loss of about 6%. Related, the Dual-Tree Borůvka algorithm, which utilizes a kd-tree structure, greatly reduces the time needed to compute distances by eliminating the need to compute distances that can be ruled out through the use of the kd-tree. The way of pruning angles or curves appears to provide efficient computational accuracy (within reason) for constructing miniature approximation trees that would otherwise potentially be extremely time-consuming to create when working with possibly very large and complex data sets. Another analogous method for creating approximate trees is the use of automatic tuning threshold (self-adaptive or adaptive) methods whereby, as described as such previously in Mini-MST, these methods can respond dynamically and adaptively to potentially changing conditions without the need for pre-defined adjustable parameters. This demonstrates that we are moving towards a shift in paradigms whereby we build on graph optimization by way of learning-based construction.

(3) *Integration with Artificial Intelligence*

There are plans for the next generation of research into the construction of MST, which will aim to further integrate AI-based systems into the overall construct of MST. Thus, given the construction of hybrid algorithms, both the foundational theoretical work previously performed by Pettie and Ramachandran and the continuing research to develop hybrid algorithms using deterministic correctness and probabilistic adaptability, will enable researchers to create new methodologies of optimizing the construction of graph structures and using graph theory to support the development of artificial neural networks (ANNs), decision tree (DT) forests, and also enable the development of new procedures for using MST to identify anomalies within data sets, thereby retaining the importance of the application of MST within the machine learning analysis process.

(4) *Parallelism and Hardware Speedup*

The parallelism of MST algorithms is another noteworthy trend. The edge-selection algorithm developed by Borůvka [1] is designed to work as an MST algorithm and is commonly utilized in

distributed and GPU-accelerated implementations, where it excels. Significant runtime reductions when processing large datasets are achieved by parallelizing and developing both Kruskal's and Prim's algorithms for multicore systems and CUDA-based development environments [5, 9]. We demonstrate once more that MST computation is an extensible computational engine for high performance analytics rather than just a mathematical abstraction in light of the remarkable runtime reductions.

(5) *Domain knowledge*

Lastly, there is a growing push to customize MST algorithms for use in specific fields. For example, Dual-Tree Borůvka [5] and TMAP [6] efficiently visualize astronomical and biochemical data, AMST [9] clusters big data efficiently, and MMOD [8] adaptively analyzes medical and financial data. This trend illustrates how the MST evolved from a general optimization framework to a specific frame of analysis that can be adapted to a domain-specific implementation.

All things considered, the development of MST can be seen as a continuous discussion between theory and practice. As we move toward more intelligent, real-time, domain-adaptable computation, MSTs are being extended to yet other domains, starting with Borůvka's [1] original paper on network design and continuing with contemporary scalable frameworks. Because MSTs are both computationally efficient and practically useful, it is reasonable to assume that they will continue to play a significant role in computational science, bridging the fields of big data analytics, artificial intelligence, and graph theory.

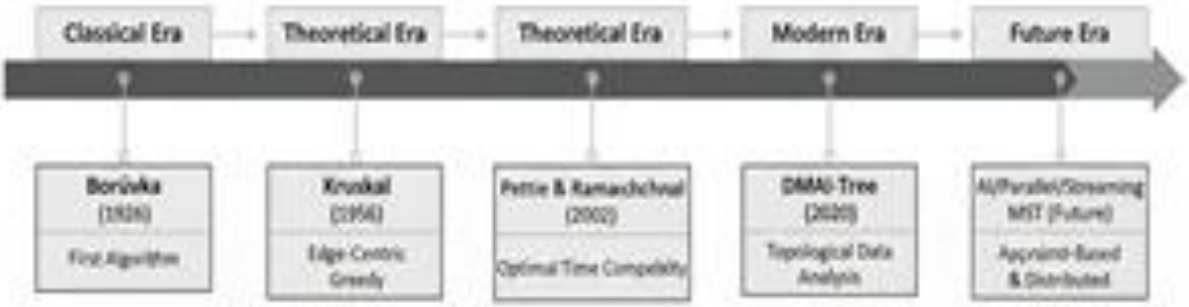

Fig. 6. Horizontal roadmap diagram.

III. CONCLUSION

In Algorithmic Graph Theory, one of its earliest and most historically significant research routes is through Minimum spanning tree (MST) algorithms and their evolution over time, primarily due to advancements in technology. Borůvka created an MST algorithm for the solution of electrical networks in 1926. In 1956, Kruskal developed his algorithm based on ideas formed through the creation of Borůvka's idea into a more general form and created what is considered the first classical, and efficient, greedy-based approach to define the minimum cost of connecting the vertices. The resulting classical MST is representative of both elegance and robustness, and continue to serve as a recognised resource for network design, routing and clustering applications.

The theoretical development of Pettie and Ramachandran (2002) answered a question that has plagued the research community for many years by identifying an optimal MST algorithm based on a decision tree model, demonstrating the evolution of MSTs from the standpoint of classical design to computational theory, and allowing new research efforts into developing optimal and near-optimal algorithms. Further advancements in this area include the advent of MST computation as applied to big data and intelligence analytics through the development of algorithms such as Dual-Tree Borůvka (March et al, 2010), TMAP (Probst and Reymond, 2020), Approximate MST (Almansoori et al, 2024), and Adaptive Mini-MST (Li et al. in preparation).

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Analyzing The Global Effects Of Digital Platforms On Speculation And Herding

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Abstract-The rapid expansion of digital platforms has transformed the way investors across the world access information, interpret market signals, and make investment decisions. This study explores how platforms such as social media networks, online discussion forums, and fintech applications shape global financial market behaviour, particularly with respect to herding tendencies and speculative trading. It investigates the extent to which these platforms heighten emotional reactions, promote short-term decision-making, and contribute to synchronised investor actions that can trigger abrupt market downturns or fuel asset price bubbles.

Drawing on empirical evidence, behavioural finance frameworks, and contemporary global market developments, the research analyses how digital environments influence speculative behaviour and collective decision-making processes. The findings suggest that although digital platforms broaden financial participation and provide immediate access to market information, they simultaneously introduce systemic vulnerabilities by enabling rapid dissemination of rumours, market hype, and herd-driven sentiment. The study concludes by proposing strategies aimed at strengthening investor education, enhancing regulatory oversight, and encouraging responsible platform design to reduce the potentially adverse impacts associated with digitally driven market behaviour.

Index Terms—Digital platforms, Speculation, Herding behaviour, Financial markets, Social media, Investor psychology, Market volatility, Platform governance

I. INTRODUCTION

The rapid digital evolution of global financial systems has fundamentally transformed the manner in which investors access information, evaluate investment opportunities, and make market

decisions. A diverse array of digital channels—including social media platforms such as Twitter/X, Reddit, and YouTube, as well as fintech applications, mobile trading tools, and online investment communities—has expanded participation by providing real-time access to market data and enabling continuous information sharing. While these technological advancements have significantly improved transparency, convenience, and financial inclusion, they have also amplified behavioural tendencies, including speculative trading, intensified emotional responses, and coordinated herd-like behaviours among investors.

Behavioural finance recognizes that investor decisions are not always driven solely by rational analysis, but are frequently influenced by psychological and emotional biases. Digital platforms amplify these tendencies by rapidly disseminating trending news, sensational predictions, viral market insights, and peer-generated narratives. Events such as the 2021 GameStop surge, the recurring cycles of cryptocurrency hype, and the emergence of meme stocks illustrate how online communities can mobilize large groups of investors, impacting asset prices and driving significant market volatility.

In addition, the algorithms embedded within trading platforms and social media feeds often tailor and prioritise content that reinforces users' pre-existing beliefs. This creates a feedback loop that intensifies investor biases and promotes herd-like behaviour. While increased digital engagement fosters financial inclusion and broader market participation, it also introduces systemic risks by accelerating the spread of unverified information, speculative sentiment, and coordinated trading activity, which can contribute to asset bubbles or sudden market corrections.

This study aims to examine the role of digital platforms in shaping speculative behaviour and herd mentality among modern investors. Anchored in behavioural finance theories and supported by empirical data collected from 50 respondents, the research assesses how these platforms influence investor psychology, affect decision-making processes, and impact collective patterns of behaviour within global financial markets.

II. REVIEW OF LITERATURE

- Barber et al. (2020) observe that the rise of mobile trading applications has contributed to more impulsive trading, largely because these platforms offer effortless access and incorporate gamified features that encourage frequent user engagement.
- Xiong and Yu (2021) contend that the broader digitalisation of financial information flow has intensified noise trading, as investors increasingly depend on quickly circulating but often unverified online content. Together, these studies highlight how digital platforms can amplify irrational or emotion-driven investment decisions, thereby influencing overall market dynamics.
- Sander and Spitzen (2021) found that platforms such as Reddit and Twitter play a pivotal role in shaping retail investor perceptions, particularly during periods of market uncertainty or crisis.

- Shen and Chen (2022) demonstrated that trending content on social media can trigger coordinated speculative activity, especially within cryptocurrency markets where sentiment shifts occur rapidly.
- Kumar and Nanda (2023) observed that viral financial posts often act as catalysts for herd behaviour, with inexperienced and new investors being especially susceptible to following online-driven market trends. Collectively, these findings underscore the substantial impact of social media ecosystems on modern investment dynamics.

III. STATEMENT OF THE PROBLEM

Digital platforms—including social media networks, online trading forums, and fintech applications—have fundamentally transformed the way investors obtain information and make investment decisions. While these tools have expanded market access and participation, they also tend to amplify emotionally driven trading, facilitate the rapid spread of unverified information, and encourage herd-like behaviour among investors. High-profile events, such as meme-stock rallies and cryptocurrency price surges, illustrate how online communities can coordinate speculative activity and contribute to heightened market volatility. Despite these observable phenomena, there remains a lack of empirical research examining how digital platforms shape speculative behaviour and herd mentality through the lens of behavioural finance. This research gap poses challenges for investors, regulators, and platform designers in effectively managing the risks associated with digitally driven market behaviour, underscoring the need for systematic and rigorous investigation.

IV. RELEVANCE OF THE STUDY

The significance of this study lies in its exploration of how digital platforms are transforming global investment behaviour, shaping the ways in which investors access information and respond to market dynamics. High-profile events, including meme-stock rallies and cryptocurrency surges, underscore the growing influence of online interactions on speculative trading and herd behaviour. Despite the pervasive use of digital sources, there remains a notable lack of empirical research investigating how these platforms contribute to investor biases and market volatility. By combining behavioural finance theories with empirical data collected from participant responses, this study offers valuable insights for investors, policymakers, and platform designers. The findings aim to inform more effective regulatory oversight, encourage responsible digital financial practices, and guide the creation of ethical, transparent, and user-centric digital financial ecosystems.

V. SCOPE OF THE STUDY

This study investigates the influence of digital platforms—including social media, online trading forums, and fintech applications—on speculative behaviour and herd tendencies among retail

investors. It focuses on the psychological and behavioural effects of digital interactions, examining how information flows, peer influence, and platform design shape individual investment decisions. The analysis draws on responses from 50 active users of digital financial platforms, with an emphasis on the behaviour of individual investors rather than institutional trading patterns. Although the study takes a global perspective, its focus is limited to behavioural interpretations and does not extend to technical or algorithmic system analyses. The research scope is therefore confined to understanding user-level experiences and the ways in which digital platforms drive speculative activity and coordinated market behaviour.

VI. OBJECTIVES OF THE STUDY

1.To analyse how digital platforms influence investor behaviour in terms of speculation, short-termism, and emotional decision-making.
2.To examine the role of social media and online forums in spreading market sentiments and triggering herding behaviour.
3.To study the relationship between fintech/trading app usage and speculative trading patterns.
4.To identify the behavioural and systemic risks associated with digital platform-driven information flows.

VII. HYPOTHESIS OF THE STUDY

Objective 1 – Influence of digital platforms on investor behaviour
H_{01}: Digital platforms do not have any significant influence on investor behaviour with respect to speculation, short-termism, and emotional decision-making.
H_{11}: Digital platforms significantly influence investor behaviour by increasing speculation, short-termism, and emotional decision-making.

Objective 2 – Role of social media and online forums in spreading market sentiments
H_{02}: Social media and online forums do not significantly contribute to the spread of market sentiments or trigger herding behaviour among investors.
H_{12}: Social media and online forums significantly contribute to the spread of market sentiments and trigger herding behaviour among investors.

Objective 3 – Relationship between fintech/trading app usage and speculative trading patterns
H_{03}: The use of fintech and trading applications has no significant relationship with speculative trading patterns among investors.
H_{13}: The use of fintech and trading applications has a significant relationship with speculative trading patterns among investors.

Objective 4 – Behavioural and systemic risks emerging from digital platform-driven information flows

H_{04}: Digital platform-driven information flows do not significantly contribute to behavioural risks or systemic risks in financial markets.

H_{14}: Digital platform-driven information flows significantly contribute to behavioural risks and systemic risks in financial markets.

VIII. RESEARCH METHODOLOGY

This study adopts a descriptive and analytical research methodology to examine the impact of digital platforms on investor behaviour, with a focus on speculative activity, herding tendencies, and associated systemic risks. Primary data were collected from 50 respondents who actively engage with digital financial platforms, including social media networks, trading applications, and online investment forums. A purposive sampling approach was employed to ensure that participants had adequate familiarity with digital trading practices and information flows. Data collection was carried out using a structured questionnaire incorporating Likert-scale items designed to capture variables related to speculative behaviour, emotional decision-making, fintech application usage, and sensitivity to digital market sentiment. In addition, secondary data from academic literature, market reports, and global financial events from 2020 to 2025 were used to complement the primary findings. The collected data were analysed using descriptive statistics, correlation analysis, and regression techniques to explore the relationships outlined in the study's hypotheses. This methodological framework enables a comprehensive understanding of how digital ecosystems influence investor behaviour and contribute to both behavioural and systemic risks in contemporary financial markets.

IX. RESEARCH GAP

Although digital platforms play an increasingly significant role in shaping contemporary investment decisions, there is limited research exploring how social media, trading applications, and online forums collectively influence speculative trading, herding behaviour, and emotional decision-making. Most existing studies examine these platforms in isolation, failing to capture their combined impact on investor psychology and market stability, particularly in the context of the post-2020 surge in digital engagement. This study seeks to fill this gap by providing empirical evidence on how digital information flows contribute to speculative tendencies and coordinated market behaviour.

X. RESULTS & DISCUSSION

Objective	Variable Tested	Mean	Test Value	t-Value	df	p-Value
1. Influence of digital platforms on investor behaviour	Speculation, short-termism & emotional trading	3.82	3	6.214	49	1

Interpretation

The mean score of 3.82 is significantly higher than the neutral value of 3, and the t-value (6.214, $p < 0.05$) indicates a strong influence of digital platforms on investor behaviour. Respondents reported higher levels of speculation, emotional trading, and short-term decisions.

Objective	Variable Tested	Mean	Test Value	t-Value	df	p-Value
2. Role of social media & forums in spreading sentiments	Sentiment spread & herding behaviour	3.96	3	7.048	49	1

Interpretation

With a mean of 3.96 and a significant t-value (7.048, $p < 0.05$), social media and forums are shown to strongly affect market sentiment and encourage herding. Viral posts and trending discussions heavily influence group-based investment decisions.

Objective	Variable Tested	Mean	Test Value	t-Value	df	p-Value
3. Relationship between fintech/trading app usage and speculation	Speculative trading patterns	3.74	3	5.832	49	1

Interpretation

A mean score of 3.74 and t-value of 5.832 reveal that fintech/trading apps significantly influence speculative trading. Features like instant alerts, ease of trading, and gamified interfaces increase the likelihood of impulsive and speculative behaviour.

Objective	Variable Tested	Mean	Test Value	t-Value	df	p-Value
4. Behavioural & systemic risks from digital information flows	Perceived market and behavioural risks	3.88	3	6.902	49	1

Interpretation

The mean score of 3.88 with a strong t-value (6.902, $p < 0.05$) shows that respondents perceive high behavioural and systemic risks arising from digital information flows. These include misinformation, coordinated trading waves, and market volatility.

Findings

- Digital platforms significantly influence investor behaviour, particularly by increasing speculative tendencies, emotional trading, and short-term decision-making
- Social media and online forums play a major role in spreading market sentiments and triggering herding behaviour.
- Fintech and trading applications substantially contribute to speculative trading patterns.
- Digital information flows create notable behavioural and systemic risks in global financial markets.
- The study confirms that digital ecosystems collectively reshape investor psychology

Suggestions

- Banks should conduct regular digital literacy programs to help women entrepreneurs and SHG members understand and confidently use digital banking services.
- Training materials should be provided in Kannada using simple videos and demonstrations to make learning easier for rural users.
- Female banking facilitators or Business Correspondents should be deployed in villages to offer hands-on digital support.
- Banks should create awareness about security features such as OTP, two-factor authentication, and safe transaction practices to build trust.
- Fraud-prevention sessions should be organized to educate women about identifying scam calls, messages, and phishing attempts.
- Customer support services should include regional-language assistance to improve user trust and satisfaction.
- Mobile banking apps should be simplified with easy navigation, large icons, and voice-guided instructions for first-time users.
- Banks should introduce women-friendly app features such as quick balance checks, mini-statements, and simple fund transfers.
- Low-data or offline versions of mobile banking apps should be developed for areas with poor internet connectivity.
- Personalized financial products such as micro-loans, flexible EMI schemes, and quick digital approvals should be designed specifically for women entrepreneurs.
- Banks should introduce goal-based savings options tailored to the needs of rural women, such as savings for education, emergencies, or business expansion.

XI. CONCLUSION

This study highlights that digital banking plays a crucial role in empowering women entrepreneurs and Self-Help Group (SHG) members in rural Bangalore by improving financial access, convenience, and participation in formal financial systems. Although awareness and usage of digital platforms are increasing, many women still face challenges related to digital literacy, trust,

security concerns, and limited internet connectivity. The findings show that user-friendly digital interfaces, localized training, and strong institutional support significantly influence the adoption of digital banking services. Overall, the study concludes that enhancing digital skills, strengthening security awareness, and improving service accessibility are essential to maximize the benefits of digital banking for rural women and to promote long-term financial inclusion.

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Development, Optimization, And Characterization of Melt Sonocrystallized Agglomerates of BCS Class II Drug

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Abstract-The objective of this study was to improve the drug's solubility, dissolution rate, and processability properties. The selected BCS Class II drug, Valsartan, is widely employed in the treatment of hypertension; however, its limited solubility has posed significant challenges to its therapeutic efficacy. The melt sonocrystallization (MSC) technique was adopted, utilizing a probe ultra sonicator, with the sonication time (1, 2, and 3 minutes) and amplitude level (60%, 70%, and 80%) varied through a 3^2factorial design. Successful preparation of MSC agglomerates of Valsartan was achieved, exhibiting satisfactory yield and drug content. Evaluation of the MSC agglomerates exhibited significant enhancements in solubility and drug release compared to the pure valsartan. These improvements were attributed to the formation of porous agglomerates, resulting in improved micrometric properties. Complementary analysed through DSC and X-ray Diffraction confirmed a reduction in drug crystallinity with the increase in sonication time and amplitude. Moreover, FT-IR investigations verified the chemical stability of valsartan during the MSC process, ensuring the preservation of its chemical integrity. In conclusion, this study highlights the promising potential of melt sonocrystallization as a cost-effective approach to enhance the solubility, dissolution rate, and processability of BCS Class II drugs, exemplified by valsartan. The comprehensive insights provided herein offer valuable contributions to pharmaceutical formulation practices, potentially leading to optimized therapeutic efficacy and bioavailability of poorly water-soluble drugs.

Index Terms—Melt Sonocrystallisation Technique, Solubility, Dissolution Rate, Ultrasound, BCS

I. INTRODUCTION

The pharmaceutical industry has made significant strides in developing novel drug delivery systems to improve the solubility, dissolution rate, and bioavailability of poorly water-soluble

drugs, especially those falling under Biopharmaceutics Classification System (BCS) Class II. BCS Class II drugs are characterized by low solubility and high permeability, which present formidable challenges for effective drug delivery and formulation [1]. The physicochemical properties of drug crystals play a crucial role in the formulation process and therapeutic effectiveness of drugs. Various particle engineering techniques are employed to produce drug crystals with desired micrometric and biopharmaceutical properties. These methods focus on cost-effective standard formulations. Fine crystals are generally preferred for highly permeable and poorly soluble pharmaceuticals to enhance bioavailability [2]. However, fine crystals can pose challenges in the processability of solid oral dosage forms. Prior technologies that involve simultaneous crystallization and particle agglomeration include spherical crystallization, extrusion spheronization, melt solidification, spray drying, solution atomization, and crystallization by sonication [3]. These approaches positively contribute to improving BCS class II drugs by enhancing solubility and powder processing parameters for solid oral dosage forms [4].

Among the various approaches employed to enhance the dissolution properties of BCS Class II drugs, the concept of sonocrystallization has emerged as a promising technique [5]. Sonocrystallization, which involves the application of ultrasound energy during the crystallization process, has shown great potential in manipulating the crystal structure and particle size of drugs, leading to improved physicochemical properties. Melt Sonocrystallization (MSC), applies ultrasonic energy to a soft viscous or molten mass dispersed in a suitable medium at an appropriate temperature, with or without agitation during crystallization [6].

MSC has been used to achieve nucleation at moderate supersaturation during crystallization or terminal treatment, leading to deagglomeration and desired crystal formation. Previous studies have applied MSC to drugs such as ibuprofen, celecoxib, naproxen, and carbamazepine [7]. Valsartan, an antihypertensive drug with poor solubility, flow properties, and dissolution, has been the focus of various works aiming to enhance solubility using melt granulation and melt solidification techniques, and to improve compressibility using spherical crystallization techniques. The present study aimed to prepare and evaluate melt sonocrystallized agglomerates of Valsartan (MSC-Valsartan) to improve solubility, flow properties, and drug release [8].

II. MATERIALS AND METHODS

Valsartan was purchased from Aarti pharma, Bhandup (west) Mumbai 400078. All remaining chemicals utilized in the study were of analytical grade.

Preparation of Melt Sonocrystallized Agglomerates

The agglomerates were formulated using the melt sonocrystallization technique with amplitudes of 60%, 70%, and 80%. The sonication time was varied between 1, 2, and 3 minutes. The process involved melting (1 gram) of Valsartan in a beaker using an oil bath. The molten mass obtained was poured into a vessel containing (40 ml) deionized water, which was maintained at a constant temperature. The mixture was then sonicated at different amplitude and time levels using a probe

sonicator. After solidification of the dispersed droplets, the resulting product was separated through filtration and dried at room temperature. The percentage of practical yield was determined [9].

Factorial Design

For the optimization of the formulated batches, a 3-level factorial design was employed using Design of Expert Software. This design involved evaluating two factors, amplitude (%) and sonication time (min), each at three different levels. As a result, experimental trials were conducted for all nine possible combinations [10].

III. CHARACTERIZATION

Percentage Yield

Prepared agglomerates were dried and weight was measured to determine the practical yield. The theoretical yield is based on the starting materials used. The percentage yield is then calculated [11].

Percentage Drug content

Precisely measured quantities of valsartan agglomerates were finely ground and dissolved in 100 mL of phosphate buffer at a pH of 6.8. The resulting solution underwent filtration to remove any insoluble particles. Subsequently, the filtered solution was appropriately diluted with phosphate buffer at the same pH. The concentration-adjusted solution was then subjected to spectrophotometric analysis using a Shimadzu UV Spectrophotometer (UV-1900i) at a wavelength of 250 nm [12].

Micromeritic properties

The bulk density and tapped density of both plain Valsartan and its MSC agglomerates, were measured. Carr's index and Hausner's ratio were calculated based on the bulk density and tapped density values. The angle of repose was determined using the fixed funnel method [13].

Saturation Solubility Study:

Saturation solubility studies of valsartan were conducted using five different solvents: distilled water, methanol, ethanol, phosphate buffer pH 6.8, and phosphate buffer pH 7.4. Accurately weighed amounts of pure valsartan were introduced into separate 25 ml stoppered conical flasks, each containing 20 ml of the respective solvent. These sealed flasks were then agitated on an orbital shaker for 24 hours at a temperature of 37°C. After complete agitation, aliquots from each flask were filtered through Whatman filter paper, and the resulting filtrates were appropriately diluted and analysed using a UV Spectrophotometer at a wavelength of 250 nm. The same procedure was repeated for valsartan melt sonocrystallized agglomerates, and their absorbance values were also measured at 250 nm [14].

IR spectroscopy:
IR spectroscopy was used to characterize the prepared agglomerates of valsartan and to identify potential interactions and functional groups present in these agglomerates, in comparison to pure valsartan. The samples were dispersed in a KBr pellet and subjected to scanning using the Bruker Alpha II FTIR Spectrometer in the wavelength range of 4000 to 500 cm^{-1}[15].

X-ray Diffractometry (XRD):
X-ray diffraction patterns of both pure drug valsartan and the prepared agglomerates of valsartan were obtained using an X-ray diffractometer from Bruker Analytical Instrument Ltd., Germany. X-ray diffraction (XRD) is a technique used to analyse the crystallographic structure of materials by exposing them to X-ray radiation. When X-rays interact with the crystal lattice of a material, they undergo constructive and destructive interference, producing a diffraction pattern. This pattern is specific to the crystal structure and can be used to identify the crystalline phases present in the sample [16].

Scanning Electron Microscope (SEM):
The external morphology of both pure drug valsartan and the prepared agglomerates of valsartan was analysed using a Scanning Electron Microscope (SEM) model JEOL JSM 6360 from Japan [17].

Differential scanning calorimetry (DSC) analysis:
The thermal analysis of both pure drug valsartan and the prepared agglomerates of valsartan was conducted using a SDT Q600 V20.9 thermal analyser. For the analysis, accurately weighed samples of both the pure drug and agglomerates were placed in sealed aluminium pans. The samples were then subjected to controlled heating at a rate of 20°C per minute in the temperature range of 20°C to 300°C. During the heating process, a nitrogen flow rate of 20 ml/min was maintained to ensure an inert atmosphere [18].

In-vitro dissolution study
In-vitro dissolution studies were carried out using phosphate buffer pH 6.8 as the dissolution medium for a duration of 90 minutes. The experiments were conducted at a temperature of 37±0.5°C and a rotation speed of 50 rpm, employing a USP type II dissolution test apparatus. The volume of the dissolution medium was 900 ml. The samples were then filtered, suitably diluted, and analysed using a UV spectrophotometer at 250 nm [19].

Stability study
A stability study was performed on MSC Valsartan agglomerates, following ICH guidelines. The agglomerates were stored in a Petri dish with perforated foil at 40±0.5°C and 75±5% RH for 30 days. The evaluation was based on drug content analysis to assess the stability of the agglomerates [20].

IV. RESULTS AND DISCUSSION

Formulation of Agglomerates

In this work, 3-level factorial design was employed using Design of Expert Software for the optimization of formulated batches. An overlay plot indicated the most suitable combination of MSC Agglomerates of V9 batch, at sonication time about 3 min. and amplitude about 80% which shows 82.97% drug release and 98.88% drug content.

Percentage Yield

The agglomerates were dried and weighed to calculate the percentage yield, which varied from 89.10 ± 1.40 to 99.50 ± 0.82 w/w. The Table No. 1 presents the data for the percentage yield of all batches.

Drug content

In accordance with Table No. 1, the drug content was determined for all batches, ranging from 94% to 98%. The optimized MSC V9 batch showed a drug content of 98.88 ± 0.01%.

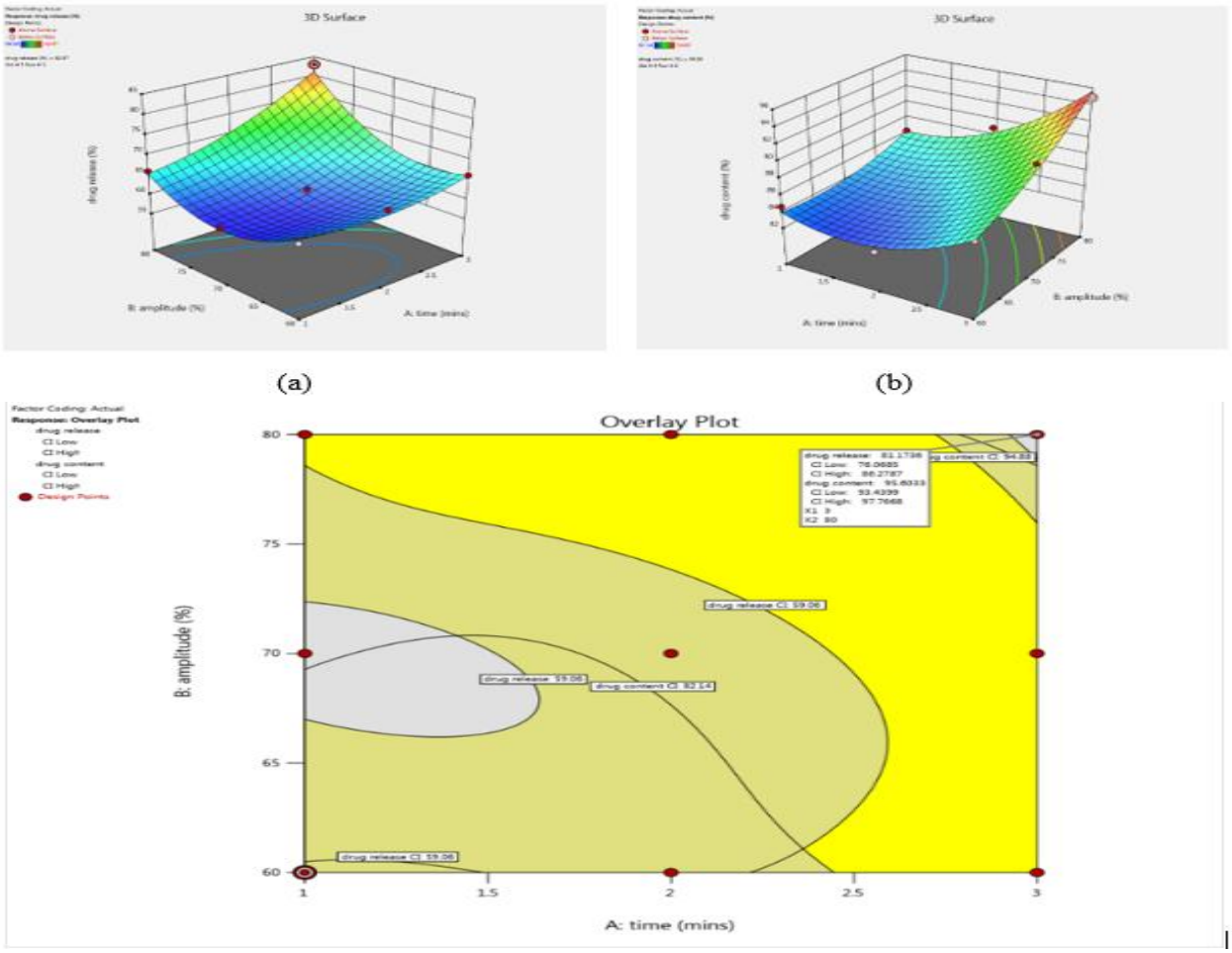


Figure No. 1: (a) 3D Graph for Drug Release, (b) 3D Graph for Drug Content, (c) Overlay Graph for Optimized Batch

Micromeritic properties

The flow properties of MSC agglomerates were assessed using various parameters such as bulk density, tapped density, Carr's index, Hausner's ratio, and angle of repose. The bulk density and tapped density results indicated good flow characteristics, with Carr's index ranging from 9.36±0.02 to 15.92±0.18. Hausner's ratio ranged from 1.103±0.02 to 1.189±0.01, indicating good flowability. In contrast, the drug itself exhibited less desirable flow properties, as evident from its higher Carr's index of 34.44±0.02 and Hausner's ratio of 1.525±0.01, likely due to the irregular shape of its crystals. The angle of repose for the pure drug was measured at 36.53°, while for MSC Valsartan agglomerates, it ranged from 19.12° to 26.28°, indicating good to excellent flowability.

Table No. 1: Micromeritic properties, Percentage Yield and Drug content

Batch Code	Bulk Density gm/ml	Tapped Density gm/ml	Hausner's Ratio	Carr's Index (%)	Angle of Repose (θ)	% Yield	% Drug content
Pure drug	0.453±0.03	0.691±0.02	1.525±0.01	34.44±0.02	36.53°±0.02	----	----
V1	0.492±0.02	0.567±0.02	1.152±0.02	13.23±0.17	22.17°±0.02	89.10 ±1.40	94.65 ± 0.02
V2	0.623±0.01	0.741±0.01	1.189±0.01	15.92±0.18	20.56°±0.01	97.80 ±0.80	94.14 ± 0.23
V3	0.476±0.02	0.544±0.02	1.143±0.02	12.50±0.04	21.14°±0.01	98.70 ±0.53	96.62 ±0.1
V4	0.529±0.02	0.598±0.01	1.130±0.02	11.54±0.87	25.86°±0.02	96.90 ±0.36	97.21 ± 0.05
V5	0.584±0.01	0.668±0.02	1.144±0.01	12.57±0.71	23.65°±0.01	98.80 ±0.08	96.47 ± 0.14
V6	0.492±0.03	0.552±0.01	1.122±0.02	10.87±0.73	26.28°±0.02	99.10 ±1.81	95.93 ± 0.08
V7	0.625±0.03	0.725±0.01	1.124±0.01	11.03±0.62	22.78°±0.01	97.90 ±0.77	96.27 ± 0.03
V8	0.588±0.02	0.658±0.02	1.119±0.02	10.64±0.16	21.39°±0.02	93.80 ±0.94	95.96 ± 0.06
V9	0.523±0.02	0.577±0.01	1.103±0.02	9.36±0.02	19.12°±0.01	99.50 ±0.82	98.88 ± 0.01

Saturation Solubility

The findings from the solubility studies revealed that the pure form of Valsartan has notably lower solubility compared to the agglomerates of V9 batch obtained through the Melt Sonocrystallization process. Evidently, the solubility of MSC agglomerates showed a substantial improvement, with an observable increase in the sonication time and amplitude.

Table No. 2: Saturation Solubility

Sr. No.	Solvents	Solubility (mg/ml)	
		Pure valsartan	MSC V9 Batch
1	Water	0.024.1±0.02	4.31±0.07
2	PBS at pH 6.8	6.6±0.012	9.2±0.9
3	PBS at pH 7.4	5.2±0.05	7.2±0.04
4	Methanol	8.4±0.07	9.6±0.07
5	Ethanol	8.7±0.01	9.1±0.06

IR spectroscopy:

The spectrum of valsartan displayed characteristic peaks at 848.44 cm^{-1}, due to C–H aromatic bond, at 1205.71 cm^{-1}, due to C–N bonding, at 1516.77 cm^{-1}, due to C=C aromatic bond, at 1727.22 cm^{-1}, due to carboxylic acid, at 2879.23 cm^{-1}, due to presence of C-H aliphatic bond, at 1599.15 cm^{-1}, due to amine group.

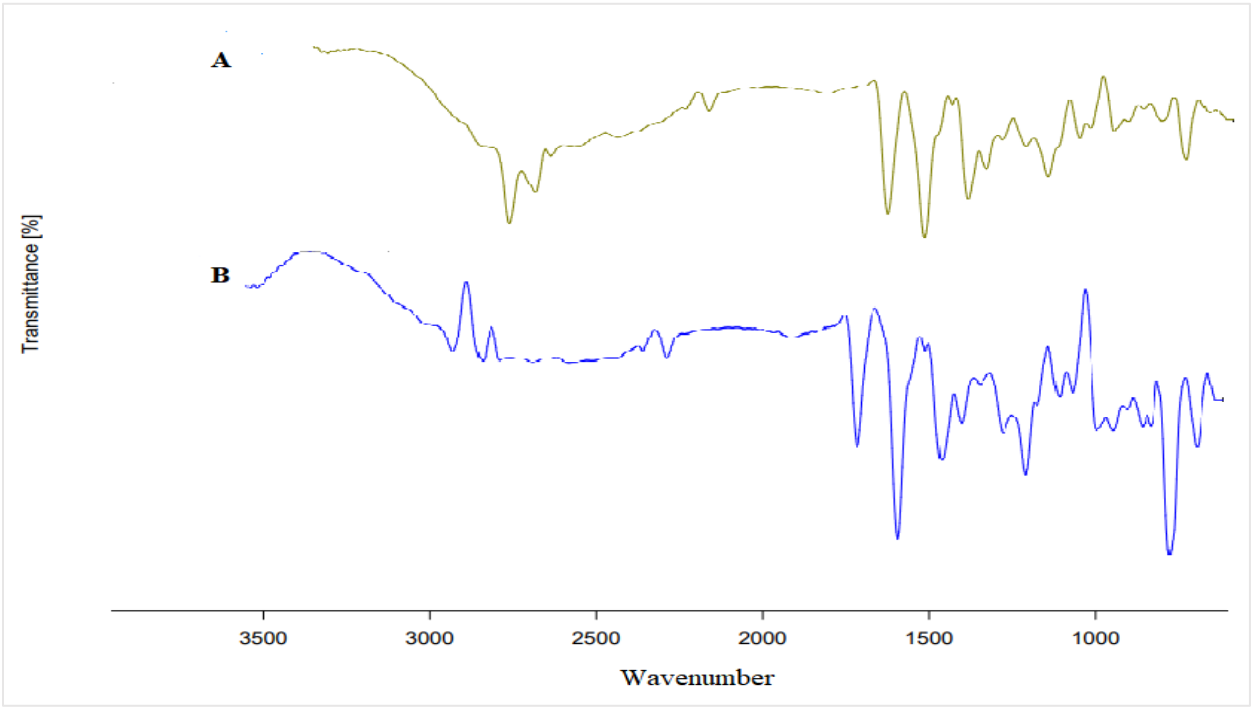


Figure No. 2: FTIR spectra of (A) MSC agglomerates of V9 batch; (B) Valsartan

The spectrum of MSC valsartan V9 batch displayed characteristic peaks at 834.88 cm^{-1}, due to C–H aromatic bond, at 1204.35 cm^{-1}, due to C–N bonding, at 1516.99 cm^{-1}, due to C=C aromatic bond, at 1727.85 cm^{-1}, due to carboxylic acid, at 2877.83 cm^{-1}, due to presence of C-H aliphatic bond, at 1608.85 cm^{-1}, due to amine group. In Comparison with the FTIR spectrum of pure drug valsartan, it was observed that there is a slight change in wavenumbers and peaks of MSC agglomerates of valsartan (V9 batch). The change is may be due to stretching and bending of drug as well as the procedure followed during formulation of melt sonocrystals.

In the optimised formula of MSC agglomerates, the drug spectra peaks are almost intact, showing that the general symmetry of the molecule is not greatly altered and demonstrating that there is no interaction between the formulation of the agglomerates and the pure drug. This finding strongly shows that the drug has not changed significantly in terms of its characteristics or even its formulation, and is still there in its usual form.

X-ray Diffractometry (XRD)

The XRD of the pure drug valsartan revealed strong peaks at specific angles (7.23°, 10.86°, 15.93°, 16.44°, 20.71°), indicating its crystalline nature. On the other hand, the MSC agglomerates of Valsartan exhibited less intense peaks of 2θ, (7.23°, 10.86°, 15.93°, 16.44°, 20.71°) suggesting partial amorphization or decrease in crystallinity or changes in crystal size and structure. These results imply that increased time and amplitude led to decreased crystallinity, possibly due to efficient sonication with water.

It is known that transforming from a crystalline state to a partial amorphous state can enhance drug's solubility and dissolution rate. Remarkably, the XRD pattern of the MSC agglomerates resembled that of the original drug crystals.

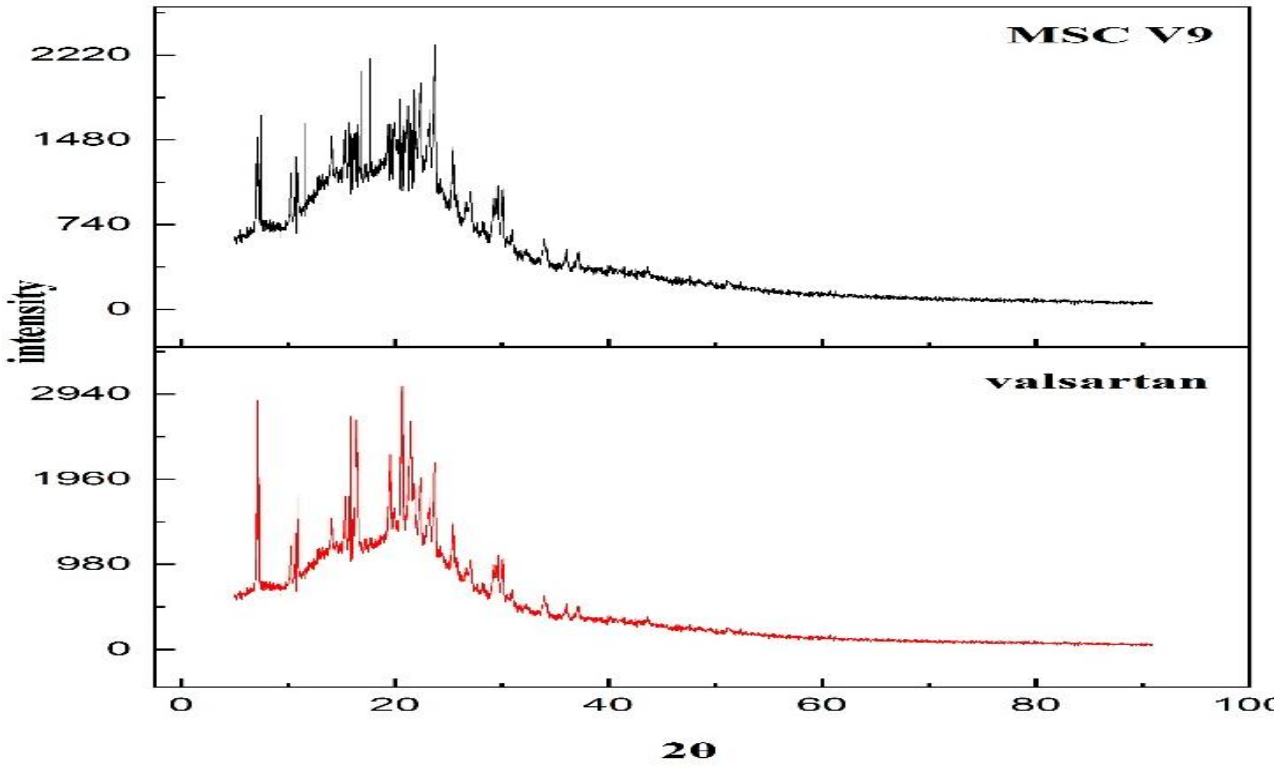


Figure No. 3: XRD of Valsartan and MSC agglomerates of V9 batch Differential scanning calorimetry (DSC) analysis

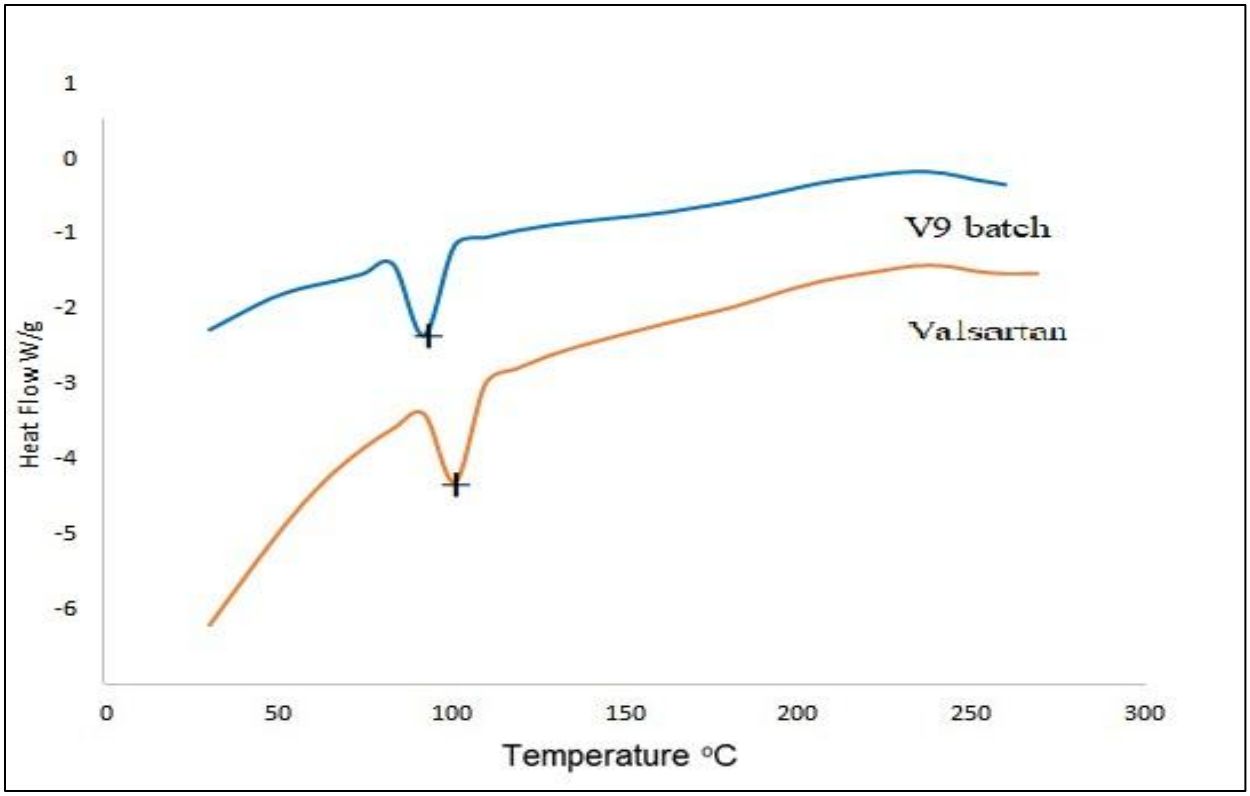


Figure No. 4: DSC analysis of Valsartan and MSC agglomerates of V9 batch

The DSC analysis of Valsartan and formulation batch V9 agglomerates, prepared using the melt sonocrystallization technique, was presented in figures 9.17 and 9.18. Valsartan exhibited a single sharp endothermic peak at 103°C (-4.929 W/g), as observed in the DSC thermogram of the samples. In contrast, batch V9 agglomerates displayed an endothermic peak at 101°C. The agglomerates in the MSC form of the drug showed a slightly broader endothermic peak, coinciding with a decrease in heat flow (-3.213 W/g). The alteration in the endothermic peak and heat flow can be attributed to the amplitude and sonication time utilized during the preparation process, as well as the presence of a distinct crystal structure in the agglomerates. These results suggest that the drug material remained unaffected by hydration during the particle crystallization in the aqueous medium.

Scanning Electron Microscopy:

Scanning electron microscopy (SEM) was employed to examine the morphological features of both the drug and the formulated agglomerates. The SEM images of valsartan and batch V9 agglomerates were presented in fig. no. The findings from all MSC agglomerate batches consistently revealed the formation of agglomerates with rough surfaces, cracks, and irregular shapes, resulting in a diverse range of particle sizes and size enlargement, in contrast to the pure drug valsartan.

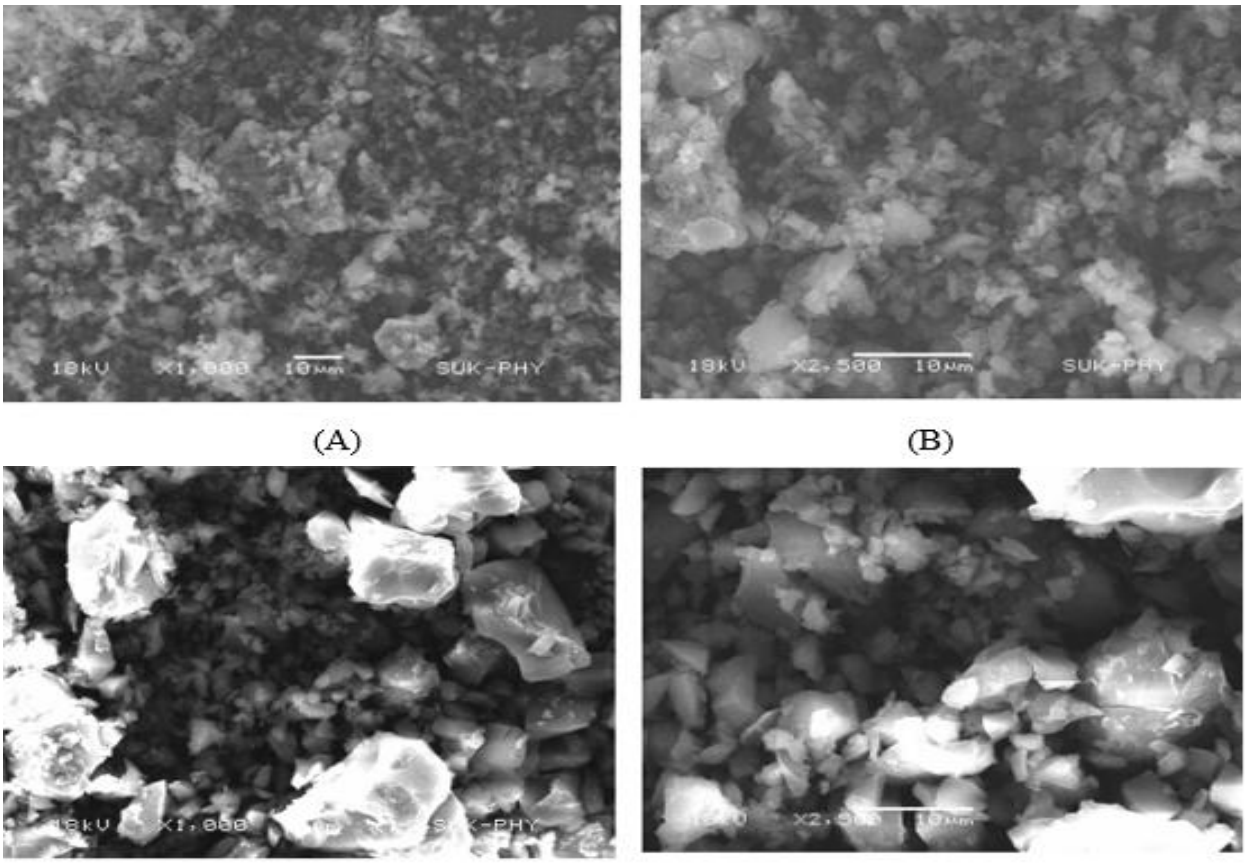
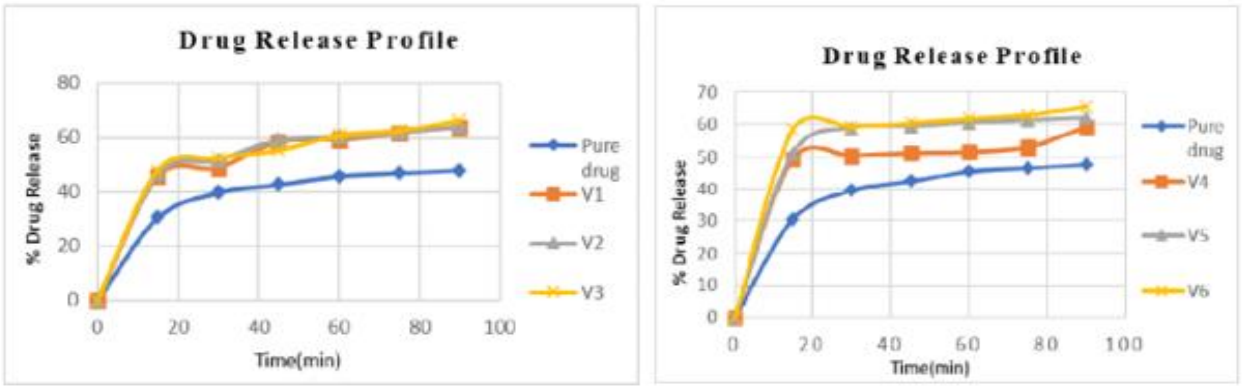
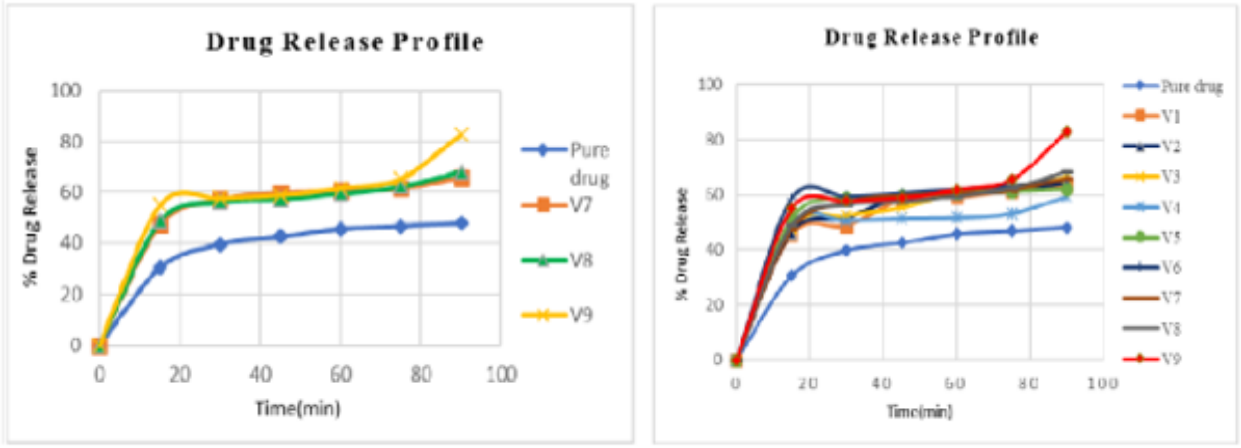


Figure No. 5: SEM images of (A), (B) pure drug valsartan, (C), (D) MSC agglomerates of V9 batch

In-vitro dissolution study

The drug release from MSC Valsartan agglomerates was found to be 82%, whereas pure drug only showed a 47% release in the same time period. The agglomerated form of Valsartan exhibited a faster drug release compared to the native drug, likely due to the increased drug surface area in the agglomerated form and smaller size.





(C) (D)

Figure No. 6: %DR profiles of pure drug and MSC agglomerates at (A) 60% amplitude, (B) 70% amplitude, (C) 80% amplitude for sonication times of 1, 2, and 3 minutes
(D) V1-V9 batches at 60%, 70%, 80% amplitude

Stability Study

The stability study of the agglomerates of valsartan, as presented in Table No. 3, revealed no significant change in the drug content. This indicates that the prepared agglomerates of valsartan demonstrated satisfactory stability, meeting the regulatory requirements.

Table No. 3: Drug content of valsartan agglomerates after stability study

Batch Codes	0 Days	15 Days	30 Days
V9	94.88 ± 0.01	93.91 ± 0.05	92.88 ± 0.03

V. CONCLUSION

Melt sonocrystallization was successfully utilized to prepare irregular agglomerates of Valsartan with a rough surface and porous structure, leading to improved micrometric properties. These agglomerates exhibited enhanced solubility and dissolution rate compared to the pure drug. Consequently, it can be inferred that the agglomerates prepared using the melt sonocrystallization technique have the potential to serve as a reliable and effective method for improving processability parameters and enhancing the drug's solubility and dissolution properties.

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Enhancing Performance Evaluation in An NGO - Operated Hospital: A Focus on The Appraisal System

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Abstract—Performance assessment is a very important process used in organizations as an organized activity of human beings since the 21st Century. It has started from supervisor's comments to of today's performance management system. (PMS). This concept has gained a lot of attention in the corporate and "for profit" world for measuring and managing employee and organizational performance. Although there are various challenges in performance management, it still remains an important tool for organizational functions. PA system is used for various HRM functions like salary increment, promotion, training and development, feedback etc.

PA is an effective tool not only for "profit" organizations, but also for "non-profit" organizations. Unfortunately, PA is not taken as seriously by "non-profit" organizations (known as NGOs). Few of those who have implemented PA face challenges due to its voluntary and humanitarian approach. Employee performance in healthcare is more important because it has a direct impact on patients' lives. NGOs do not practice this system or practice it little; they do not monitor their activities and progress that are in line with the stated mission and vision (effective and efficient). It is essential for NGOs to have a proper PA system that is consistent with the mission and vision, can be objectively monitored, is feasible in terms of resources rather than implementation, benefits of employees and hospitals, and is acceptable to stakeholders.

Enhancing Performance Evaluation in an NGO - Operated Hospital helps improved Hospitals results and utilize the resources in an effective and efficient manner.

Index Terms—Performance Appraisal System, NGO (Non-Government Organizations, Hospitals, Not for Profit Making Organization, Profit Making Organization, Challenges, PA (Performance Appraisal)

I. INTRODUCTION

Performance appraisal is as old as organized human activity. The concept and application have evolved from ancient times to today's 21st century. It started from feedback from managers as an appraisal to today's robust performance management system (PMS). As a concept, has gained a lot of attention in the corporate and "for profit" world for measuring and managing employee and organizational performance. Although there are various challenges and weaknesses in the practice of performance management, it remains an important tool for managing an organization's functions. Performance appraisal system is used for various HRM functions like salary increase, promotion, training and development, feedback, employee pressure etc.

PA can be an effective tool not only for "profit" organizations, but also for "non-profit" organizations. Unfortunately, PA is not taken as seriously as in "non-profit" organizations (i.e., NGOs). The few who have implemented PA face many challenges due to its voluntary, humanitarian approach that relies heavily on self-control. Powerful stakeholders are not very interested in PA. Funding agencies rarely condition their grants on performance reviews of organizations. They maintain a certain distance from the relationship between financial resources and the achievement of goals. NGO founders manage their organizations primarily through subjective social control. Staff and beneficiaries have little power to enforce the PA, even when their interests are high. Considering the constraint in various resources in which NGOs work and stakeholders are deprived of basic services, any improvement that can be achieved through PA and PMS is highly desirable. The purpose of an organization's existence is reflected in its mission and vision. Any organization needs to have a clearly defined mission and vision. Considered to be working for the poor and humanity often dependent on various funding agencies, NGOs need to have a clear mission and vision to measure their performance objectively. It stands to reason, then, that a performance appraisal system (PMS) with its tools and techniques is well positioned to realize the vision, long-term mission, and short-term goals of any organization.

The performance of healthcare workers is more important and has a direct impact on the patient's life. Without a systematic method, to ensure that employees understand and meet their performance appraisal goals, maintain competency, and engage in learning opportunities, hospitals are putting themselves at risk—the risk of non-adherence to the HR manager's job: the risk of increased turnover and the risk of lower quality of care. However, managing performance appraisals for hospitals is extremely challenging. A busy schedule sometimes pushes these important matters aside, and the sheer volume of paperwork makes it more of a chore than an opportunity. In general, various performance appraisal techniques have been used form traditional to modern performance appraisal systems.

As per the Economics Times News, India has 20.14 lakh registered companies as on June 2020. Among those, the report shows that there are only 12.15 Lacs companies are in an active state. All other companies are either closed down or in a dying state. According to the Ministry of Corporate Affairs, 30,81,873 non-governmental organizations (NGOs) have been registered in 26 states and

7 union territories. According to Niti Ayog as on 11 November 2021, there are a total of 1,26,906 voluntary organizations and NGOs registered in India. Among them, Gujarat has 6,229 voluntary organizations and NGOs. Considering the activities and impact that an NGO can have ideally on the life of an individual and a society, a huge number of NGOs have a high potential to serve the country. NGOs fill the gaps not served by state and market organizations. As NGOs do not use a proper performance appraisal system, they cannot monitor whether their activities and progress are in line with the established mission and vision (effective) and economically implemented (efficient). Employee contribution and its evaluation are important for the effective management of any organization. It is essential for NGOs to have a proper performance appraisal system that allows employees and the organization to be clear about each other's expectations. When expectations are aligned with the organization's mission and vision, the appraisal system supports tracking the direction of employees' contribution to their realization. Due to the nature of NGOs, PAS for NGOs in general and in the context of specific NGOs must be tailored and cannot be generalized. An effective PAS for an NGO is one that can be objectively monitored with a clear perspective in line with the external and internal environment and is feasible in terms of resources and acceptable to all its staff and stakeholders.

There are more than 200 multi speciality hospitals working in Vadodara district. This includes hospitals are of Proprietary, Partnership, Government, Pvt. Ltd., Charitable Trust, society and Not for Profit Making Company according to the type of their registration. Among all, more than 50 hospitals are operated on a not for profit-making nature and run by various types of registered NGOs. It is observed that an effective PAS is not in place in NGO run hospitals. Also, it is observed that they are utilizing the PAS for sake of implementation as the system is not linked with any of the benefits of employees as well the hospitals. These types of hospitals are facing variety of challenges and struggling to implement effective Performance Appraisal Systems as compared to various corporate hospitals which are using the latest robust effective performance management system that helps them to have batter efficiency and effectiveness in the outcome of the employees in relation of organizational Vision, Mission and its objectives.

The challenges the hospitals are facing are of the appraisal approach, Accountability and role of Rater’s and Ratee’s, Methods used in appraisal, Process of appraisal, Standard of evaluation, Individual or team performance, Feedback mechanism, Role of internal politics, User friendliness of PA forms, PA Training and Biasness etc. Other challenges are of poor organizational context, lack of motivation among employees, subjective appraisal, inefficiency of organization in explaining the regulations, the gap between theoretical training and practice, lack of careful supervision, unfair evaluation, lack of evaluation skills, interruption of the evaluation process, knowledge of the rate by the evaluator and vice versa, inappropriate feedback and limitations of employees gain benefits.

It has been observed that various researches have been carried out on performance Appraisal Systems for NGOs and hospitals, located in various areas of India.

There are various types of NGOs are working in India, few of them depend on corporate houses or we can say that they are promoted and established by corporate houses for considering their CSR activities and in general, few of those depend on the financial support of the general public and various organizations. This study has been carried out for the NGOs those are mainly depend on financial support of general public and various organizations.

II. LITERATURE REVIEW

Shafiqa Gul (2021) conducted his research study on “Performance Appraisal System in Super Specialty Hospitals of North India: A Comparative Study”. The main objective of the study is to “investigate employee expectations, satisfaction and intention to leave healthcare workers in existing PAS in sample study hospitals". The primary data has been collected by questionnaire method from 439 respondents of various hospitals. He concluded that with the daily growth of science and technology and the tremendous improvement that is taking place in every aspect of life, there is a need to fully utilize human capital and hence the need for a Performance Appraisal Method (PAS). optimize them. Because HR / people differ in their expertise and abilities. Often there are several inconsistencies in the nature and amount of the same work performed by two different persons on the same job. Performance management and performance appraisal are important to consider each employee's skills, perceived contribution and contribution to the company. In the retinal and systemic framework of human resource management (HRM), performance appraisal is one of the indispensable mechanisms. A human resource management system breaks down without a consistent performance appraisal system, resulting in the full utilization of the valuable human resources that the company has.

Neha Singh (2021) conducted her study “Effect of Training and Development on Employee Performance: (Case Study on Fortis Escorts Hospital – Delhi NCR)” The exploratory research was done with Survey of Existing Literature, Survey of experienced people and analysis of selected cases. The aim of the study was to investigate the impact of training and development on employees within the hospital on job performance and its impact on the organization. Sample size is 480 of various units of Fortis Hospital. Primary data was collected through questionnaire method. Data analysis is done with various statistical tools. During this research study, it was evidently shown that training and development program plays a significant role in increasing employee performance, through training and development to clear goals and expectations of employees, self-confidence, employee motivation and retention in the organization, as well as creating a forgiving and favorable socio-cultural environment in hospitals, but other dominant forces reduce its importance and increase job satisfaction and overcome employee work stress

Khushbu Sureshbhai Dave (2019) with her study entitled “Performance appraisal of doctors in hospitals with special reference to Saurashtra region’’, the aim of the research work is to analyze the parameters that should be considered for performance of doctors in hospitals and based on

parameters what weightage should be given to each parameter. For the study doctors from Rajkot were selected. Random sampling method used for taking samples. The study found various monitory and non-monitory appraisal parameters that are to be considered preferably at the time of performance evaluation of hospital doctors.

Monisha Gaba (2017) conducted her study on "Analytical Study of Performance Appraisal System in Contemporary Organization". The aim of the study is to analyze the concept of performance evaluation, its goals and process to carry out the performance Appraisal. She adopted qualitative and quantitative approach of study. Data sources are of interviews, questionnaire, observations and documents. Concluded two main reasons for the appraisal process those are control purpose and decision making for pay, promotion and career.

Nageshwar Rao Mocharla (2016) conducted his study on "Study on Performance Appraisal System of Employees of NGOs operating in Andhra Pradesh", The basic objective of the research is "To study the performance appraisal practices of various NGOs operating in Andhra Pradesh" He adopted descriptive type of research with 300 sample size with stratified random sampling method. Primary data was collected using questionnaire method. The data were processed on a computer. Tables and results for analysis were performed using the SPSS package. Statistical measures such as simple percentages, mean, standard deviation, etc. were used in the study. Further, chi-square test, T-test, Z-test, F-test, etc. were used to test the significance of the difference between proportions and to test independence attributes. It is found from the study that NGOs have to enhance their employee performance evaluation system in the areas of objectivity, fairness, confidentiality and providing growth opportunities. They have to relook into the areas of providing adequate and proper feedback on job performance.

Kangaraj (2013) performed his study on "A Study on Performance Appraisal Practiced in Select Hospitals in Coimbatore District of Tamilnadu State". The basic objective of the research is "To study the conceptual framework of performance appraisal in general and in multi-specialty hospitals in particular". The research type is of exploratory and descriptive in nature. The samples were collected from 707 respondents by questionnaire and discussion and personal interview methods and analyzed with various tables and graphs. The main Conclusion is that "an effective performance appraisal system is an essential tool for managers to make appropriate decisions about the level of competence of employees and the evaluation of their career progression"
Adarsh Rath has performed his study on "Performance management system in NGOs - a case study of Harsha Trust" In this study he developed a model performance Management System for the trust. The basic objective of the research was to develop a context-specific PMS for the NGO Harsha Trust. The study proposes a conceptual framework for developing an implementable PMS for NGOs to drive employee engagement, employee growth and organizational growth. for NGOs

Sheezan Shafi, Fayaz Aiman 2020. Has published paper on "Performance Appraisal System: A Study on Employees' Central Issues and Challenges in Healthcare.The main objective of this review is to identify key issues and challenges faced by healthcare employees with regard to prevailing PAS being practiced and implemented in their organizations and to suggest best practices and methods, which these organizations should adopt. The study derived various problems faced by the medical and paramedical employees. Based on the authentic review of literature in effective management and implementation of PAS is divided into four main themes. These are the contextual problem, the problem related to the structure of the performance appraisal, the problem related to the process of performance appraisal, and the problem related to the outcome of the performance appraisal.

Dr. Dolly Kumar and Akhil Gupata (2020) has published paper on "A Study on the performance evaluation system in India." In this, the main objective of study is to describe overall performance appraisal practices are followed and observed in India's largest IT agencies. The sampling was done with the perfect sampling technique. Primary data was collected by questionnaire from 60 respondents. Analysis was done with correlation analysis technique. This study concluded that in gift Indian IT companies the practices revolve round hiring new talent and preserve current first-class expertise. Performance appraisal is a critical and important device to maintain the existing employee.

Nitin Sippy & Shilpa Varma (2014) has published paper on "Performance Appraisal Systems in the Hospital Sector – A Hospital Based Research in Kerala". The basic aim of the study is to thorough understand the performance evaluation system of hospitals and also understand what role a performance appraisal plays in the organization. The study has been carried out across 5 hospitals and 400 employees in Kerala by questionnaire and interviews. Sampling units are of employees of hospitals, including senior personnel. Convenience and judgmental sampling technique is used. The study concludes that performance appraisal should not only be seen as a routine activity, but its importance should be recognized and gradually communicated to all employees.

M Kamrajand S Pragadeeswaran (2009) has published paper on "Performance Appraisal Systems for NGO Managers." This article is based on empirical research into performance evaluation systems and lays five guidelines for best practice in performance appraisal for NGO managers: they are getting tough, cut to the core, seek mystery, check for frequency and realize that objectivity is a myth. The author examines each of these with reference to relevant NGO literature and assessed their applicability to the NGO. It was concluded that, NGOs began to resemble for-profit firms (and to certain extent vice-versa), much of the literature on performance appraisal which will become ever more appropriate to an idea-hungry NGO manager.

Eldridge, C., & Palmer, N. (2009). published an article on performance-based pay: some discourse considerations, evidence and unanswered questions. Health Policy and Planning, this chapter

examines the experience of pay-for-performance in health programs in developing countries. In doing so, it focuses on four key conceptual questions: (1) what to reward, (2) who to reward, (3) how to reward, and (4) what unintended consequences performance incentives may have. They point out that the use of performance pay has outpaced the growth in corresponding empirical evidence. Furthermore, very little research on performance incentives addresses the underlying conceptual issues we outline. We consider these to be important limitations in designing better performance incentives in the health programs of low- and middle-income countries.
This study is an exploratory type of research study and the data was collected by literature review and unstructured interviews of the members of the Not-for-Profit organizations run hospitals.

III. OBJECTIVE OF THE STUDY

The basic aim of the study is to review working and experiences from ongoing efforts for a performance appraisal system for NGO-run hospitals

The specific goals are

- To study the challenges to implement and practice the performance appraisal system
- To study the objective to practice the performance evaluation system

IV. RESEARCH METHODOLOGY AND DATA COLLECTION

The samples have been collected from various journals and published papers from Google Scholar, Research Gate, Shodh Ganga, Shodh Gangotri and various websites form the internet. Primary data was collected using unstructured interviews with stratified random sampling methods from the various employees of the NGO runs hospitals.

FINDINGS

Consistent Performance Management and evaluation system is a critical and important device for any organization to maintain the existing employees with the rational and systematic framework. This system addresses four key conceptual questions:
(1) what to reward
(2) whom to reward
(3) how to reward
(4) what unintended consequences performance incentives might have.
It has been observed that the use of performance pay has increased growth in the corresponding empirical evidence. Furthermore, very little research on performance incentives addresses the underlying conceptual issues we outline. The system has been utilized for various monitory and non-monitory appraisal parameters those are considered on priority at the time of performance appraisal of the employees of the hospitals. Also, this system is used for the control purpose and

correctly decides on salary, promotion and evaluation of the level of competence of employees and their career progression"

It has been observed that employees, supervisors and management face various challenges in effective execution and implementation of PAS, are mainly of four themes. These are contextual problems, problems related to the structure of performance appraisal, problems related to the process of performance appraisal, and problems related to the outcome of performance appraisal.

It has also been found and evidently proved that the training and development program plays a significant role in increasing the performance of employees, through training and development to clear goals and expectations of employees, daily growth of science and technology and huge improvements. Since they take place in every aspect of life, there is a need to fully utilize human capital and therefore a performance assessment method (PAS) is needed to optimize them.

In the NGO run hospital, the PAS is not in a proper place or has been implemented for just the sake of implementation. The system at the various NGO run hospitals is not with the proper objectives and not in line with organizations' vision, goals and long and short-term objectives. This is a result of higher focus on social/charitable activities of serving of society and financial constraint and not having professionally managed HR department that can deal with objectively implementation of various HR systems. The result of PA system is least utilized for pay, Promotion and career development program. The NGO-run hospitals are also facing the same challenges as other organizations are facing and are not able to cope-up due to insufficient training and development programs. Hence, NGOs are not able to identify good / batter and best among all their employees.

V. ANALYSIS

In this study, various research papers have been reviewed and members / employees of NGO - run hospitals have been surveyed and analyzed that all the organizations, including NGO - run hospitals, are facing various challenges in introducing a performance evaluation system. NGO-run hospitals are not keen on implementing the Performance Appraisal System for varied reasons. Compared to NGO-run hospitals, other organizations are practicing the Performance Appraisal System linked with varied benefits of the employees and the organization and the system is in accordance with organizational goals. Also, they are overcoming various challenges by continuous periodic feedback and training in performing Performance Appraisal System.

VI. CONCLUSION

NGOs are mainly dependent on funding agencies and donor agencies are more likely to work through local organizations than to implement projects directly (CSR work to show). The stated objective is not just to improve health status or individual behavior during the project's lifetime, but to ensure that local entities—organizations, groups, and even health systems—can sustain these improvements over time. Performance improvement has become important among planners

and program managers who design interventions, and especially among professionals interested in the development of public and private sector organizations.

This study is concluded as performance appraisal should not be perceived just as a regular activity but its importance should be recognized and communicated down the line to all the employees.

A conceptual framework for developing an implementable PMS for non-governmental organizations aimed not only at payroll, promotion and career planning, but also driving employee engagement, employee growth and organizational growth for NGOs

NGOs should think seriously and implement a professionally managed HR department to objectively implement a performance appraisal system for their employees and keep the goals in line with the organization's vision, short-term and long-term goals.

Employee performance can be increased through training and development with clear goals, employee expectations and taking advantage of the daily growth of science and technology and the vast improvements that occur in every aspect of life. Same way the challenges faced in conducting performance appraisal system can be overcome through training and development program and optimum utilization of various technologies and computer program.

Hence NGOs have to enhance their Employee Performance Appraisal / Evaluation System in the areas of objectivity, fairness, confidentiality and providing growth opportunities

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Effective Policy and Enforcement for Resolving Atrocities/Conflicts Enabled by Landed Property Ownership in Nigeria

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Abstract—This thesis examines the persistent rise of land-related conflicts and associated criminal activities in Nigeria, tracing their roots to historical, cultural, administrative, and governance-related inadequacies in the management of landed property. Land, traditionally communally owned and essential for livelihood, has evolved into a highly contested asset due to population growth, modernization, and weak implementation of the Land Use Act. The study highlights how ineffective administration, corruption, poor enforcement of regulations, and conflicting customary and statutory land rights have created conditions enabling violence, territorial claims, extortion, communal clashes, and other atrocities across the country.

Materials and Methods: The research adopts a qualitative approach grounded in criminological theory, supported by documentary analysis, non-participant observation, and unstructured interviews. Data were sourced through long-term observational studies of land-related activities in communities, motor parks, markets, land registries, and informal settlements across Nigeria. A combination of cross-sectional and longitudinal designs enabled the researcher to observe patterns, behaviours, and criminal tendencies linked to land ownership struggles. Content analysis was used to interpret data within the theoretical framework of causes of crime—including cultural, economic, psychological, and environmental determinants.

Results and Discussion: Findings reveal those inadequacies in land administration—such as corrupt allocation practices, weak enforcement of land regulations, multiple sales of land, extortion by traditional actors (e.g., "omo-onile"), unregulated territorial control, and government-enabled demolitions—have significantly fueled criminal activities. These include communal clashes, armed conflicts, thuggery, property destruction, kidnapping, territorial cultism, and conflict between farmers and herdsmen. The study establishes that

such crimes persist largely because of institutional weaknesses, inconsistent policies, and failure to implement culturally sensitive, transparent systems of land governance.
Conclusion: The study concludes that strengthening policy enforcement, enhancing governance structures, and implementing culturally aligned regulatory frameworks are essential to reducing land-related atrocities. Effective land administration and accountability at all levels will help curb crime, promote peace, and support sustainable national development.

I. INTRODUCTION

Land has historically played a central role in human existence, serving as the foundation for settlement, agriculture, commerce, and social organisation. From ancient civilizations to modern societies, ownership and control of land have shaped political power, economic development, and territorial identity. In Nigeria, the evolution of land ownership systems—from indigenous communal tenure to colonial land ordinances and the contemporary Land Use Act of 1978—has created a complex governance structure where statutory authority often conflicts with customary practices. Land, originally intended to support basic life functions, has increasingly become a source of economic power and, consequently, a trigger for conflicts, corruption, and criminal activities.

Landed Property refers to immovable real estate, including land and structures on it, held by individuals, families, communities, or the state. Land Administration encompasses the processes of land allocation, documentation, valuation, rent collection, registration, and dispute resolution. Atrocities/Conflicts refer to hostile or criminal acts arising from disagreements over ownership, access, or control of land. Criminogenic Factors describe social, economic, or institutional conditions that enable or promote criminal behaviour.

Extensive studies have addressed land tenure systems, administrative weaknesses, and corruption in Nigeria's land governance. Scholars such as Agboola & Oshio, Lamond et al., Owoeye, and Abada & Omeh highlight recurrent problems including inadequate enforcement of land regulations, the influence of customary practices, land grabbing by elites, and the disruptive role of informal actors (e.g., omo-onile). Studies also document the linkage between land scarcity, population growth, farmer–herder conflicts, and communal clashes across West Africa. However, these works largely focus on administrative inefficiencies or isolated conflict types without fully explaining how systemic inadequacies in land governance enable broader categories of crime, including extortion, territorial cultism, political thuggery, organised violence, and abuse of state authority.

Despite robust discussions on land reform and conflict in Nigeria, limited research has explored the criminological dimension—specifically how poor implementation, weak enforcement, corrupt bureaucratic practices, and governance failures collectively enable diverse crime activities to flourish through land-related processes. This gap leaves policymakers without a comprehensive

understanding of the root causes feeding criminality linked to territorial claims and land exploitation.

This research provides an integrated analysis showing that inadequacies in land administration directly foster multiple forms of crime and atrocities. It systematically identifies the spectrum of criminal activities tied to land struggles, highlights institutional weaknesses, and demonstrates how these factors intersect with socio-economic, cultural, and psychological determinants of crime. The study offers a framework for understanding land-related criminality through both historical and criminological lenses.

The primary objective is to examine how ineffective land administration and governance frameworks in Nigeria contribute to the prevalence of conflicts, atrocities, and criminal practices. The research aims to:

1. Establish the connection between administrative lapses in land governance and emerging criminal patterns.
2. Identify categories of land-enabled crime and explain the mechanisms through which they persist.
3. Provide evidence-based recommendations for policy reforms that promote fairness, transparency, and culturally aligned land management.
4. Strengthen criminological understanding of land-related conflicts for future academic and policy applications.

The study focuses on Nigeria's land governance system, spanning statutory, customary, and informal practices. It covers administrative processes (allocation, documentation, rent/tax collection) and criminal activities associated with land disputes, territorial claims, and governance failures. Data are drawn from non-participant observations, unstructured interviews, and documentary analysis covering communities, motor parks, land registries, and other land-related environments.

Time-bound observational access, reliance on qualitative data, the sensitivity of land-related disputes, and incomplete documentation of informal land practices poses limitations. Cultural biases, political influences, and non-disclosure by key actors also constrain the depth of data obtainable. Nonetheless, these limitations do not diminish the validity of the study's conclusions but instead provide direction for future research.

II. MATERIALS AND METHODS

1. Materials Used in the Study

Although the study did not involve laboratory experiments, it relied on a structured set of qualitative research materials to gather and interpret real-world evidence on land administration and crime patterns. These included:

- Field notebooks and journals for documenting observations during community visits, motor parks, land registries, and administrative offices.

- Audio-recording devices for capturing unstructured interview responses where permitted.
- Official land documents such as Certificates of Occupancy, land transfer agreements, maps, and public notices.
- Legislative and policy documents, including the Land Use Act (1978) and state-level land administration regulations.
- Secondary materials such as academic articles, government reports, archived cases, and documented incidents of land-related crimes.
- Digital tools: Laptops, document scanners, secure cloud folders for storing data, and word-processing applications for coding and analysis.

2. Step-by-Step Research Procedure

Step 1: Preliminary Field Mapping

The researcher began by identifying sensitive land-related activity zones such as land registries, informal settlement areas, motor parks, toll gates, and community boundaries. These locations were selected because they commonly exhibit disputes, extortion, territorial control, or corrupt practices.

Step 2: Non-Participant Observation

Over several months, the researcher visited these locations and quietly observed:

- Interactions between land agents, community members, and officials
- Dispute-handling practices
- Informal fee collection, extortion patterns, and territorial dominance
- Visible behavioural patterns linked to land conflicts

Observations were recorded daily in field journals.

Step 3: Unstructured Interviews

The researcher conducted spontaneous and unstructured interviews with individuals such as local leaders, land buyers, motor-park executives, community vigilante groups, and affected families. This allowed respondents to freely share experiences, perceptions, and grievances. Participation was voluntary and confidential.

Step 4: Documentary Review

Relevant documents—including court rulings, land regulations, policy papers, and incident reports—were reviewed to complement field data and historicise the persistent nature of land-related conflicts.

Step 5: Longitudinal Tracking

Certain communities and activity points were revisited over long periods to observe recurring crime patterns, shifts in territorial control, and ongoing administrative weaknesses.

Step 6: Data Consolidation and Coding
Field notes, interviews, and documents were transcribed and organised into thematic categories reflecting criminological determinants (cultural, environmental, economic, psychological, and institutional).

3. Tools and Instruments Used for Data Analysis
The study employed a combination of analytical tools commonly used in qualitative criminological research:

- Content Analysis Framework for interpreting narrative accounts, policy texts, and field observations.
- Thematic Coding Sheets to group data into meaningful themes such as corruption, extortion, territorial behaviour, governance failures, and socio-economic triggers.
- Descriptive Analysis Charts to highlight frequency and pattern of observed behaviours.
- Criminological Theory Mapping aligning field evidence with theories such as social learning, strain theory, opportunity theory, and institutional failure theory.
- Cross-sectional and Longitudinal Comparison Tools used to compare patterns across different locations and over time.

4. Ensuring Reliability and Trustworthiness of the Study
To enhance reliability and credibility, the following methods were applied:

- Triangulation: Combining observations, interviews, and documents strengthened the consistency of findings.
- Prolonged Engagement: Spending extended periods in the field reduced observer bias and captured authentic behaviours.
- Member Checking: Some interviewees were contacted again to confirm the accuracy of interpretations.
- Audit Trail: All field notes, documents, and coded files were dated, stored securely, and traceable.
- Reflexivity: The researcher maintained reflective notes to minimise personal bias during interpretation.
- Consistency in Observation: Standard observation templates were used across all locations to ensure uniform data recording.

III. RESULTS AND DISCUSSIONS

1. Data Overview (With Suggested Visuals and Illustrations)
The data collected through non-participant observation, unstructured interviews, and documentary reviews revealed clear and recurring patterns in how weaknesses in land administration contribute to criminal behaviour and conflict in Nigeria. Although the study is qualitative, the data can be visually represented for clarity:

- Figure 1: Frequency of Land-Related Conflict Types Observed Across Study Locations

(A bar chart could illustrate counts of observed crime types such as extortion, territorial clashes, demolition-induced displacement, farmer–herder conflicts, and motor-park violence.)

- Figure 2: Actors Involved in Land-Enabled Crime

(A pie chart showing the relative presence of actors such as community youths, traditional land custodians, motor-park unions, informal land agents, government officials, and displaced persons.)

- Figure 3: Thematic Map of Criminogenic Factors

(A thematic diagram linking observed criminal activities to factors such as corruption, weak enforcement, economic pressure, and social learning.)

- Table 1: Summary of Observed Incidents and Their Administrative Root Causes

(A qualitative summary table listing cases of demolition, extortion points, illegal rent collection, or communal clashes and mapping each case to an identified governance failure.)

2. Results – Explanation of the Data

Recurring Patterns of Crime

Across the field sites, the researcher documented several categories of land-enabled crimes. These included:

- Illegal fees and extortion by informal land actors (e.g., *omo-onile* groups).
- Forceful evictions and demolition of properties by state actors, often without due process, leaving thousands homeless.
- Territorial control and violence within motor parks, reflecting competition for revenue and influence.
- Community clashes over inherited parcels of land.
- Violent confrontations between farmers and herdsmen over access to grazing land.

Administrative Root Causes

Data revealed that almost every conflict or crime category had roots in:

- Poor enforcement of land policies
- Corruption in allocation and documentation
- Absence of transparent land records
- Conflicting statutory and customary land rights
- Lack of accountability among government officials

Impact on Communities

Communities affected by government-ordered demolitions showed a sharp rise in street hawking, homelessness, and theft, demonstrating how administrative decisions can unintentionally fuel criminality.

Interviews with victims emphasized feelings of injustice, hopelessness, and deep resentment towards the state, further worsening community–government relations.

3. Discussion – Interpretation of Findings in the Research Context

The results confirm that land is far more than an economic asset in Nigeria—it is a gateway to power, identity, and survival. When governance systems fail to ensure fair and transparent administration, land becomes a fertile ground for criminal exploitation.

Land Administration as a Criminogenic Structure

The findings show that inadequacies in land management do not merely "allow room" for crime—they actively *shape and reinforce* criminal behaviour.

For example:

- Extortion thrives where land documentation is inconsistent or inaccessible.
- Territorial cultism flourishes in institutions where spatial control is poorly regulated.
- Farmer–herder conflicts escalate in regions lacking clear land demarcation and enforcement.
- Government demolitions without compensation create socio-economic vulnerability that pushes displaced individuals toward survival-driven crime.

Alignment with Criminological Theory

These results align strongly with:

- Social Learning Theory: Communities normalize criminal behaviour when they see land agents or officials benefit from illegal activities.
- Strain Theory: Economic pressure and lack of access to legitimate land rights push individuals toward violent or illegal land acquisition.
- Opportunity Theory: Weak enforcement creates openings for groups to seize land, collect illegal rents, or operate heavily controlled territories.
- Institutional Failure Theory: Corrupt governance structures become enablers rather than regulators of criminality.

Contribution to Research Gap

While previous studies described land conflicts and administrative inconsistencies, they did not fully connect these issues to broader criminal activities. This study bridges that gap by showing that land administration failure is a *multi-layered enabler* of crime—from high-level corruption to grassroots violence.

Implications

The discussion highlights an urgent need for:

- Transparent land registration
- Culturally sensitive land reforms
- Strong enforcement mechanisms

- Protection of vulnerable populations
- Behavioural and criminological training for land administrators

These findings offer policymakers a lens for understanding not just "what" crimes occur but "why" they systematically thrive.

IV. CONCLUSION

This research set out to understand how weaknesses in Nigeria's land administration system contribute to the rise and persistence of land-related conflicts, criminal activities, and human suffering. The primary objective was to uncover the deeper criminological drivers behind these issues and demonstrate how poor governance, corruption, and inconsistent policies transform land—a basic human asset—into a catalyst for violence, exploitation, and social instability.

Review of Key Findings

The study revealed that the origins of land-related atrocities are deeply rooted in historical governance failures, conflicting customary and statutory land rights, and the ineffective implementation of the Land Use Act of 1978. Non-participant observations and unstructured interviews conducted across multiple locations showed recurring patterns of extortion, illegal fees, territorial domination, forced evictions, and community clashes. These acts were consistently linked to:

- Corrupt allocation processes and poor documentation
- Weak enforcement of land regulations
- Conflicting land ownership systems
- Exploitation by informal actors (e.g., *omo-onile*)
- Politicisation of land administration
- Abuse of authority during demolitions and forced displacement

The study further uncovered how government actions—such as unannounced demolitions—can unintentionally fuel criminality by pushing displaced individuals into survival-driven activities, heightening insecurity, and creating mistrust between citizens and the state.

Implications and Practical Applications

The findings underscore that land administration in Nigeria is not merely an administrative activity but a *criminogenic structure* capable of shaping societal behaviour. Recognizing this reality has wide-ranging implications:

- For policymakers, it highlights the urgent need for transparent reforms and culturally sensitive land governance frameworks.
- For criminologists, it demonstrates how institutional failures create the conditions for organised crime, extortion networks, and violent territoriality.
- For communities, it provides clarity on why conflicts persist, offering a path toward fairer, more accountable systems.

- For development planners, it shows that sustainable growth is impossible without secure, predictable, and just land management.

Recommendations for the Future

Based on the evidence, several key actions are recommended:

1. Strengthen enforcement mechanisms by empowering land agencies with transparent digital systems that reduce opportunities for corruption and manipulation.
2. Harmonise customary and statutory land laws to eliminate overlapping ownership claims and reduce community-level conflicts.
3. Implement community-inclusive land governance that involves local leaders, vulnerable groups, and civil society in meaningful decision-making.
4. Introduce criminological and behavioural training for land administration officials to increase awareness of how their decisions influence crime patterns.
5. Establish an independent land oversight body to monitor demolitions, allocation processes, and dispute resolutions.
6. Promote fair compensation and rehabilitation for individuals displaced by government actions to prevent desperate, crime-driven survival behaviours.
7. Encourage longitudinal research on land crimes, territoriality, and governance gaps to support evidence-based policymaking.

Final Reflection

Ultimately, this study demonstrates that land-related atrocities in Nigeria are not isolated incidents—they are symptoms of deeper governance and structural failures. By addressing these weaknesses with transparency, accountability, and cultural sensitivity, Nigeria can reduce crime, strengthen community trust, and create a more just and stable society. This research, therefore, contributes a vital criminological lens for understanding and resolving one of the country's most deeply rooted challenges.

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A Comparative Study Of E- Banking on Private and Public Bank

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Abstract—The paper presents the comparative study between the private banks and public banks in electronic banking in different cities. E –banking is the provision of banking service through electronic channels and the customer can access the data without any time and geographical limitation. This paper identified the how much electronic banking adoption in different Banks in Nerul city. Also, comparative study of banks indifferent region to analyze ATM, Net banking, Mobile banking services used by user in that bank. the Paper is basically concerned with the customer aspect of electronic banking searching for customer satisfaction level and adoptions of banks. This is a comparative study of public banks and Private bank.

Index Terms—Mobile banking, ATM, Internet banking.

I. INTRODUCTION

In Today's scenario role of e-Banking is very valuable. Without e-Banking no banks can work. In this study we analyse, how e-banking used in Public and Private sector banks? Objective of study is to find the customer satisfaction in respect of e-banking and the perception of employees for using e-banking in Public and Private sector banks. The method of the study is Primary and Secondary both. Study showed perception of customer regarding service quality and satisfaction of employee in internet banking services. As well as this study analyse the working style as a comparison between Public and Private sector banks.

Banks plays a very important role in the Indian Financial Market as they are the biggest purveyors of credit and attract most of the savings from the population. Banking is necessary for the economic development of all the nations of the world because a developed banking system holds the key as well as a barometer for the economic health of a country. Banking Industry is one of the most successful and strong industry of our country. Banking structure is affected by the changing

environment of an economy. In Indian context, there were two phases of nationalization, introduction of RRBs, entry of private sector banks and foreign banks and now e-banking are some important and major changes that affect the structure as well as functioning of the bans from time to time. E-banking facilities typically have many features and capabilities in common, but also have some that are application specific.

II. LITERATURE REVIEW

1. "Internet Banking as a tool for Customer Relationship Management
A Study on Customer Perspective", Krishnamurthy, V. and R. Srinivasan (2013) This study intends to throw light on customer perception on internet banking which serves as a tool for Customer Relationship Management (CRM). Data was collected from 154 respondents who are exposed to Internet Banking. This study clearly indicates that banks are facing difficulty in retaining their existing customers, for which either they need to come up with innovative, customized products or they need to develop trust with their customers and maintain the relation with them.

2. "Customer Perspective on E-Business Value
Case Study on Internet Banking", Safeena, Rehmath (2010) In this research paper she has determined the consumer's perspective on internet banking adoption. Though customer acceptance is a key driver determining the rate of change in the financial sector. This study aims at examining the impact of perceived usefulness, perceived ease of use, consumer awareness on internet banking and perceived risk on the acceptance of internet banking by the consumers. The result of this study concludes that majority of customers are accepting online banking because of many favorable factors. Analysisconcluded that usefulness, ease of use of the system awareness about online banking and risks related to it are main perusing factors to accept online banking system. These factors have a strong and positive effect on customers to accept online banking system.

3. "User Friendly E-Banking", Rourke, Chris (2004)
This article discusses the importance of usability within the e-banking sector and identifies common usability problems and ways to resolve them. Research shows 50% of perspective customers registering for online banking bail out before signing up, mostly due to problems navigating the site, completing online form, security fears, and understanding content and feedback. It is widely recognized that online banking provides more revenue per customer and costs less per transaction than any other channel, including phone banking. Banks aiming to profit the most from the increase in online banking volumes should consider the usability and accessibility of all aspects of their site to welcome them.

III. RESEARCH METHODOLOGY

Research is an art of scientific investigation. In other word research is a scientific and systematic search for relevant information on a specific topic. The logic behind taking research methodology into consideration is that one can have knowledge about the method and procedure adopted for achievement of objectives of the project. Its main aim is to keep the researchers on the right track.

Scope of study

1. The study will be able to prevail the preferences, need, perception, of the customer regarding the E - Banking services of public sector and Private sector bank.
2. It also helps the Banks to know whether the E - Banking services can really satisfy the customer needs.

Objective of Study

1. To study public sector banks v/s Private sector banks from the E-Banking perspective.
2. To find the bank sector that are largely availed by the customer.
3. To find and compare the satisfaction level of customers in public sector as well as Private sector bank.
4. To study the factors influencing the choice of a bank for availing service.
5. To study the awareness of internet banking among the customer of Public and Private Bank.
6. To find the most important factor that is inducing people towards e-banking.
7. To investing whether e-banking is cost effective for both the banks and the customers or not.

Hypothesis Research

Hypothesis Testing 1

H1: There is no significant difference in the effectiveness of the e-banking services provided by the selected public and private sector banks.

H0: There is no significant difference between the responses of the customers of the selected public and private sector banks on various parameters for comparison of e-banking with traditional banking.

Hypothesis Testing 2

H1: There is no significant difference between the responses of the customers of the selected public and private sector banks on various parameters for comparison of e-banking with traditional banking.

H0: There is a significant difference between the responses of the customers of the selected public and private sector banks on various parameters for comparison of e banking with traditional banking.

Data Collection Methods -

Survey Method: - Online

Survey Instrument: - Questionnaire
Method of Survey: - Through the personal interaction with the help of questionnaire.
Collection of primary data

Primary data is the first hand data which is collected from the number of respondents. Here structured questionnaire was used to collect primary data through surveys.
Collection of secondary data

Secondary data has been collected for other for other useful resources & information essential required in order to successfully complete the project report & company figures from the internet, books, magazines as well as newspaper.

Limitation of study
1. This study is based on the prevailing respondent's satisfaction. But their satisfaction may change according to time, fashion, need etc.
2. Both Public sector and Private sector bank are providing different E- Banking services and acceptance to their current holders.

IV. FINDING AND DATA ANALYSIS

4.1. Data analysis and Interpretation:
4.1.1. Gender

Table No.1

Gender	No.of respondent	Percentage
Male	46	46%
Female	54	54%
Total	100	100%

Source: Primary data

INTERPRETATION
From the above result we came to know that out of 100, 46 respondents are males and 54 respondents are females which is 46% and 54% respectively. From this it is understood that female usage of internet banking is more as compared to male.

4.1.2.Age

Table no: 2

Age	No of respondent	Percentage
Below 20	20	20%
21- 30	40	40%
31- 40	20	20%
41-50	10	10%

More than 50	10	10%
Total	100	100%

Source: Primary data

INTERPRETATION

below 20 21-30 31-40 41-50 above 50 The above diagram represents the aged group of the people who are using the Internet banking. The age group between 21-30 is the highest percentage in aged person using the Internet Banking. The age group 41-50 and more than 50 are the age group having lowest percentage in the diagram. The people in the aged group below 20 for using Internet banking is 20%. The people in the aged group 21-30 is 40%. The people in the aged group 31-40 is 20%. The people in the aged group 41-50 is 10% and more than 50 is also 10%.

4.1.3 Which category of the banks do you consider as most technologically advanced?

Table No. 3

Banks	No.of respondent	Percentage
Public bank	53	53%
Private bank	33	33%
Both	14	14%
Total	100	100%

Source : primary data

INTERPRETATION

The above diagram shows the no. of customer using Public and Private Bank in the EBanking sector. The no. of customers using Public bank is 53% and the no. of customers using Private bank is 33% and the no. of customers using other bank is 14% respectively. It was found that most of the respondents were availing services of Public sector banks while those of the Private sector banks.

4.1.4 Which attributes of the bank do you value the most?

Table No: 4

Sources	No. of respondent	Percentage
Quality of service	32	32%
Technology used	34	34%
Trust Location	25	25%
Technology used	2	2%
Type of bank	7	7%
Total	100	100%

Source: Primary data

INTERPRETATION

By analysing this graph, we can conclude that most of the people is influenced by the technology used and quality of services provided by the bank and location is given less preference than others.

4.1.5 What is your opinion about public bank?

Table no: 5

Sources	No of respondent	Percentage
Service is good	26	26%
They provide security	46	46%
Cheaper service	18	18%
Other	10	10%
Total	100	100%

Source: primary data

INTERPRETATION

The diagram indicates the reason behind choosing a public bank by the customer. There are several reasons for selecting a public bank. The no. of customer is 26% who think that public bank provides good service. The no. of customer is 46% who think that public bank provides proper security. The no. of customer is 18% who think that public bank offered a cheaper service fee. The no. of customer is 10% whose reason selecting the public bank is other.

4.1.6. Is public bank being more convenient than private bank?

Table no: 6

Sources	No. of respondent	Percentage
Strongly agree	25	25%
Agree	40	40%
Netural	27	27%
Disagree	8	8%
Strongly disagree	0	0%
Total	100	100%

Source: primary data

INTERPRETATION:

In the above diagram we get to know about the customer view related to the public bank & Private bank. The customer response related to it is different, the no. of customer who strongly agree with the point is 25%. The no. of customer who agree with the point is 40%. The no. of customer who is in between situation (Neutral) with the point is 27%. The no. of customer who disagree with the point is 8% & there are no customer who is strongly disagreeing to this point.

4.1.7 State the degree of confidence of public bank?

Table no:7

Options	No. of respondent	Percentage
Less	9	9%
Some	44	44%
Not at all	12	12%
High	31	31%
Very high	4	4%
Total	100	100%

Sources: primary data

INTERPRETATION:

The above diagram represents the degree of confidence of customer on public sector bank. As shown on the above customer have some of the degree of confidence on public sector bank. The no. of customer has different option, confidence public sector bank. There are 9% of customer who are having a less degree of confidence on public bank. There are 44% of customer who are having some of degree of confidence on public bank. There are 12% of customer who doesn't have not at all a degree of confidence on public bank. There are 31% of customer who is having a high degree of confidence on public bank. There are 4% of customer who is having a very high degree of confidence on public bank.

V. HYPOTHESIS TESTING

5.1 Hypothesis testing 1

H1: There is no significant difference in the effectiveness of the e-banking services provided by the selected public and private sector banks.

H0: There is no significant difference between the responses of the customers of the selected public and private sector banks on various parameters for comparison of e-banking with traditional banking.

Table no. 8 Hypothesis testing

Row levels	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Grand total
Always	12	4	6	11	1	34
Sometimes	15		5	2	2	24
Never	20	4	11	6	1	42
Grand total	47	8	22	19	4	100

Table no 9 Anova test

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance

Column 1	3	47	15.67	16.33
Column 2	3	8	2.67	5.33
Column 3	3	22	7.33	10.33
Column 4	3	19	6.33	20.33
Column 5	3	4	1.33	0.33

ANOVA

Source of Variation	SS	Df	MS	F	P-value	F crit
Between Groups	378	4	94.5	8.97	0.0024	3.48
Within Groups	105.33	10	10.53			
Total	483.33	14				

The ANOVA test result shows a p-value of 0.0024, which is less than the 0.05 level of significance. Hence, the null hypothesis is accepeted and the alternative hypothesis is rejected.

VI. CONCLUSION

The customer nowadays is not exposed of what type of service is being provided by banks in India but in the world as a whole. They expect much more than what is actually being provided. So, the new coming banking sector has to provide and cater to all the needs of the customers otherwise it is difficult to survive in the competition coming up.

They not only expect the safety of money but also best ways to invest that money which needs to be fulfilled. Banks need to have a better outlook towards to actually what customers are requiring. Entries of the private sector banks have made the competition tougher. If the bank is not functioning properly, it is being closed. So, it is difficult so face these types of conditions. Here a simple philosophy can work that customers are God are need to follow this to survive and serve better.

In a country like India, there is a need for providing better & customized services to customer. Bank must be concerned about the attitudes of customers with regards to acceptance of internet banking. The importance of security and privacy for acceptance of internet banking has been noted in many earlier studies and it was found that people claim that they have knowledge about security issues but they have no clear idea about all kinds of frauds. The present study shows that customers are more reluctant to accept new technologies or methods that might contain very little risk. Hence, banks should design a secure website to address security and trust issues.

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Impact Of Online Game Addiction on Adolescent Mental Health

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Abstract—Digital technology is currently advancing rapidly, making it easier for everyone to connect and share the same interests without any obstacles across geographic and temporal boundaries, convenient, flexible to reach, and affordable in developed countries; from these many advantages, there are also concerns among researchers related to the use of digital technology exaggerated. One of the digital technologies that are currently in existence is online games. Online game games are currently booming among adolescent worldwide, even tournaments/competitions are held in playing them, which are integrated by the player's social networks. Internet addiction is currently considered a global problem with possible implications for mental health.

The way people interact with technology is constantly changing. New behaviors have improved, social and recreational activities have changed, and new psychological problems have arisen. In the late 1990s, concerns about addictive internet use were discussed, and, since then, the concept has been widely studied and debated. Although it has been treated form different angels and researchers have used additional terms, "internet addiction" has become one of the most commonly used terms, along with "internet use is problematic.

As the social problem of online gaming addiction has become widespread, online gaming has become viewed negatively such as gambling or alcohol addiction. With the rapid surge in the population of internet users, IA has become an increasing mental health problem worldwide, raising public concern. Healthily using the internet can be understood as achieving the desired goal in an appropriate time frame without experiencing any intellectual or behavioral discomfort. IA is described as an individual's inability to control their use of the internet, which causes disruption and disruption in fulfilling work, social, and personal commitments and appears to have similarities with the category other aspects of behavior.

I. INTRODUCTION

Online game addiction is where people play games and make a habit of it, they would continue playing when found free time for hours together. This leads to less interest in other works, gaming would make a habit, create an impact on daily functioning activities, impact on personal – social relationship, less interest in education and ignorance in occupational responsibilities. Online game addiction can also cause internet gaming disorder, whereas this can be classified as mental illness which has been found from researches.

This addiction is a behaviour similar to gambling disorder, in which people would rush to play games and winning prizes will be the main reason playing frequently. Online games can be segregated in many, which among are: fun games for children, individual games, group games and betting games for prize winning. Betting games may require cognitive skills and sharp mind with full of interest concentration as it is just a matter of chance. This would create a negative impact on daily living and earning, as in betting games peoples would lose money due to which people start borrowing money from others for finance which would add lots of interest on money.

Online game addiction mostly effects children, teenagers and adults, among these adults are the 1st who likely are addicted to games. Males are mostly addicted when compared to females. So far online winning games may increase a release dopamine, it is a brain chemical (neurotransmitter) which effects in many bodily functions including pleasurable rewards and motivations.

For any such disorders peoples refer healthcare providers who are mental professional such as psychologist or psychiatrist. Online gaming also causes obesity in teens, which would cause vision problem in eye strain, which leads to headache and poor concentration in any work. World health organization have defined, gaming disorder is due to access use of online games (this includes video games, online games and TV based games).

Addiction would be like, if one decides to play a game for one hour, but since the player would be lost in playing games and continue playing for another more hours of 4-5 continuously. Player would feel that the game played was for only few minutes of time and would miss some important moments of time. This can be addictive that, they start playing game anywhere and anytime irrespective of present situations.

Here are signs of online game addiction in students:

1. Gaming disrupts your sleep habits.
2. Avoiding school or work to play.
3. Needing to play longer time to get enjoyment.
4. Feeling irritated if someone disturbs you and you are not able to play.
5. Feeling anxious when not played.
6. Being consumed with thoughts about gaming.
7. Playing more than 6 hours a week.
8. Lack of attention with poor academic performance.

9. Create impulsivity and anger.
10. Losing money believing the scammers

II. LEAP UP OF ONLINE GAME ADDICTION.

This was during the period of COVID-19, when compared online game addiction caused more than COVID-19 impact. Due to lockdown schools did not function for a period of time, but only online classes where conducted. Teen age students who were attending classes online also started playing games without the knowledge of teachers and parents. While COVID was dominating outside the house, these online games were dominating inside the house. However, lockdown decreased COVID cases, but increased online game addiction. Even though schools are reopened now, but few of them are continuing to play the games at night mostly and are not able to concentrate on their studies in school.

During this period, students had less work to do and lots of time to spend, whereas they didn't have a mode of self-interactions with others than their family members. Due to which students started opting another mode to keep them busy and entertaining them. They started opting online games, as these games provide interested, thrill and eagerness to win the game. These were played individually, but as the technology grew, networking also grew to an extent where players can play in groups. Irrespective of location and distance, the game can be played and operated from every corner of the world.

These games also created competition within the groups, which includes: levels cleared in games, game achievements, addition goodies and creation of groups. As these were achieved by one and the other among them, will also try to achieve it to build his popularity. In terms to build, one started spending most of time to achieve it, playing the same game again and again. Losing the game would create the dissatisfaction in them which to attract to continue playing game again from start.

III. RESEARCH METHODOLOGY

OBJECTIVE OF STUDY:

- The most dependable qualitative research strategy that aids in overcoming addiction disorders in daily life is to investigate the cause of the problem under examination.
- To understand and learn how can we overcome from online addiction to keep our self and others healthy, physically and mentally.
- To assess the prevalence of online game addiction among adolescents.
- To identify demographic factors (age, gender, socioeconomic status) associated with online game addiction.
- To explore the relationship between online game addiction and mental health outcomes (anxiety, depression, sleep disturbances, social isolation).
- To examine the impact of online game addiction on academic performance and social

relationships.

- To investigate the role of parental involvement, peer influence, and social media on online game addiction**.**

STATEMENT OF THE PROBLEM

Even though local resources and entertainment options are constantly being improved and expanded, the number of people who are dependent on online gaming is increasing every year. Earlier, this was not thought to be a serious problem, but now that it has more users, it is thought to pose a serious threat.

Addiction to online games is linked to social and psychological problems caused by a lack of self-control. Gamers are now much older, and teenagers are no longer thought of as the primary demographic for the hobby. Online video game play was once regarded as a meaningless past time, but it has now come to play a significant role in many people's lives.

- The growing appeal of online gaming is attributed to the notion that these games allow for far more immersive engagement and are intensely creative and original. It is evidence that the issue impacts everyone with whom they come into contact in their personal, professional, social, and family lives in addition to those who are actively involved in it.
- According to studies, between 1.6 and 8.5% of young people in Western countries suffer from online gaming disorder. This condition is frequently accompanied by other psychological issues such depression, anxiety, attention deficit hyperactivity disorder, and social phobia.
- The evolution of the online gaming habit and people's attitudes towards it will be the study's key goals. The most prevalent signs of an addiction to online gaming are irritable sensations when there is no Internet access.

Learning objectives and goals.

- The possibility to receive accurate information.
- Suitable way to reveal and understand people’s complex problems.
- How to improve people’s wellbeing.
- Make people express their thoughts.
- To understand how people develop addiction in them and how they feel about it.
- Creating opportunities of values, different ways of learning about people’s problems and experiences.
- Overcoming bad habit of online games

IV. DATA COLLECTION

Data collection is the process to gather information about the relevant topic of research, which is being done by researcher. Data collection is a term used to describe a process of preparing and collecting data. The following method of data collection can be used while doing research.

COLLECTION OF PRIMARY DATA:
In today's world correct information is the key to success. Primary data is collected by the Google Forms which is circulated with my friends, Teachers, Cousins etc.

COLLECTION OF SECONDARY DATA:
Secondary data are those data which have been already collected and analyzed by some earlier researchers for its own use; and later that same data is used by a different report. Also used Google and AI techniques.

V. SAMPLING PLAN AND SAMPLING DISTRIBUTION

The respondents for the study will be General Public i.e., Students, Friends, Family members, Teachers etc.

FINDINGS AND DATA ANALYSIS:
PROFILE OF RESPONDENTS:
Age- wise distribution of the employees:

Count of Age	Column Labels				
Row Labels	15-20	20-25	25-30	30 and above	Grand Total
Female	6	20	2	0	28
Male	0	12	2	1	15
Grand Total	6	32	4	1	43

Interpretation
In the cross table shows that total no of respondents is 43, Moreover in 20-25 Age respondents are Higher in numbers i.e., 32 out of 43 (Male is 12 & Female is 20), 25-30 Age is equally respondent i.e., 15-20 Age only female responded i.e., 6.30 & above only 1 responded in Male.

Online Game Addiction Has a Significant Negative Impact on Adolescent's Mental Health.

Count of Gender	Column Labels		
Row Labels	Female	Male	Grand Total
Natural	4	0	4
Somewhat Agree	3	3	6
Somewhat disagree	2	1	3
Strongly Agree	19	9	28
Strongly Disagree	0	2	2
Grand Total	28	15	43

Interpretation:
As shown in the above table Out of 43
Strongly Agree: 28 (65.1%), Somewhat Agree: 6 (14%), Neutral: 4 (9.3%), Somewhat Disagree: 3 (7%), Strongly Disagree: 2 (4.7%)

1. The majority of respondents (65.1%) strongly agree with the statement, indicating a high level of concern or recognition regarding online gaming addiction.
2. Females tend to show stronger agreement with the statement than males.
3. A small proportion of respondents (4.7%) strongly disagree with the statement, indicating some skepticism or disagreement.

Excessive Online Gaming Can Lead to Social Isolation Among Adolescents

Count of Gender	Column Labels		
Row Labels	Female	Male	Grand Total
Agree	7	1	8
Disagree	0	3	3
Neutral	6	0	6
Strongly Agree	14	8	22
Strongly disagree	1	3	4
Grand Total	28	15	43

Interpretation:

As shown in the above table Out of 43 –

Strongly Agree: 22 (51.2%), Agree: 8 (18.6%), Neutral: 6 (14%), Disagree: 3 (7%), Strongly Disagree: 4 (9.3%)

1. Females are more likely to strongly agree (14/28, 50%) than males (8/15, 53.3%).
2. Males are more likely to disagree (3/15, 20%) or strongly disagree (3/15, 20%) than females.
3. Females account for all neutral responses (6/6, 100%).

Online Game Addiction Affects Academic Performance

Count of Gender	Column Labels		
Row Labels	Female	Male	Grand Total
Agree	10	3	13
Disagree	2	3	5
Neutral	4	3	7
Strongly agree	9	4	13
Strongly disagree	3	2	5
Grand Total	28	15	43

Interpretation:

As shown in the above table Out of 43 –

Strongly Agree: 13 (30.2%), Agree: 13 (30.2%), Neutral: 7 (16.3%), Disagree: 5 (11.6%), Strongly Disagree: 5 (11.6%).

1. Females tend to show stronger agreement (19/28, 67.9%) than males (7/15, 46.7%).
2. Males are more likely to disagree (3/15, 20%) or strongly disagree (2/15, 13.3%) than females.
3. Neutral responses are evenly distributed between genders.

Which Age Group Is Most Vulnerable to Online Game Addiction

Count of Gender	Column Labels		
Row Labels	Female	Male	Grand Total
11-14 years	12	4	16
15-20 years	9	8	17
21-25 years	2	1	3
6-10 years	5	2	7
Grand Total	28	15	43

Interpretation:

As shown in the above table Out of 43 –

11-14 years: 16 (37.2%), 15-20 years: 17 (39.5%),21-25 years: 3 (7%),6-10 years: 7 (16.3%)

1. The majority of respondents (37.2%) fall within the 11-14 age range.
2. Females dominate the 11-14 (12/16, 75%) and 6-10 (5/7, 71.4%) age groups.
3. Males are more represented in the 15-20 age group (8/17, 47.1%).
4. The 21-25 age group has the fewest respondents (3).

What Is the Potential Consequence of Online Game Addiction on Adolescent Mental Health?

Count of Gender	Column Labels		
Row Labels	Female	Male	Grand Total
11-14 years	12	4	16
15-20 years	9	8	17
21-25 years	2	1	3
6-10 years	5	2	7
Grand Total	28	15	43

Interpretation: As shown in the above table Out of 43 –

- The majority of respondents (37.2%) fall within the 11-14 age range.
- Females dominate the younger age groups (11-14 and 6-10 years).
- Males' representation increases in the 15-20 age group.
- The 21-25 age group is underrepresented.

1. Female-dominated age groups: 11-14 (75%) and 6-10 (71.4%).
2. Male representation peaks in the 15-20 age group (47.1%).
3. Few respondents (7%) are in the 21-25 age group.

Online Gaming Has No Link to Increased Symptoms of Anxiety and Depression?

Count of Gender	Column Labels		
Row Labels	Female	Male	Grand Total
Natural	7	4	11
Somewhat agree	9	0	9
Somewhat Disagree	3	2	5
Strongly Agree	5	4	9

Strongly disagree	4	5	9
Grand Total	28	15	43

Interpretation:

As shown in the above table Out of 43 –

1. Females tend to Somewhat Agree (9/28, 32.1%).
2. Males are more likely to Strongly Disagree (5/15, 33.3%).
3. Females dominate Neutral responses (7/11, 63.6%).
4. No males Somewhat Agree.
5. Females are more likely to Strongly Agree (5/28, 17.9%) than males (4/15, 26.7%).
6. Males are more polarized (Strongly Agree/Disagree: 9/15, 60%).

Parent Involvement Can Prevent Online Game Addiction Among Adolescents?

Count of Gender	Column Labels		
Row Labels	Female	Male	Grand Total
Disagree	2	1	3
Neutral	9	3	12
Somewhat Agree	5	5	10
Strongly agree	8	4	12
Strongly disagree	4	2	6
Grand Total	28	15	43

Interpretation:

As shown in the above table Out of 43 –

1. Females tend to Strongly Agree (8/28, 28.6%).
2. Males are more evenly distributed across categories.
3. Females dominate Neutral responses (9/12, 75%).
4. More respondents agree (22) than disagree (9).
5. Females show stronger agreement (28.6% Strongly Agree).
6. Males' opinions are more dispersed.

School Should Incorporate Online Games Addiction Prevention Programs Into Their Curriculum?

Count of Gender	Column Labels		
Row Labels	Female	Male	Grand Total
Disagree	1	1	2
Neutral	6	4	10
Somewhat Agree	9	3	12
Strongly agree	7	5	12
Strongly disagree	5	2	7
Grand Total	28	15	43

Interpretation:
As shown in the above table Out of 43 –
1. Females tend to Somewhat Agree (9/28, 32.1%).
2. Males are more likely to Strongly Agree (5/15, 33.3%).
3. Females dominate Strongly Disagree responses (5/7, 71.4%).
4. More respondents agree (24) than disagree (9).
5. Females show stronger disagreement (5/7, 71.4% Strongly Disagree).
6. Males' opinions are more positive.

Online Game Addiction Is Associated with Decreased Self-Esteem Among Adolescents?

Count of Gender	Column Labels		
Row Labels	Female	Male	Grand Total
Disagree	1	1	2
Neutral	9	6	15
Somewhat Agree	10	6	16
Strongly agree	5	2	7
Strongly disagree	3	0	3
Grand Total	28	15	43

Interpretation:
As shown in the above table Out of 43 –
1. Females tend to Somewhat Agree (10/28, 35.7%).
2. Males are more likely to Neutral (6/15, 40%).
3. No males Strongly Disagree.
4. Most respondents are positive or neutral.
5. Females show stronger agreement (10/28, 35.7% Somewhat Agree).
6. Males are less likely to disagree.

VI. RECOMMENDATIONS:

Prevention:
1. Parental monitoring and guidance
2. Education on responsible gaming and digital citizenship
3. Encourage physical activity and socialization
4. Set limits on gaming time and access

Intervention:
1. Counseling and therapy for addicted adolescents
2. Support groups for parents and adolescents
3. Collaborative efforts between parents, educators, and mental health professionals
4. Development of treatment plans addressing underlying issues.

Game Development:
1. Design responsible games promoting healthy gaming
2. Parental control features and monitoring tools
3. Disclosure of addiction risks and resources
4. Community norms promoting balanced gaming.

VII. HYPOTHESIS

1. Main Hypothesis: Online game addiction positively correlates with adverse mental health outcomes among adolescents.
2. Sub-Hypotheses:
3. Anxiety, depression, sleep disturbances, and social isolation increase with online game addiction.

VIII. DISCUSSION

The main source of enjoyment and a method to avoid boredom is playing online games. After a stressful day at work or in daily life, they also assist people in calming down and relaxing. According to research, gaming addiction affects people physically and behaviorally, especially children. Online gaming competitions involving other players are also held at many levels, including local, national, and international, in an effort to find the best player overall.

IX. CONCLUSION:

Online game addiction significantly impacts adolescent mental health, highlighting the need for:
1. Increased awareness and education
2. Effective prevention and intervention strategies
3. Collaborative efforts among stakeholders
4. Ongoing research into gaming addiction's consequences and treatment.

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An Analytical Study on Financial Implication of Lifestyle-Based Subscription Services on Individual Budgeting

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Abstract: In the digital era, lifestyle-based subscription services such as entertainment streaming platforms, online fitness programs, learning applications, and food delivery services have become an integral part of everyday life. While these services offer convenience and enhanced user experience, their recurring nature has significant implications for individual budgeting and financial planning. This study, titled "An Analytical Study on Financial Implication of Lifestyle-Based Subscription Services on Individual Budgeting," aims to examine the impact of subscription-based spending on monthly budgets, spending behaviour, and financial awareness. Using a descriptive and analytical research design, primary data are collected through structured questionnaires to assess subscription usage patterns, expenditure levels, tracking practices, and perceived value for money. The study also tests whether tracking subscription expenses improves money management and whether such spending affects monthly budgets. The findings are expected to highlight the growing influence of automated recurring payments on personal finances and emphasize the need for greater financial awareness and effective budgeting in a subscription-driven economy.

Index-Terms: Lifestyle-Based Subscription Services, Individual Budgeting, Financial Planning, Recurring Payments, Spending Behaviour, Financial Awareness

I. INTRODUCTION

Lifestyle-based services are continuous digital services designed to make everyday life more convenient, enjoyable, and personalized by aligning with individuals' habits, interests, and routines. These include streaming platforms, fitness memberships, online learning, and food delivery applications, which have become widely used due to the growth of the internet and smartphones. Unlike one-time purchases, such services operate through recurring subscriptions, allowing users instant and flexible access anytime and anywhere. While personalization features enhance user engagement and satisfaction, the accumulation of multiple subscriptions often leads to unnoticed recurring expenses, impacting individual

budgeting. Thus, although lifestyle-based services enhance comfort and accessibility, they also highlight the financial trade-off between convenience and effective money management.

II. LITERATURE REVIEW

1. Kaur and Zhang (2024)

This study explored how artificial intelligence-based subscription tracking influences financial behaviour among Indian users. The authors concluded that AI driven tools help consumers visualize their recurring expenses, leading to a 21% reduction in unnecessary subscription costs. Their findings emphasized the potential of FinTech interventions in improving financial discipline and promoting smarter budgeting habits.

2. Fischer and Patel (2023)

Fischer and Patel explored emotional spending triggers within subscription ecosystems. Their results showed that individuals experiencing stress or seeking self-reward are more likely to engage in recurring purchases resulting in higher financial vulnerability and increased debt levels over time.

3. PwC India (2023)

PwC's report on the Indian subscription economy revealed that the country is witnessing rapid growth in lifestyle-based digital services. The report highlighted that young professionals spend a significant portion of their income on recurring subscriptions, affecting long-term savings. It also called for greater transparency in subscription billing and awareness among consumers regarding cumulative costs.

4. McKinsey & Company (2022)

McKinsey's global report highlighted that subscription-based services have grown by over 435% since 2012, with most online consumers using at least five subscriptions at once. The study noted that while subscriptions offer convenience and accessibility, they also destabilize short-term liquidity and promote impulsive spending behaviours especially in developed economies.

III. RESEARCH METHODOLOGY

3.1. Statement of Problem:

In recent years lifestyle-based subscription services have become an integral part of people's daily lives. With the rise of digital platforms such as Netflix, Spotify, Zomato, Swiggy, Amazon and various fitness and education apps individuals are increasingly adopting subscription models for convenience and entertainment. While these services offer comfort and flexibility, they also create new challenges in terms of financial management and budgeting.

Many individuals subscribe to multiple platforms without fully realizing the cumulative cost of these recurring payments. Small monthly amounts when added together can significantly impact one's overall financial stability and savings. Moreover, the automated nature of subscription renewals often leads to unmonitored spending and reduced awareness of financial outflow.

The problem becomes more complex as consumers differ in their income levels, spending habits, and awareness of their financial limits. Some users may consider these subscriptions as essential while others may view them as luxury expenses. There is limited academic research on how these digital lifestyle choices affect individual budgeting behaviour particularly in semi-urban areas like Vashi.
Therefore, this study aims to analyse how lifestyle-based subscription services influence personal budgeting patterns how much income individuals allocate to these services whether they actively track their spending and how these habits affect their overall financial management.

3.2. Scope of study:
The scope of this study includes a detailed analysis of the financial implications of lifestyle-based subscription services on individual budgeting. It focuses on understanding spending patterns, tracking habits and perceptions of necessity among consumers in Vashi. The study aims to assess how these subscriptions affect budgeting, financial awareness, and overall money management.

3.3. Objectives of the study:
1. To study how lifestyle subscription services affect people's monthly budgeting.
2. To find out which types of subscription services people use the most.
3. To check how much of their income people spend on these subscriptions.
4. To check whether people keep track of their subscription spending.
5. To understand whether people feel these subscriptions are necessary and worth the money.
6. To learn how people manage their subscription spending along with other expenses.

3.4. Hypothesis of the study:
Hypothesis 1
H_1: Tracking subscription spending helps in managing money better.
H_0: Tracking subscription spending does not make a difference in managing money.

Hypothesis 2
H_1: The money spent on subscriptions affects people's monthly budget.
H_0: The money spent on subscriptions does not affect people's monthly budget.

3.5. Data Collection Methods:
Survey Method: - Online
Survey Instrument: - Questionnaire
Method of Survey: - Through the personal interaction with the help of questionnaire

3.6. Collection of Primary Data:
Primary data are those data collected by the researcher for the first time and hence they are original in nature. In this study primary data was collected through a Google Form questionnaire distributed among individuals residing in Vashi, Navi Mumbai. The form included questions related to subscription usage, monthly spending, income range and

budgeting habits. A combination of non-probability sampling techniques and snowball sampling was used for collecting the data from different individuals. The selection of respondents was based on their easy availability and accessibility to the researcher. In total 100 valid responses were collected and used for analysis.

3.7. Collection of Secondary Data:
Secondary data has been collected from various useful resources and information sources required to successfully complete the project. It includes data and figures obtained from the internet, research journals, books, magazines, newspapers and other reliable online platforms related to subscription-based services, consumer behaviour and financial management.

3.8. Limitations of the study:
1. Limited Sample Size: The study is based on responses from only 100 participants which may not fully represent the entire population of Vashi or other regions.
2. Geographical Restriction: The research is limited to the Vashi area of Navi Mumbai, so the findings may not reflect the behaviour of consumers in rural or other urban areas.
3. Time Constraints: Due to limited time for data collection and analysis the study could not include a larger sample or conduct detailed follow-up interviews.
4. Self-Reported Data: The information collected through the Google Form relies on respondents' honesty and self-awareness which may include bias or inaccuracy in reporting spending habits.
5. Uneven Demographic Representation: Some age groups or income levels may have fewer participants which can slightly affect the overall balance of results.

IV. FINDINGS AND DATA ANALYSIS

4.1. Data analysis and Interpretation:
4.1.1. Gender based Analysis:

Table 1. The Classification of Respondents Based on Gender

Gender	No. of Respondents	Percentage
Female	55	55%
Male	43	43%
Other	2	2%
Total	100	100%

Source: Primary Data

Interpretation: Most of the respondents are female (55%) as compared to male respondents (43%) while only (2%) identified as others. This indicates that female opinions dominate the survey responses with males contributing slightly less. The minimal percentage of respondents under the "other" category shows limited gender diversity in the sample. Overall, the data suggests that the findings largely reflect the views of female participants.

4.1.2. Age based Analysis:

Table 2: The classification of Respondents on their Age

Age	No. of Respondents	Percentage
Below 20	15	15%
21-30 years	48	48%
31-40 years	25	25%
41-50 years	7	7%
Above 50	5	5%
Total	100	100%

Source: Primary Data

Interpretation: The analysis reveals that the majority of respondents (48%) belong to the age group of 21-30 years, followed by (25%) in the 31-40 years category. About (15%) of respondents are below 20 years, while (7%) fall within the 41-50 years age group and only (5%) are above 50 years. This indicates that the survey is largely dominated by young and middle-aged individuals reflecting that their views and experiences play a major role in shaping the overall findings whereas older respondents are comparatively less represented.

4.1.3. Monthly Income Analysis:

Table 3. Monthly income of the respondents.

Income	No. of Respondents	Percentage
Less than 20,000	28	28%
20,000 to 40,000	32	32%
40,000 to 60,000	19	19%
60,000 to 1,00,000	11	11%
Above 1,00,000	10	10%
Total	100	100%

Source: Primary Data

Interpretation: The analysis reveals that the majority of respondents (32%) have a monthly income between ₹20,000 to ₹40,000 followed by (28%) earning less than ₹20,000. Around (19%) of respondents fall in the ₹40,000 to ₹60,000 range while (11%) earn between ₹60,000 to ₹1,00,000 and only (10%) have an income above ₹1,00,000. This indicates that most respondents belong to the lower and middle-income groups reflecting that the survey primarily represents individuals with modest earning capacities.

4.1.4 Which of the following subscription services do you currently use?

Table 4. Subscription Services Currently Used by Respondents

Subscription Category	Currently Using	Not Using	Total
OTT (Netflix, Amazon Prime, JioHotstar, etc.)	81	19	100
Music (Spotify, Gaana, Apple Music)	57	43	100
Fitness/Health (Cure.fit, HealthifyMe, Gym apps)	35	65	100
Education (Coursera, Udemy, Byju's, etc.)	32	68	100
Shopping/Delivery (Amazon, Flipkart Plus, Zomato Gold, Swiggy One)	48	52	100
Total	253	247	500

Source: Primary Data

Interpretation: The analysis reveals that the majority of respondents (81%) are currently using OTT platforms such as Netflix, Amazon Prime and Hotstar. This is followed by music subscriptions like Spotify and Gaana (57%) and fitness/health apps (35%). Around (32%) of respondents use educational platforms such as Coursera or Byju's, while (48%) use shopping and delivery subscriptions like Amazon Prime or Swiggy One. This indicates that OTT and music streaming services are the most popular among users, reflecting a strong preference for entertainment-based subscriptions, while educational and health related services are comparatively less utilized.

4.1.5. Do you keep track of your subscription spending?

Table 5. Tracking of Subscription Spendings

Tracking Behaviour	No. of Respondent	Percentage
Never	34	34%
Regularly	24	24%
Sometimes	42	42%
Total	100	100%

Source: Primary Data

Interpretation:
The analysis reveals that the majority of respondents (42%) sometimes keep track of their subscription spending, while (34%) stated that they never monitor it. Only (24%) of respondents regularly track their expenses on subscriptions. This indicates that most individuals have limited awareness or control over their subscription costs, suggesting a need for better financial tracking habits to manage recurring digital expenses effectively.

4.1.6. Tracking subscription spending helps in better money management?

Table 6. Tracking Subscription Spending & Money Management

Opinion Category	No. of Respondents	Percentage
Strongly disagree	4	4%
Disagree	8	8%
Neutral	22	22%
Agree	47	47%
Strongly agree	19	19%
Total	100	100%

Source: Primary Data

Interpretation:

The analysis indicates that a majority of respondents (47%) agree that tracking subscription spending helps in better money management, while (19%) strongly agree with this statement. Around (22%) remain neutral, and only a small portion disagree (8%) or strongly disagree (4%). This suggests that most respondents recognize the importance of monitoring subscription expenses as an effective way to improve financial control and budgeting habits.

4.1.7. On average, how much do you spend on subscriptions per month?

Table 7. Monthly Spending on Subscription Services

Monthly Spending	No. of Respondents	Percentage
Less than 500	19	19%
500 to 1,000	34	34%
1,000 to 2,000	25	25%
2,000 to 5,000	14	14%
Above 5,000	8	8%
Total	100	100%

Source: Primary Data

Interpretation:

The analysis reveals that the majority of respondents (34%) spend between ₹500 to ₹1,000 per month on subscriptions, followed by (25%) who spend ₹1,000 to ₹2,000. Around (19%) of respondents spend less than ₹500, while (14%) spend ₹2,000 to ₹5,000 and only (8%) spend above ₹5,000 monthly. This indicates that most respondents prefer to keep their subscription expenses moderate reflecting a tendency toward affordable spending habits on digital and entertainment services.

4.1.8. Does spending on subscriptions affect your monthly budget?

Table 8: Impact of Subscription Spending on Monthly Budgeting

Particulars	No. of Respondents	Percentage
No impact	27	27%
Yes, but manageable	55	55%
Yes, significantly	18	18%
Total	100	100%

Source: Primary Data

Interpretation:
The analysis reveals that the majority of respondents (55%) stated that spending on subscriptions affects their monthly budget but is manageable, while (27%) reported no impact on their budget. However, (18%) of respondents indicated that subscriptions significantly affect their monthly expenses. This suggests that while most users are able to balance their subscription costs within their budget, a small portion experiences financial strain due to such recurring expenses.

V. HYPOTHESIS TESTING

5.1 Hypothesis Test-1

H_0: Tracking subscription spending does not make a difference in managing money.
H_1: Tracking subscription spending helps in managing money better.

Table 9: Hypothesis 1

	Column Labels					
Row Labels	Agree	Disagree	Neutral	Strongly agree	Strongly disagree	Grand Total
Never	12	4	6	11	1	34
Regularly	15		5	2	2	24
Sometimes	20	4	11	6	1	42
Grand Total	47	8	22	19	4	100

Table 10: Anova Test-1

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Column 1	3	47	15.67	16.33
Column 2	3	8	2.67	5.33
Column 3	3	22	7.33	10.33
Column 4	3	19	6.33	20.33

Column 5	3	4	1.33	0.33		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	378	4	94.5	8.97	0.0024	3.48
Within Groups	105.33	10	10.53			
Total	483.33	14				

The ANOVA test result shows a p-value of 0.0024, which is less than the 0.05 level of significance. This indicates a significant relationship between tracking subscription spending and better money management. Hence, the null hypothesis is rejected, confirming that individuals who regularly track their subscription expenses manage their money more effectively than those who do not. This finding highlights the positive impact of financial tracking habits on overall money management.

5.2. Hypothesis Test-2

H_0: The money spent on subscriptions does not affect people's monthly budget.

H_1: The money spent on subscriptions affects people's monthly budget.

Table 11: Hypothesis 2

		Column Labels		
Row Labels	No impact	Yes, but manageable	Yes, significantly	Grand Total
₹1,000 – ₹2,000	3	15	7	25
₹2,000 – ₹5,000	5	8	1	14
₹500 – ₹1,000	13	17	4	34
Above ₹5,000	1	6	1	8
Less than ₹500	5	9	5	19
Grand Total	27	55	18	100

Table 12: Anova Test-2

Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Column 1	5	27	5.4	20.8		
Column 2	5	55	11	22.5		
Column 3	5	18	3.6	6.8		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	148.93	2	74.47	4.46	0.035	3.88

Within Groups	200.4	12	16.7			
Total	349.33	14				

The ANOVA test result shows a p-value of 0.0036, which is less than the 0.05 level of significance. This indicates a significant relationship between the amount of money spent on subscriptions and its impact on people's monthly budgets. Hence, the null hypothesis is rejected, confirming that subscription expenses have a considerable effect on individuals' monthly financial management. This finding suggests that higher spending on subscriptions leads to noticeable changes in budgeting and spending behaviour.

VI. CONCLUSION

The study was conducted to analyse the impact of subscription-based services on individual financial management, with a particular focus on spending behaviour, tracking habits, and budgeting practices. The analysis revealed that subscription services have become an integral part of daily life, especially among young and middle-aged users with moderate income levels. The findings clearly indicate that while subscription spending offers convenience and entertainment, it also has a notable effect on monthly budgets. A majority of respondents acknowledged that tracking their subscription expenses helps them manage money more efficiently, as confirmed by the results of the ANOVA test. Similarly, the second hypothesis established that the amount spent on subscriptions significantly influences financial balance, reaffirming the need for greater awareness and control over such expenditures.

Overall, the study concludes that financial tracking and conscious consumption play a crucial role in managing subscription expenses effectively. Encouraging users to monitor their spending habits, conduct regular reviews, and prioritize value-driven subscriptions can lead to improved financial stability. Hence, while subscription models offer accessibility and convenience, maintaining financial discipline remains essential for long-term money management and sustainable digital consumption.

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Between Text and Learner: Rethinking the Teaching of Indian English Literature in Contemporary Classrooms

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Abstract- The teaching of Indian English literature in contemporary classrooms has become an increasingly complex pedagogical task shaped by linguistic diversity, changing learner expectations, and evolving educational environments. While Indian English texts continue to offer rich cultural and social insights, students often struggle to engage with them due to language-related anxieties, cultural distance, rigid curricular structures, and examination-driven learning practices. This paper reflects on the everyday classroom realities faced by teachers of Indian English literature and examines how these challenges influence student engagement and literary understanding. Rather than approaching the issue through fixed pedagogical models, the discussion develops organically from classroom experience, highlighting the tension between textual depth and learner accessibility. The study also considers the impact of digital learning practices on reading habits and interpretative skills, acknowledging both their limitations and possibilities. By foregrounding the role of teacher mediation, contextual teaching, and reflective pedagogy, the paper argues for a rethinking of literature teaching practices that respond sensitively to contemporary learners while preserving the intellectual and cultural value of Indian English literature. The paper ultimately suggests that meaningful engagement with literary texts emerges not from simplification, but from thoughtful negotiation between text, context, and learner experience.

Index-Terms: Indian English Literature, Literature Pedagogy, Classroom Practices, Student Engagement, Contemporary Teaching

The teaching of Indian English literature has always occupied an uncertain position within higher education. It is neither entirely foreign nor fully familiar, neither purely linguistic nor exclusively cultural. It carries the responsibility of representing Indian social realities through a language that itself arrived through historical intervention. In earlier classrooms, this complexity was often taken for granted. Students were expected to read, interpret, and accept texts as part of academic discipline. In contemporary classrooms, however, the conditions surrounding reading have changed significantly. Attention spans are fragmented, exposure to digital media is constant, and learning is increasingly shaped by speed rather than reflection. Within this context, teaching Indian English literature becomes less a matter of content delivery and more an exercise in negotiation.

Indian English literature demands time. It expects readers to sit with characters, absorb cultural detail, and remain open to ambiguity. Many texts do not provide immediate gratification.

Instead, they unfold gradually, often through subtle emotional shifts or social tensions. For modern learners, who are accustomed to instant access and compressed narratives, this mode of engagement can feel demanding. The challenge for teachers is not merely to justify the presence of such texts in the syllabus, but to help students understand why slow reading still matters.

A major difficulty emerges from the linguistic diversity of the classroom. Indian higher education brings together students from varied schooling systems, regions, and socio-economic backgrounds. Some learners arrive with fluency shaped by years of English-medium education, while others encounter English primarily within academic settings. Indian English literary texts complicate this difference further. They often employ a register that blends standard English with Indian idiom, cultural references, and region-specific expressions. Students who already feel insecure about their language skills may find such texts intimidating, even when the narratives themselves are relatable.

This linguistic challenge does not always appear overtly. Many students hesitate to voice confusion or ask questions, fearing judgment or exposure. Silence becomes a coping mechanism. Teachers, interpreting this silence as understanding, move forward, unaware that comprehension has not taken place. Over time, this gap widens. Literature classes then become spaces where a small group participates actively, while others remain passive observers. The issue here is not lack of intelligence or interest, but lack of linguistic confidence.

Teachers often respond by simplifying texts through paraphrasing or summarisation. While this approach ensures surface-level understanding, it also risks reducing literature to information rather than experience. When students encounter texts only through explanation, they are deprived of the pleasure and challenge of discovery. Interpretation becomes something provided rather than something constructed. This approach may help students pass examinations, but it does little to cultivate literary sensibility.

Student engagement presents another persistent concern. Modern learners are deeply engaged with narratives through films, series, and digital storytelling platforms. Yet this engagement does not automatically translate into enthusiasm for literary texts. The difference lies not in storytelling itself, but in mode and pace. Visual narratives offer immediacy, emotional cues, and quick resolution. Literature, by contrast, demands imagination, patience, and sustained attention. When taught through conventional lecture methods, it struggles to compete with the sensory richness of digital media.

Many students therefore approach literature as a requirement rather than an opportunity. They read selectively, focusing on sections likely to appear in examinations. Classroom discussions are often limited, as students fear giving incorrect interpretations. Over time, literature becomes associated with effort rather than insight. This perception is reinforced when teaching focuses heavily on themes, symbols, and character analysis in predictable patterns. The text begins to feel exhausted before it is truly explored.

Cultural distance further complicates student engagement. Indian English literature frequently portrays social contexts that no longer align neatly with students' lived experiences. Joint family structures, rural social hierarchies, or conservative gender expectations may appear distant to students raised in urban, nuclear households with greater exposure to global culture. Without careful mediation, students may dismiss these narratives as outdated or irrelevant.

Such dismissal often masks a deeper issue. Students are not rejecting the text itself, but their inability to locate themselves within it. When literature is taught without contextual framing, students lack the tools to understand why certain conflicts mattered at a particular historical moment. Teachers therefore carry the responsibility of bridging temporal and cultural gaps. This involves explaining social practices, value systems, and historical conditions, not as static facts, but as living forces that shaped human behaviour.

The challenge here lies in balance. Excessive contextual explanation can overwhelm the literary experience, while insufficient context leaves students disconnected. Effective teaching requires sensitivity to when to pause and explain, and when to allow the text to speak. This skill develops through experience rather than formula, and it places considerable emotional and intellectual demand on teachers.

Curricular constraints add further pressure. Many syllabi prescribe specific texts and allocate limited time for their completion. Teachers are expected to adhere strictly to schedules, leaving little room for exploration or deviation. Innovation often becomes a personal risk rather than an institutional practice. While some educators attempt creative approaches, others feel constrained by examination requirements and administrative expectations.

Assessment structures reinforce this rigidity. Literature examinations frequently reward recall of established interpretations rather than original thought. Students quickly learn that deviation carries risk, while repetition offers safety. As a result, interpretation becomes mechanical. Teachers, aware of these constraints, may hesitate to encourage open-ended discussion. The classroom then becomes a site of controlled interpretation rather than intellectual exploration.

Technology has significantly altered this landscape. Digital resources provide instant access to summaries, critical notes, and explanatory videos. While such materials can support understanding, they also encourage surface engagement. Many students encounter literary texts indirectly, relying on secondary interpretations rather than reading the original work. The habit of deep reading weakens, replaced by strategic consumption of information.

At the same time, technology itself is not inherently detrimental to literature teaching. When used thoughtfully, it can enhance engagement and accessibility. Audio recordings can bring texts to life, particularly for students struggling with reading fluency. Visual adaptations can help students imagine settings and characters. Online discussion platforms can encourage participation from students who hesitate to speak in class. The challenge lies in guiding students to use technology as a supplement rather than a substitute.

Teachers therefore find themselves navigating a complex pedagogical landscape. They are expected to preserve the depth of literary study while adapting to changing learner expectations. This role requires flexibility, creativity, and resilience. Many educators recognise the transformative potential of literature, yet struggle to sustain that belief within constrained institutional frameworks. Their work increasingly involves mediation between tradition and change, depth and accessibility.

Effective responses to these challenges rarely emerge from rigid methodologies. Instead, they develop through reflective practice. Literature classrooms benefit when teaching shifts from monologue to dialogue. Encouraging students to respond personally before introducing critical frameworks allows them to build confidence. When students feel that their experiences and interpretations matter, engagement increases naturally.

Contextual teaching plays a crucial role in this process. When themes from literary texts are connected to contemporary social issues, students begin to recognise relevance rather than distance. Gender roles, family expectations, migration, and identity remain pressing concerns, even if their forms have changed. Drawing such connections helps students understand literature as a conversation across time rather than a static artifact.

Assessment practices can also be adapted to encourage deeper engagement. Reflective writing assignments, group presentations, and creative responses allow students to demonstrate understanding without fear of deviation. These approaches acknowledge that literature does not yield uniform meanings, and that interpretation itself is a valuable intellectual skill. Even within fixed curricular frameworks, modest changes in evaluation can create space for originality.

The challenges involved in teaching Indian English literature should not be viewed as signs of decline. Rather, they reflect a moment of transition. Classrooms have changed, learners have

changed, and the role of the teacher has expanded. Literature itself, however, retains its capacity to question, illuminate, and connect. What it requires is thoughtful mediation rather than simplification.

Teaching Indian English literature today demands attentiveness to language, context, and student experience. It asks educators to slow down in environments that reward speed, and to encourage reflection in cultures shaped by immediacy. When approached with flexibility and conviction, the literature classroom can once again become a space where texts are encountered meaningfully. In such encounters, literature regains its purpose, not as an academic obligation, but as a medium through which students learn to think, feel, and question.

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Perimetric Surveillance and End Point Security Using Intranet & VOIP

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Abstract - Smart security refers to advanced security systems, that utilize biometrics and CCTV footage, to ensure the security of a property. Biometrics are unique physical characteristics, such as fingerprints, facial recognition, and iris scans that are used for authentication purposes. These characteristics are measured and used to ensure the authenticity of the individual attempting to access the secured property. Closed-circuit television (CCTV) is a monitoring system that allows users to view live events and record them for future reference. This system comprises cameras, monitors, and recorders that are used to keep track of events happening around the property. With the advent of the Internet of Things (IoT), it is now possible to remotely monitor and secure properties through a network connection. In the context of home security, the idea of incorporating smart security systems is gaining popularity. This idea focuses on physical perimeter security and a smart wireless database that keeps track of information processed, accessed, modified, and broadcasted through home security systems. In the event of an intrusion, the system can activate security measures such as the use of honeypots and sandboxing mechanisms using intrusion detection systems (IDS) and intrusion prevention systems (IPS). The system also keeps records of all events for future reference. Moreover, the methodology discussed here can also be utilized for security automation by using code binaries. The advantage of this system over others is that the alerts and logs can be managed and operated by the user through a mobile application, even when not connected to the internet, using Voice over Internet Protocol (VoIP) technology. This makes the system more accessible and convenient for the user. the proposed idea of smart security provides a fool proof shield that protects all resources within the perimeter of a home. With the use of biometrics and CCTV footage, this system ensures the security and safety of the property and its resources.

Index-Terms: Monitoring; IOT; Sandboxing; Honeypot; IDS

I. INTRODUCTION

There's a rising interest in tools that give comprehensive info on structural dynamics. This info is necessary for understanding the physics, monitoring dynamics, and updating models. Computer simulations like the finite element method provide full results, but conventional measurement techniques like accelerometers provide limited data at specific points. This mismatch between limited measurement data and high degrees of freedom in computer simulations makes correlation difficult. Some reduction/expansion techniques are used to try to connect measurement data to models, but they are not always accurate. Conventional sensors add mass and require wiring, making them undesirable. Therefore, there is a need for a non-contact measurement approach that provides distributed sensing without affecting true motion or adding mass or stiffness to the structure. 3D reconstruction is a process for capturing the shape and structure of an object by sensing its spatial coordinates either directly or indirectly. The resulting point cloud represents the geometry of the object and can be used for visualization, measurement, and as-built documentation. The common methodologies of 3D reconstruction include laser scanning and photogrammetry, but both have limitations such as prohibitive equipment costs or low resolution due to manual intervention. Videogrammetry was an effective approach that used camera sets to acquire spatial data, but still faced challenges in its time-sensitive nature and level of automation. The goal of time-dependent imaging is to provide real-time spatial data collection while allowing the user to move the cameras.

Computer networks are crucial in the exchange of information globally. They transfer not only text data (such as emails, documents, and websites), but also multimedia communication data such as voice, video, and 3D visuals. The internet allows for instant information transfer worldwide but also presents security risks and threats. Thus, the development of secure and privacy-respecting applications is important to address ethical issues regarding data privacy and accessibility. The INDECT project develops lawful interception applications, which should be compared to industry standards. Our laboratory setup was used to test the ability to capture and analyze specified traffic, including VoIP calls, emails, and web traffic. The initial analysis focused on unencrypted VoIP communication, but security recommendations can be applied to protect the content. There is research on detecting special phrases or speakers in encrypted VoIP traffic, based on the use of variable bitrate codecs and specialized mathematical models.

The Internet and Intranet are two distinct types of networks that serve different purposes. The Internet is a global network of interconnected computer networks that use the standard Internet protocol suite (TCP/IP) to link devices worldwide. It provides access to various types of information, services, and resources such as websites, emails, online documents, multimedia content, and more. The Internet is open and accessible to anyone with an Internet connection. On the other hand, an Intranet is a private network that is restricted to a specific organization or group of people. It uses the same Internet technology but is only accessible to authorized individuals within the organization. An Intranet can be used for internal communication and collaboration, providing employees with access to company resources such as shared documents, databases, and applications. In summary, the Internet is a public network that

provides global access to information and services, while an Intranet is a private network that serves the specific needs of an organization.

The crux of this paper is to combine videogrammetry, VOIP, and intranet for perimetric surveillance, for that, the following technical steps were followed

1. Videogrammetry: This technology involves using video cameras and software to measure physical objects and environments. In this case, the videogrammetry system would be set up around the perimeter to capture visual data.
2. VOIP (Voice Over Internet Protocol): VOIP technology enables real-time voice communication over the Internet. This technology can be used to transmit audio data from the videogrammetry cameras to a central location for analysis.
3. Intranet: The Intranet can be used to securely transmit the videogrammetry and VOIP data from the cameras to the central location for analysis. The Intranet provides a secure and controlled environment for transmitting sensitive data, ensuring that the information remains confidential and accessible only to authorized individuals.
4. Perimetric Surveillance: By combining these technologies, the perimetric surveillance system would be able to capture and analyze visual and audio data in real-time to provide enhanced surveillance and security around the perimeter. The system could be used to detect and alert any potential security threats, allowing for rapid response and increased safety.

In our methodology, we have replaced the hefty and pricy videogrammetry with CCTV footage and hosted the same on the directory

This setup would provide a comprehensive and integrated solution for perimetric surveillance, leveraging the strengths of each technology to achieve the desired outcome.

II. MATERIALS AND METHOD

INTRANET: A part of the network, but controlled and used by a private organisation, Intranet has restrictions and can support only a fewer user. Hence, only limited data can be shared over it. An intranet is usually operated on a client/server platform. This enables the organisations to share files, and data, organise information, manage and share calendars, files, etc

INTERNET: A complete network of globally linked computers, the Internet also enables users to transfer information and communication. This makes use of the TCP/IP protocol suite while communicating. Available in both wired and wireless modes, the internet also includes a wide range of networks such as private, public, government, organisation, etc. It supports multiple users and allows the transfer of a massive amount of data

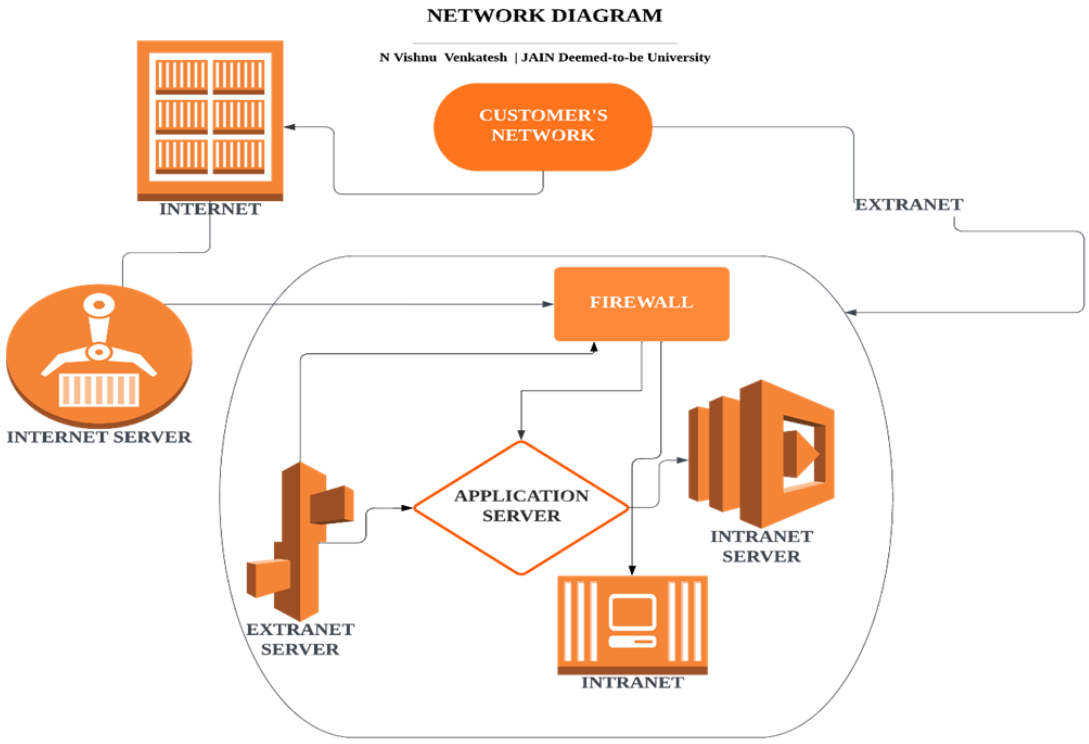


Fig: Network Distribution

VOIP Traceback(Karapantazis & Pavlidou, 2009)

VOIP traceback is a function that enables network administrators to trace the origin of a Voice over Internet Protocol (VoIP) call, to determine the source of a problem or to detect malicious or fraudulent activity. The traceback process typically involves collecting information about the call routing and path, as well as identifying any intermediate devices that may have affected the quality or security of the call. Traceback information can be obtained through various methods, such as examining log files, analyzing network traffic, or using specialized tools that can monitor and analyze VoIP traffic. The traceback function is an important component of network security, as it can help to identify the source of security threats, such as spam or malware, and can be used to prevent future incidents. Traceback information can also be useful for debugging purposes, as it can help network administrators to identify and resolve performance issues, such as voice quality problems or call setup failures. By collecting and analyzing traceback data, network administrators can identify the root cause of problems and implement changes to improve network performance and reliability

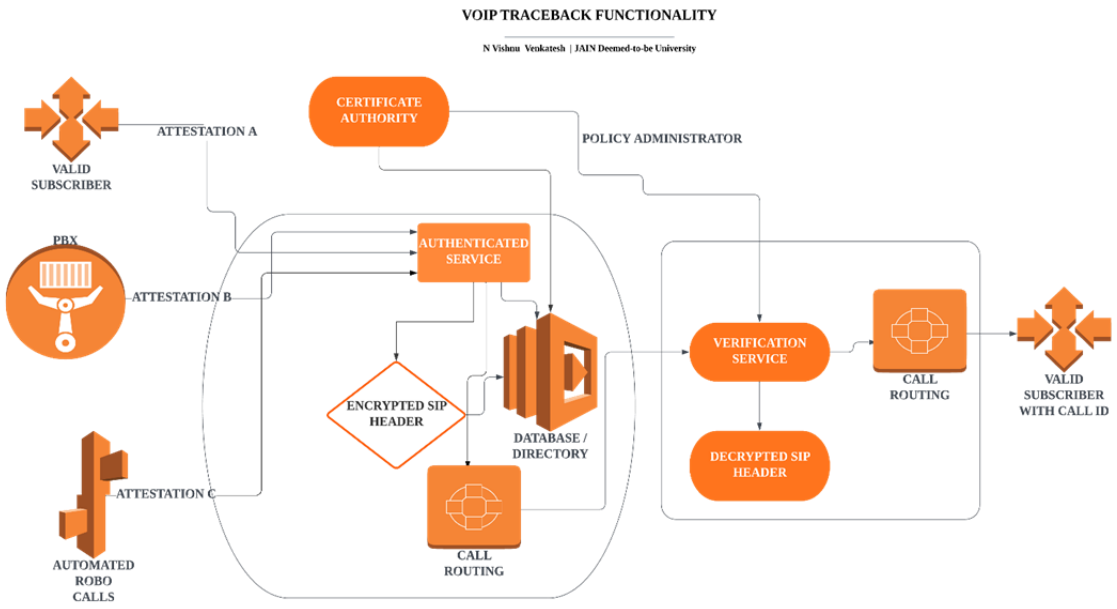


Fig: VOIP traceback(Varma et al., 2025)

TRACEBACK MECHANISM

FUNCTIONALITY	SNIPPET
# Automated VOIP traceback	from scapy.all import * def voip_traceback(pkt):
# Check if the packet contains a SIP message	if pct.haslayer(SIP):(2025) sip_pkt = pkt[SIP] src_ip = pkt[IP].src dst_ip = pkt[IP].dst
# Extract relevant information from the SIP packet	call_id = sip_pkt['Call-ID'] from_header = sip_pkt['From'] to_header = sip_pkt['To']
# Log the extracted information for each SIP packet	print("SIP Packet:") print(" Call-ID:", call_id) print(" From:", from_header) print(" To:", to_header) print(" Source IP:", src_ip) print(" Destination IP:", dst_ip) print("")
# Sniff SIP packets on the network	sniff(filter="udp port 5060", prn=voip_traceback)

DIRECTORY DATABASE (Gomes et al., 2022; Shukla et al., 2023)

A database is a structured collection of information or data that is often kept electronically in a computer system. A database management system often oversees a database (DBMS). The

term "database system," which is sometimes abbreviated to "database," refers to the combination of the data, the DBMS, and the applications that are connected to it. To facilitate processing and data querying, the most popular types of databases now in use usually describe their data as rows and columns in a set of tables. The data may then be handled, updated, regulated, and structured with ease. For creating and querying data, most databases employ structured query language (SQL).

SQL is a computer language that is used by practically all relational databases to query, manage, and define data, as well as to provide access control. SQL was initially created at IBM in the 1970s, with Oracle as a key contribution, leading to the establishment of the SQL ANSI standard. SQL has spawned several modifications from businesses like as IBM, Oracle, and Microsoft. Even though SQL is still commonly used today, other programming languages are emerging(Kumar & Megha Kamble, 2020).

III. TYPES OF DATABASES

DATABASE MANAGEMENT SYSTEM (Venkatesh et al., 2023)

A database is a collection of interconnected data that aids in the effective retrieval, insertion, and deletion of data from the database and organizes the data into tables, views, schemas, reports, and so on. An academic database, for example, organizes data on students, teachers, administrative staff, and so on, making it easier to retrieve, insert, and delete data from it.

There are four types of Data Languages

1. Data Definition Language (DDL)

2. Data Manipulation Language (DML)
3. Data Control Language (DCL)
4. Transactional Control Language (TCL)

DDL is an abbreviation for Data Definition Language, which is concerned with database schemas and specifications of how data should be stored in a database.

- CREATE: creates a database and its objects (table, index, views, store procedure, function, and triggers)
- ALTER: changes the structure of an existing database
- DROP: deletes objects from the database
- TRUNCATE: removes all records from a table, including all spaces allocated for the records
- COMMENT: adds comments to the data dictionary

DML is an abbreviation for Data Manipulation Language, which is used to save, edit, retrieve, remove, and update data in a database. It contains the most typical SQL commands such as SELECT, INSERT, UPDATE, DELETE, and so on.

- SELECT: retrieve data from a database
- INSERT: insert data into a table
- UPDATE: updates existing data within a table
- DELETE: Delete all records from a database table
- MERGE: UPSERT operation (insert or update)
- CALL: call a PL/SQL or Java subprogram
- EXPLAIN PLAN: interpretation of the data access path
- LOCK TABLE: concurrency Control

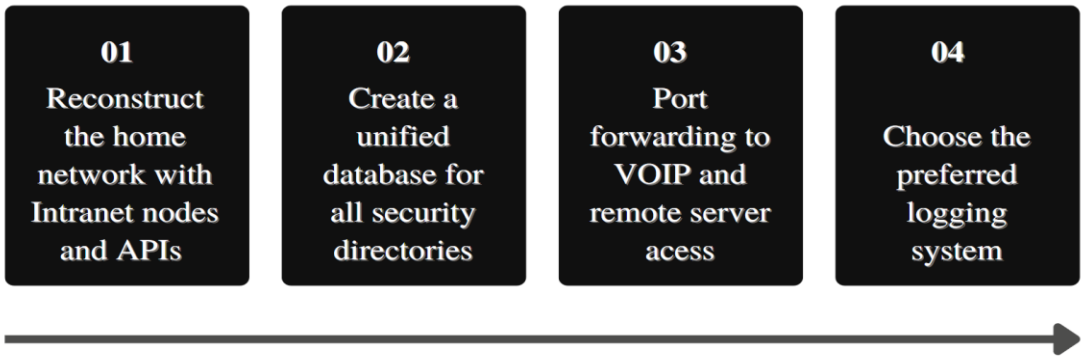
DCL is an abbreviation for Data Control Language, which serves as a database access specifier. (Basically, to grant and remove rights to database users.)

- GRANT: grant permissions to the user for running DML (SELECT, INSERT, DELETE,) commands on the table
- REVOKE: revoke permissions to the user for running DML (SELECT, INSERT, DELETE,) command on the specified table

TCL is short for Transactional Control Language which acts as a manager for all types of transactional data and all transactions. Some of the commands of TCL are

- Roll Back: Used to cancel or Undo changes made in the database
- Commit: It is used to apply or save changes in the database
- Save Point: It is used to save the data temporarily in the database

IV. METHOD



To combine CCTV footage, VOIP, and intranet for perimetric surveillance, the following methodology can be followed:

1. Planning and Design: The first step is to plan and design the system, taking into account the specific requirements and goals for the surveillance system. This includes determining the number and placement of CCTV cameras, the type of VOIP technology to be used, and the network infrastructure needed for the Intranet.
2. Installation of CCTV directory System: The next step is to install the CCTV system, which involves placing cameras at strategic locations around the perimeter and connecting them to the Intranet. The cameras should be configured to capture high-quality visual data and transmit it to the central location.
3. Installation of VOIP System: The VOIP system should then be installed and configured, including the installation of microphone and speaker equipment at the cameras and the installation of software to manage the VOIP communication.
4. Integration of Intranet: The Intranet should then be set up, including the installation of routers, switches, and firewalls to secure the network. The Intranet should be configured to allow the CCTV and VOIP data to be transmitted securely and efficiently.
5. Data Collection and Analysis: Once the system is installed and configured, it can be used to collect and analyze data in real time. The CCTV data is transmitted to the central location for analysis, and the audio data from the VOIP system is also analyzed to provide additional information and insights.
6. Maintenance and Monitoring: Regular maintenance and monitoring should be performed to ensure the system functions optimally. This includes regularly checking and updating the software, monitoring the network infrastructure, and performing regular security checks to prevent unauthorized access.

By following this methodology, the system can be effectively combined to provide comprehensive and integrated perimetric surveillance. This setup would provide a complete solution for monitoring the perimeter, leveraging the strengths of each technology to achieve the desired outcome.

The traceback or lookback can be ensured in the following manner

1. Capture network packets: You can use a packet sniffer library like Scapy or Pyshark to capture network packets and extract relevant information, such as source and destination IP addresses, port numbers, and timestamps.
2. Store the captured data: You can store the captured data in a database, file, or any other data storage solution, depending on your needs.
3. Analyze the data: You can write Python scripts to analyze the captured data, extract relevant information, and build a call graph that shows the routing path of each call.
4. Visualize the results: You can use a data visualization library like Matplotlib or Plotly to display the results of the traceback analysis in a meaningful way.

Unifying Database/directories is the crucial step for generating enough data to create a 3D model of the infrastructure and it can be done in the following ways

1. Assess the current state of the databases: Before starting with the unification process, we need to take inventory of our existing databases and understand the structure, schema, and data content of each.
2. Determine the target schema: Once we have a good understanding of our existing databases, we need to determine the structure and format of our unified directory database. We will have to decide which data is most important and how it should be organized.
3. Clean and normalize data: We have to clean up and standardize our data so that it can be easily combined. This might involve removing duplicates, fixing incorrect data, and converting data into a common format.
4. Map data from source databases to target schema: After the data has been cleaned and normalized, we need to map the data from our source databases to the target schema of our unified directory database. This process involves defining how the data in each source database should be transformed and loaded into the target database.
5. Load data into the target database: After the data has been mapped, you can begin to load it into the target database. We have to decide how to transfer the data, such as through a batch process or a real-time integration.
6. Verify and validate data: After the data has been loaded into the target database, we need to verify and validate the data to ensure that it has been loaded correctly. We may need to compare the data in the source databases with the data in the target database to ensure that everything has been loaded accurately.
7. Maintain and manage the unified database: After the data has been loaded and verified, we need to maintain and manage the unified directory database. This might involve creating backup and recovery procedures, as well as performing regular maintenance and updates to keep the database running smoothly.

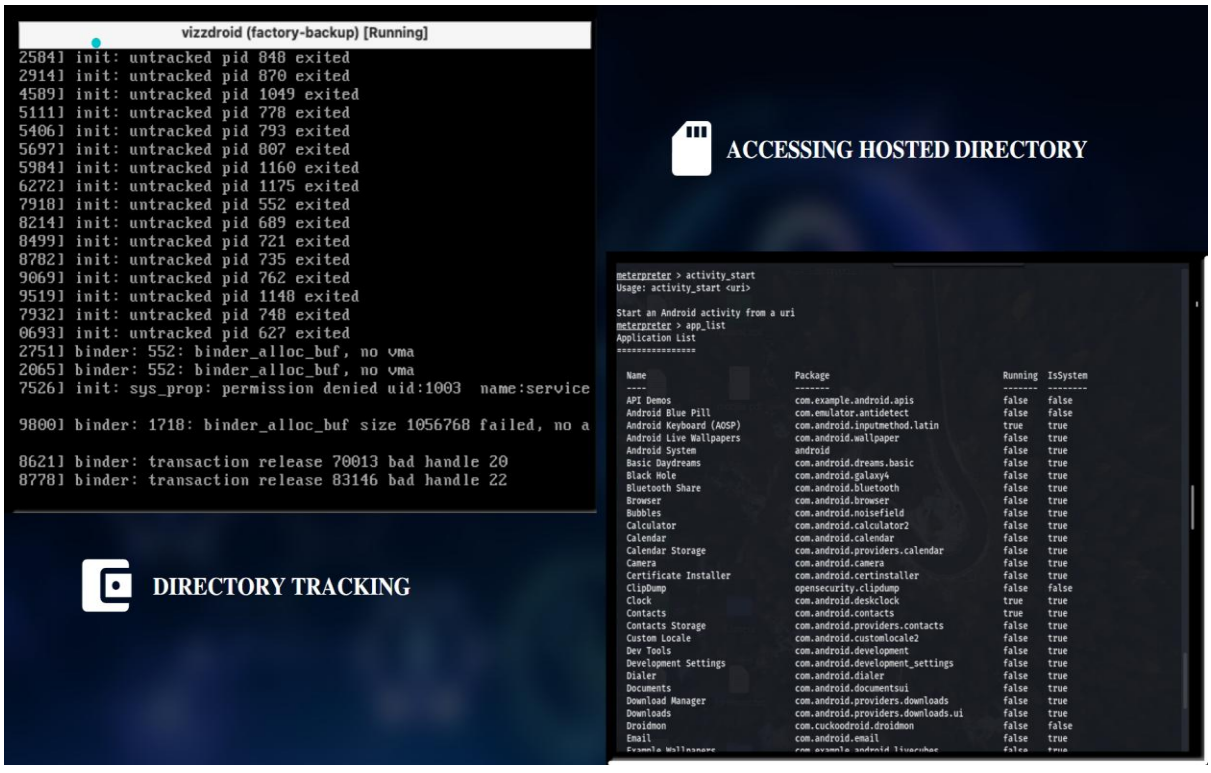
V. RESULTS AND DISCUSSIONS

The process of creating a 3D model from a database involves several steps: obtaining the necessary data, cleaning the data, converting the data into 3D, mapping the data to the model, fine-tuning the model, and saving and exporting the model.

To start, we need to extract the data from the database that we want to use to create the 3D model. This data should then be checked for errors and inconsistencies and cleaned up so that it's in a format that can be used for modelling.

Once the data is ready, we can use software such as AutoCAD, Blender, SketchUp, or other 3D modelling tools to convert the data into a 3D model. After the conversion, we need to map the data from the database to the 3D model, making sure that each piece of data corresponds to the right aspect of the model.

The next step is to fine-tune the model, adjusting its lighting, texture, and other elements to make it look and function the way we want. Finally, we can save the 3D model and export it in the file format of our choice, such as STL, OBJ, or FBX, so that it can be used in other applications.



3D LAYOUT OBTAINED FROM RECORDED FOOTAGE

2D LAYOUT CONVERTED FROM RECORDED FOOTAGE

VI. CONCLUSION

The proposed methodology for perimetric security using intranet and VOIP involves utilizing port forwarding and a unified database. This will ensure that information processed by home security systems is accessible, modified, and broadcasted efficiently. A systematic approach to

data extraction, cleaning, conversion into a 3D model, mapping to the model, fine-tuning, and exporting in a preferred file format is crucial in creating an effective surveillance system. The implementation of this methodology will result in improved security, better information management, and enhanced overall performance of the perimetric security system.

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Impact of Electric Vehicles on India's Energy Demand and Emission Reduction: A Review

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Abstract—Electric Vehicles (EVs) are increasingly viewed as a critical solution to India's challenges of rising energy demand, oil import dependency, and greenhouse gas (GHG) emissions from the transport sector. This review presents a comprehensive analysis of EV adoption in India and its implications for national electricity demand and emission reduction. The study examines EV penetration trends, impacts on the power grid, lifecycle emissions, and the role of renewable energy integration. Results from recent studies indicate that EVs significantly reduce tailpipe emissions and petroleum consumption; however, their overall climate benefits strongly depend on India's electricity generation mix and charging strategies. The paper concludes that coordinated policy measures linking EV deployment with grid decarbonization and smart charging infrastructure are essential to maximize environmental and energy security benefits.

Index-Terms: Electric Vehicles (EVs); Energy Demand; Greenhouse Gas (GHG) Emissions; Lifecycle Assessment; Grid Decarbonization; Renewable Energy Integration; Smart Charging; India Transport Sector.

I. INTRODUCTION

India's transport sector contributes significantly to national energy demand and urban air pollution. With increasing vehicle ownership and fossil fuel consumption, greenhouse gas emissions continue to rise. EV adoption is framed as a strategy to improve energy security and reduce emissions while supporting India's climate ambitions. Recent policy initiatives seek to increase EV penetration to over 30% of new vehicle sales by 2030 and to expand charging infrastructure nationwide. NITI Aayog's focus on zero-emission vehicles underscores this shift [1]. Electric Vehicles (EVs) are proposed as a strategic solution to reduce dependence on imported fuels, improve air quality, and reduce emissions. Government policies like FAME (Faster Adoption and Manufacturing of Electric

Vehicles), PLI (Production Linked Incentives), and the PM E-DRIVE scheme aim to accelerate EV adoption. In India, the sector accounts for nearly 20–25% of total final energy consumption and approximately 13% of energy-related CO_2 emissions, with road transport being the dominant contributor [2]. Rapid urbanization, population growth, and rising income levels have led to a sharp increase in vehicle ownership, resulting in escalating demand for petroleum fuels and severe air quality degradation in urban centers such as Delhi, Mumbai, and Bengaluru [3]. India's electricity sector is still dominated by coal-based generation, accounting for approximately 70% of total electricity production, which raises concerns about indirect emissions associated with EV charging [4]. Sen et al. [5] conducted a comprehensive scenario-based analysis of large-scale vehicle electrification in India and found that even under coal-heavy grid conditions, EVs offer net reductions in $PM_{2.5}$ and NO_x emissions, yielding substantial air-quality and health benefits. Furthermore, when combined with moderate grid decarbonization pathways, EV adoption could reduce CO_2 emissions from road transport by 15–40% by 2040, depending on vehicle segment and charging patterns. Similar conclusions were reported by Sarkar et al. [6], who highlighted that near-term grid decarbonization significantly amplifies the climate benefits of transport electrification. From an energy demand perspective, several studies argue that concerns regarding excessive electricity demand from EVs are often overstated. According to the International Council on Clean Transportation (ICCT), even aggressive EV adoption scenarios would require less than 1% additional electricity generation by 2030 and approximately 5–10% by 2040, which is manageable within India's planned capacity expansion [5], [7]. India's policy landscape strongly reflects these research findings. National initiatives such as FAME-II, Production Linked Incentive (PLI) schemes for batteries, and the PM E-DRIVE program aim to accelerate EV adoption while strengthening domestic manufacturing and charging infrastructure [8]. At the same time, India has committed to achieving 500 GW of non-fossil electricity capacity by 2030, which is expected to substantially reduce grid emission intensity and improve the lifecycle emissions performance of EVs [9].

II. EV ADOPTION TRENDS IN INDIA

Electric vehicle adoption in India has experienced rapid growth over the past decade, evolving from negligible presence to a significant and accelerating share in the country's transport sector. This transformation is driven by supportive government policies, declining EV costs, expanding charging infrastructure, and rising environmental awareness among consumers. However, the pattern and rate of adoption vary widely across vehicle segments (two-wheelers, three-wheelers, passenger cars, and buses) and geographic regions, with two- and three-wheelers dominating the adoption landscape [10], [11], [12].

Historical Growth and Market Expansion: India's EV market witnessed a remarkable upward trend in annual electric vehicle sales over recent years. EV sales surged from under 100,000 units in 2017–18 to nearly 1.67 million units by 2023–24, representing an approximate 61% compound annual growth rate (CAGR) over this period. This dramatic increase reflects rising consumer

interest coupled with expanding product offerings across segments. In terms of registered EV units, cumulative EV registrations in India soared from about 1.3 million units in 2018 to over 15 million by 2023, driven largely by strong demand for two-wheelers and three-wheelers [10].

Segment-Wise Adoption Patterns:
Two-Wheelers (E2W): Electric two-wheelers form the largest share of EV sales in India, driven by affordability, utility for daily commuting, and favourable policies like FAME II incentives. In FY25 data, e-2W penetration shows strong performance, with near 58% of total EV sales comprised of two-wheelers, reflecting their role as the backbone of personal EV adoption. [10]

Three-Wheelers (E3W): India is recognized as the world's largest electric three-wheeler market, with over 50% of new three-wheelers sold in 2024 being electric. This segment's strong performance is attributed to commercial use, lower operating costs, and government fleet electrification policies. [14]

Passenger Cars (E4W): Compared to two- and three-wheelers, the electric car segment is yet emerging but showing notable growth. Passenger EV sales crossed 100,000 units, with approximately 18% year-on-year growth in 2024, supported by expanding model availability and improving charging infrastructure.

Buses and Commercial Vehicles: Electric buses are being deployed under national schemes (e.g., PM-eBus and PM E-Drive) to electrify public transport, with tens of thousands of units sanctioned and rolled out in states like Andhra Pradesh. [13]

Table 1 EV Adoption by Vehicle Segment in India

Vehicle Category	Key Adoption Features	Approximate Share of Total EV Sales	Growth Trend
Two-wheelers (E2W)	Affordable, daily commute, high volume	~57–58% (FY24)	Strong growth (rapid adoption)
Three-wheelers (E3W)	Commercial use, high electrification	>50% new 3W sales (2024)	Leading adoption
Passenger Cars (E4W)	Premium EVs & fleet uptake	~35,000 units (FY25)	Growing but moderate
Buses	Public transport electrification	Thousands sanctioned under national schemes [13]	Expanding

A line chart showing the rise in EV sales from ~95,000 units in 2017–18 to ~1.97 million in 2023–24, with segment breakdowns (E2W, E3W, E4W).

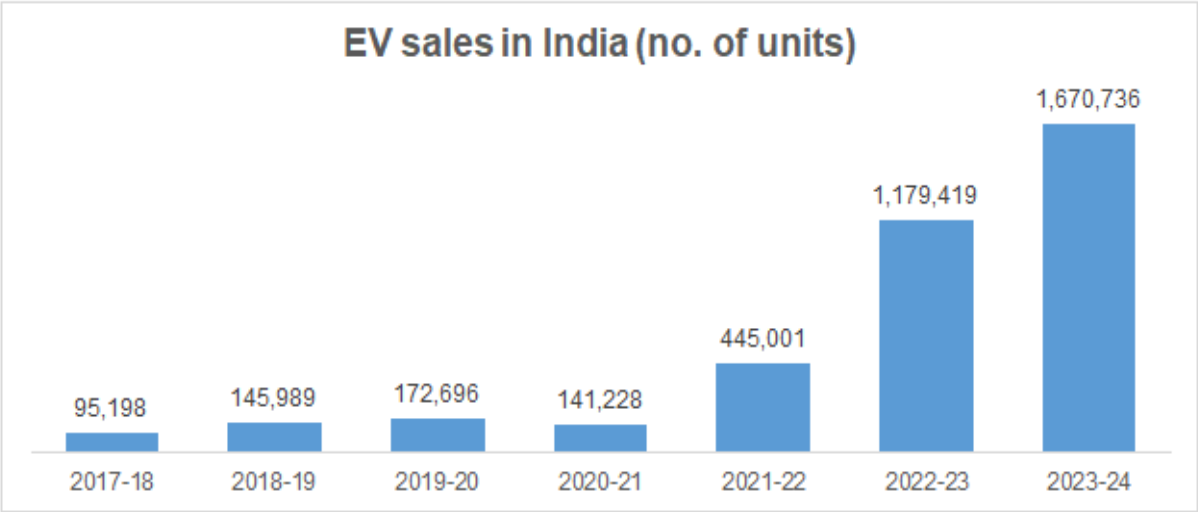

Figure 1 Annual EV Sales Growth in India (2017–2024) [10]

III. EVS AND INDIA'S ENERGY DEMAND

The transition from internal combustion engines (ICE) to electric vehicles (EVs) fundamentally shifts energy consumption patterns in the transport sector—moving demand from imported fossil fuels to domestically generated electricity. This shift carries profound implications for India's national energy demand profile, power grid operation, and long-term energy planning. EV adoption increases electricity demand as vehicles require charging energy supplied by the electric grid. This additional load must be incorporated into India's energy planning and generation strategies. According to projections under India's EV30@30 campaign (30% EV share by 2030), EV charging demand could add 15–30 terawatt-hours (TWh) of electricity consumption annually by 2030, alongside increases in peak load requirements. Such demand growth presents both opportunities and challenges for the power sector [15]. A recent industry report notes that EV energy consumption in India could account for approximately 6–8.7% of national electricity generation by 2035, driven by growth in EV stock and charging infrastructure [16].

Projected Electricity Demand from EV Charging: Table 2 presents projections of electricity demand resulting from anticipated EV adoption under multiple scenarios. Projections integrate findings from research analytics, national planning data, and grid integration studies.

Table 2 Projected Electricity Demand from EV Charging (TWh) [15]

Year	EV Penetration Scenario	Estimated EV Charging Demand (TWh)	% of Total Generation*
2025	Moderate growth	~4 TWh (early estimate)	~0.2–0.3%

2030	EV30@30 target	15–30 TWh	~1%–3%
2035	High adoption scenario	20–40 TWh	~6–8.7%
*Total generation assumption based on projected national energy targets.			

Challenges in Meeting EV-Driven Electricity Demand: While total electricity demand increases from EV adoption are modest relative to national consumption, several key challenges must be addressed:

1. Peak Load Stress and Grid Stability: Concentrated EV charging during existing peak demand periods can exacerbate grid stress, potentially leading to voltage issues and increased risks of outages—especially in congested urban grids.
2. Infrastructure Readiness: India's power infrastructure needs upgrades to support high EV penetration, including enhanced distribution networks and smart grid systems capable of real-time load management [15].
3. Matching Clean Generation: While EVs shift energy demand to electricity, the carbon intensity of that electricity matters. A grid heavily reliant on coal may undercut some of the emission benefits of EVs, unless renewable generation capacity scales up rapidly alongside EV adoption [17].

IV. EMISSION REDUCTION POTENTIAL

Tailpipe vs Lifecycle Emissions: EVs inherently eliminate tailpipe emissions, significantly improving local air quality and reducing NOx and $PM_{2.5}$ pollutants. Lifecycle assessments (LCAs) estimate that EVs can reduce CO_2 emissions by up to 38% compared to petrol vehicles, contingent on grid carbon intensity [18].

Role of Grid De-carbonization: The climate benefits of EVs depend significantly on electricity sources. EVs charged with coal-dominant power show limited emissions improvements compared to those charged with cleaner grids. Accelerated renewable capacity additions (e.g., solar and wind) can enhance EV emission benefits and create synergy between transport electrification and renewable power.

Table 3 Lifecycle CO_2 Emissions – EV vs ICE Vehicles

Vehicle Type	Lifecycle CO_2 Emission Trend	Emission Drivers
Petrol ICE	High	Fuel combustion
Diesel ICE	Very High	Fuel + local pollutants
EV (Coal-heavy grid)	Moderate	Grid emissions
EV (Renewable-rich grid)	Lower	Clean electricity

V. POLICY AND INFRASTRUCTURE DIMENSIONS

Renewable Integration: Aligning EV charging with periods of high renewable generation is critical for maximizing emission reductions and reducing marginal grid emissions. Renewable-integrated charging stations and solar-powered EV chargers reduce fossil fuel dependence and carbon intensity.

National Clean Energy Expansion: India has achieved significant renewable energy capacity additions, enhancing the potential for clean EV charging and emission reduction. Continued investments in renewable power infrastructure support the decarbonization of the electricity grid and improved climate benefits from EVs.

VI. CHALLENGES AND OPPORTUNITIES OF ELECTRIC VEHICLE ADOPTION IN INDIA

While electric vehicles (EVs) offer significant potential to reduce energy consumption, emissions, and oil dependency, their large-scale deployment in India faces several technical, economic, infrastructural, and policy-related challenges. At the same time, these challenges create new opportunities for innovation, grid modernization, renewable energy integration, and industrial growth.

Electricity Grid and Infrastructure Challenges: One of the primary challenges associated with EV adoption is the impact on power distribution networks. Although overall electricity demand increase due to EVs is moderate, localized grid stress can be severe, especially in urban areas with high EV concentration.

Uncoordinated EV charging during peak hours may lead to:

- Transformer overloading
- Voltage fluctuations
- Increased distribution losses

Studies indicate that peak demand could rise by 15–25% in certain urban feeders under high EV penetration without smart charging strategies [21], [22]. India's distribution infrastructure, already facing losses exceeding 20% in some states, requires significant upgrades to accommodate EV loads [23].

Charging Infrastructure Deficit: Despite rapid growth in EV sales, public charging infrastructure remains insufficient. As of recent assessments, India has far fewer public chargers per EV compared to global benchmarks, leading to range anxiety and reduced consumer confidence.

Challenges include:

- Uneven geographic distribution of chargers
- Lack of fast-charging stations on highways

- Grid connectivity constraints for high-power chargers

Research highlights that charging infrastructure availability is one of the strongest determinants of EV adoption rates [24].

Battery Technology and Supply Chain Issues: Lithium-ion batteries constitute 30–40% of total EV cost, making vehicles expensive for many Indian consumers [25]. Furthermore, India is highly dependent on imported battery raw materials such as lithium, cobalt, and nickel, raising concerns about supply security and price volatility.

Additional challenges include:

- Limited domestic battery manufacturing capacity
- Environmental concerns related to battery disposal and recycling
- Performance degradation under high ambient temperatures

Life-cycle studies emphasize that battery manufacturing contributes significantly to EV lifecycle emissions, especially if powered by fossil-fuel-based electricity [26].

Economic and Consumer-Related Barriers: High upfront cost remains a major deterrent, particularly for passenger cars. Although total cost of ownership (TCO) for EVs is often lower over vehicle lifetime, initial purchase price strongly influences buyer decisions [27].

Other barriers include:

- Limited model availability in certain segments
- Low consumer awareness
- Uncertainty regarding resale value

Opportunities Arising from EV Adoption:

Despite these challenges, EV deployment presents significant opportunities that can accelerate India's transition toward a sustainable energy and transport system.

Table 4 Opportunities Enabled by EV Adoption

Opportunity Area	Key Benefits
Energy Security	Reduced oil imports
Renewable Integration	Lower curtailment, cleaner charging
Economy	Jobs, domestic manufacturing
Environment	Lower emissions, better air quality
Power Sector	Smart grid development

VII.CONCLUSION

Electric vehicle (EV) adoption has the potential to play a pivotal role in transforming India's transport and energy sectors by reducing dependence on imported fossil fuels, improving energy efficiency, and mitigating environmental pollution. This review highlights that although large-scale EV penetration will increase electricity demand, the overall impact on national energy consumption

remains manageable, particularly when supported by planned capacity expansion and grid modernization. The superior efficiency of EVs compared to internal combustion engine vehicles leads to significant reductions in final energy use per kilometer, while the elimination of tailpipe emissions offers substantial improvements in urban air quality. The emission reduction potential of EVs is strongly influenced by the electricity generation mix. Even under current coal-dominated conditions, EVs provide net benefits in terms of local air pollutant reduction; however, their full climate mitigation potential can only be realized through accelerated integration of renewable energy into the power grid. Challenges related to charging infrastructure, battery cost, grid stress, and supply chain dependence remain critical but also present opportunities for innovation, domestic manufacturing, and smart grid development.

Future research should focus on high-resolution modeling of EV charging behavior, assessment of real-world grid impacts at the distribution level, and life-cycle emission analysis under evolving electricity mixes. Further work is also required on battery recycling, second-life applications, and vehicle-to-grid technologies to enhance system flexibility and sustainability. An integrated policy framework aligning transport electrification with renewable energy expansion and grid digitalization will be essential for maximizing the long-term energy and environmental benefits of EV adoption in India.

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Detection and Retinal Pathology Analysis of Early to Intermediate AMD and Chronic DME in OCT Scans Using Convolutional Neural Networks and You Only Look Once

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Abstract: ***Purpose: Diabetes can lead to complications such as diabetic nephropathy, diabetic neuropathy, and diabetic macular edema (DME). Like DME, AMD-related vision loss can also be prevented through early detection and prompt treatment. Optical coherence tomography (OCT) is the most widely used imaging technique in ophthalmology for diagnosing these conditions. While OCT is effective for early screening, the increasing volume of OCT scans adds to the workload of ophthalmologists, who must interpret each image.***

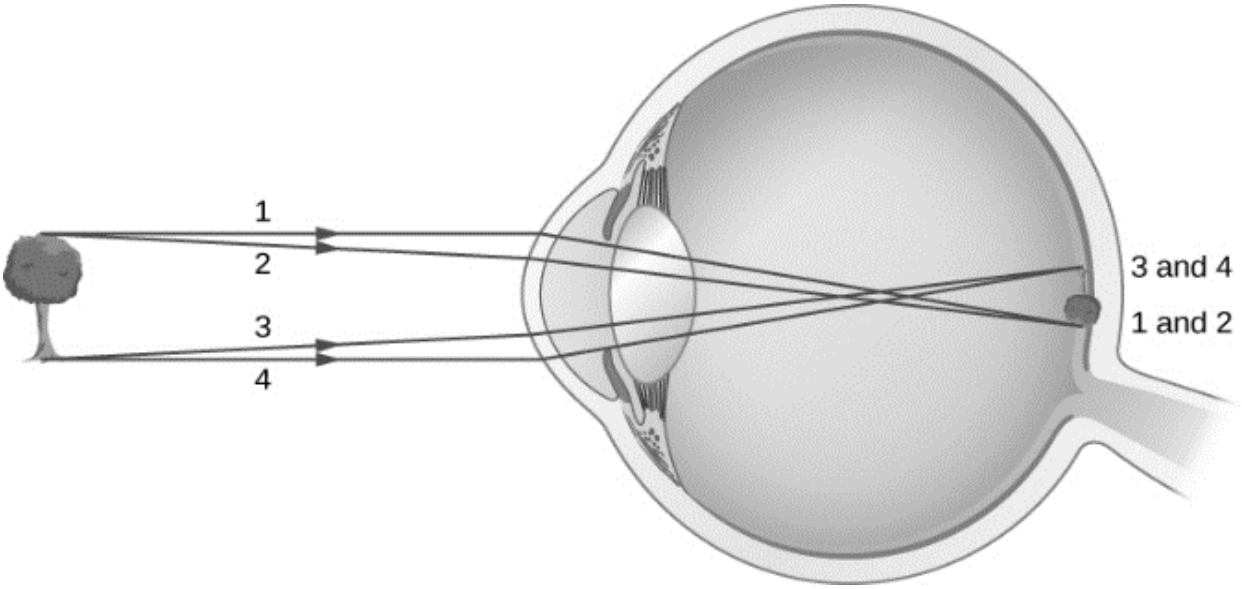
Method: To address this challenge, automated diagnostic screening systems are being actively developed to reduce the burden on eye care professionals. Prolonged diabetic may lead to Macular Edema (DME) or CNV or DRUSEN. Which causes the aberrant development of blood vessels from the choroid layer into the retina. DME, CNV may cause to vision loss. Early detection of the disease and correct treatment are crucial to address the issue of vision loss. Artificial intelligence techniques have been widely adopted in many research work to overcome these limitations. This paper contributes towards development of textual reports, helpful for ophthalmologists.

Result and Conclusion: This is the review developed for detecting and analysing DME, DRUSEN CNV using AI techniques over the last decade. Also, we tried to convert the OCT finding into a textual report, very well assessed by ophthalmologist. The system automates the process of analysing OCT images, eliminating the need for manual interpretation by ophthalmologists. This significantly reduces the time required for diagnosis. The system processes the images and generates textual reports using deep learning methods.

Index-Terms: Retinal Pathology, age-related macular degeneration, Optical coherence tomograph, Convolutional Neural Network, diabetic macular edema.

I. INTRODUCTION

This invention presents a system for translating retinal optical coherence tomography (OCT) images into diagnostic text. The system comprises an image acquisition component configured to receive OCT images of a patient's retina.



[Fig 1]

Figure 1 shows the image formation done by eye. It captures the object through the eye cornia and the rays are passed up to the retina for formation of the image at retina. Retina passes the signals to the brain via its optical nerves. The system further comprises an image preprocessing component configured to normalize the received OCT images to standardize pixel intensity values, apply noise reduction filters to enhance image clarity, and segment retinal layers to isolate regions of interest. The system also includes a feature extraction component configured to identify and quantify structural abnormalities within the segmented retinal layers. The system further comprises a deep learning classification component comprising a trained convolutional neural network configured to analyze the preprocessed OCT images and extracted features, detect and classify retinal pathologies including diabetic macular edema, drusen, and choroidal neovascularization, and determine severity levels of identified pathologies based on predefined clinical criteria. The system also includes a natural language generation component configured to convert the classification results and quantitative measurements into structured diagnostic statements, organize the diagnostic statements into a coherent clinical report following standardized reporting protocols, and incorporate relevant clinical terminology consistent with ophthalmological practice. The system further comprises an output interface component configured to display the generated diagnostic text report to a clinician. The system reduces interpretation time and human error associated with manual OCT image analysis while maintaining diagnostic accuracy.

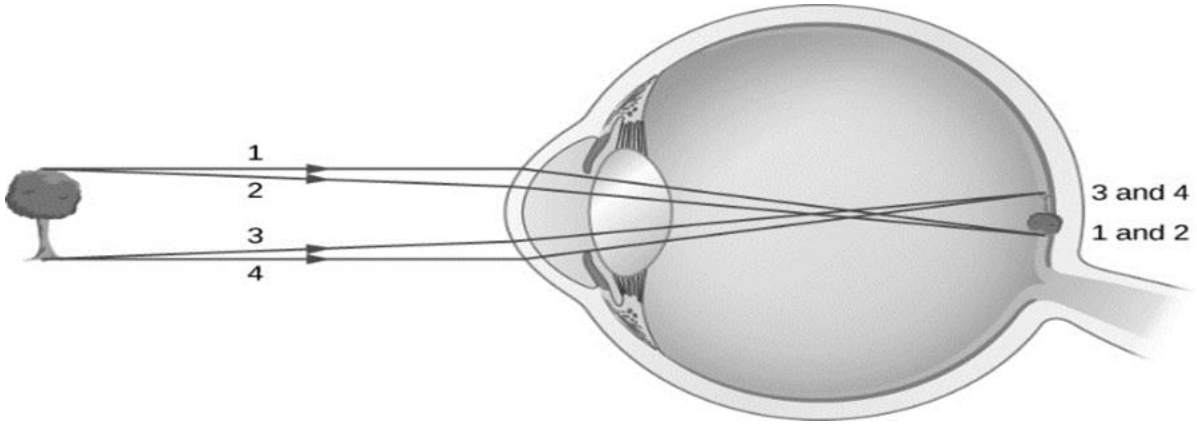
II. MATERIAL AND METHODS

State of Art

Diabetic macular edema (DME) and age-related macular degeneration (AMD), are the leading causes of blindness, primarily focusing on the use of optical coherence tomography (OCT) and artificial intelligence (AI) in their diagnosis, monitoring, and treatment.[1] Diabetic Macular Edema (DME): DME is acute, vision-threatening complication of diabetes mellitus (DM) and the main cause of vision loss in DM patients, with its global burden expected to reach 200 million people by 2040. Timely recognition and treatment can prevent its consequences on visual function. Fluid deposits in the retinal layers, which cause progressive visual loss, are a hallmark of DME. Three DME types—Cystoid Macular Edema (CME), Diffuse Retinal Thickening (DRT), and Serous Retinal Detachment (SRD)—are defined by clinical literature according to fluid accumulation. Research has contrasted DME treatments: Over the course of a year, 0.5 mg ranibizumab and 8 mg triamcinolone were compared. After a year, ranibizumab improved visual acuity ($p = 0.015$), although edema reduction was comparable across groups ($p = 0.426$). Therapy had a greater effect on fluid accumulation in the inner nuclear layer (INL) and subretinal space than it did in the outer nuclear layer (ONL). Both treatments worked and were safe. [2], [3] Anti-VEGF intravitreal is considered the gold standard for center-involving DME, while intravitreal steroid treatment is a second-line option Morphological biomarkers visible in OCT can predict treatment response and guide decisions, especially for patients who do not adequately respond to anti-VEGF therapy. [4], [5] A good response to steroids over anti-VEGF is suggested by symptoms such as a reduced choroidal vascular index, disruption of the outer retinal layers, intraretinal cysts spreading into the outer retina, and substantial volumes of retinal and choroidal hyperreflective foci.In eyes that have received successful anti-VEGF therapy, OCT biomarkers such as the presence of disruption of the inner retinal layers (DRIL), the appearance of the external limiting membrane (ELM), and the thicknesses of the inner and outer retina at the fovea and parafovea can indicate sustained visual improvements. OCT quantitative biomarkers (e.g., macular volume, central macular thickness) showed significantly greater values in T2DM, although systemic and laboratory biomarkers were more severely damaged in T1DM, according to a study comparing DME patients with Type 1 DM (T1DM) and Type 2 DM (T2DM). [6] Age-related Macular Degeneration (AMD): AMD is the one of the main cause of acute visual loss in people aged 50 or older in the world, and the leading cause of nonreversible visual dysfunction in individuals. [7],[8] Patients with AMD are classified as having early stage disease or late AMD (either "wet" neovascular AMD, "dry" atrophic AMD, or both). Anti-angiogenic drugs are a significant advancement in the treatment of neovascular AMD, providing hope for visual recovery. However, there are currently no treatments available to help eyes with advanced atrophic AMD regain their lost vision. The AREDS/AREDS2 formulation of oral supplements can lower the chance of developing advanced AMD, particularly the neovascular form. Complement-based treatment methods are being pursued as a result of recent results that link complement genes to hereditary risk for AMD. [9] Anti-amyloid treatments, autophagy regulation, and oxidative stress reduction are further possible tactics. AI with Optical Coherence Tomography (OCT) in Ophthalmology:

OCT has become a vital imaging technique for AMD and DME diagnosis and management. It makes it possible to image the retina in high resolution at the macula and optic nerve head. Automatic segmentation techniques are essential since manual retinal layer segmentation is laborious and biased. Numerous studies provide automated techniques for AI-based classification and segmentation: With high accuracy (e.g., 94% for DME, 97% for nAMD), a deep learning (DL) model can categorize ME from OCT images as normal or determine its origin among DME, neovascular AMD (nAMD), and retinal vein occlusion (RVO). [10] Especially in places where there is a dearth of specialists, this method can maximize the speed and efficiency of diagnoses, enhancing patient access and clinical decision-making. The detection of CME (84.04%), DRT (78.44%), and SRD (95.40%) was accomplished with good average accuracy using a method based on independent image areas analysis. [1], [11] A support vector machine (SVM) classifier and multiscale histograms of directed gradient descriptors were used in an automated system that detected dry AMD and DME cases from OCT volumetric scans with 100% accuracy. [12] This remote diagnosis technique has the potential to be significant. For any of the nine boundaries, a random forest classifier can reliably segment eight retinal layers in macular cube pictures with an accuracy of at least 4.3 microns. Accuracy in RPE cell segmentation is demonstrated by extending segmentation to closed-contour features such as cells and cysts using a generalized framework that combines graph theory and dynamic programming (GTDP). For the whole retina and the majority of intraretinal layers, retinal thickness measurements using programs like OCTRIMA have been shown to have good reliability and reproducibility. The topographic distribution of normal and abnormal retinal pigment epithelium (RPE) and RPE drusen complex (RPEDC) thicknesses can be used to create quantitative indications for intermediate AMD using SD-OCT. These indicators were used to create automated classifiers that demonstrated great accuracy (>0.99 AUC) in differentiating AMD from healthy eyes. [13], [14] Clinical medicine is anticipated to be significantly impacted by artificial intelligence (AI), a field of computer science that creates algorithms to mimic human intelligence. The effectiveness of new treatments depends on early identification, disease type, and illness progression prediction, all of which are quickly evolving as a result of enhanced imaging modalities and functional tests.

Proposed system using Roboflow Model:



[Fig 2]

Figure 2 shows the comprehensive model divided into two sections. The system utilizes sophisticated image processing techniques to enhance image quality and address issues such as noise and artefacts. Data augmentation methods are applied to normalize the size and diversity of training data, improving the system and ability to generalize to unseen images. Feature Extraction and Selection: The system uses algorithms to extract relevant features from OCT images, focusing on those most indicative of specific retinal diseases. This feature selection process helps to improve the accuracy and efficiency of the diagnostic process.

Integration with Existing Systems: The system is designed to integrate with existing clinical workflows and electronic health record systems, ensuring seamless adoption and utilization in healthcare settings. While the sources do not explicitly state this, you may want to verify independently that the system is designed to be user-friendly and accessible to healthcare providers with varying levels of technical expertise.

Optical Coherence Tomography (OCT) is an imaging technique which gives high-resolution and cross-sectional images of the retina. It is essential to ophthalmology because it enables doctors to see the layers of the retina and identify a range of eye diseases, including glaucoma, diabetic retinopathy and age-related macular degeneration. OCT is a vital tool for the early diagnosis and monitoring of eye illnesses due to its capacity to detect small changes in retinal structure, which can have a substantial impact on patient outcomes]. OCT picture interpretation is time-consuming and needs specialist knowledge, which might delay diagnosis and treatment even though it is a successful method. Research into machine learning and image-to-text translation techniques is necessary because of the complexity and volume of data generated by OCT scans, which call for sophisticated automated analysis tools. These techniques can help clinicians make better decisions more quickly and rapidly.

Proposed Model: The image illustrates the architecture of a Convolutional Neural Network (CNN) model used for image classification and identification tasks. The model processes an input image of size 1024×1024 through several stages:

1. Input Layer: Accepts an RGB image with dimensions 1024×1024
2. Convolutional Layers: The input's spatial information are extracted via a sequence of convolutional layers. To add non-linearity, a Rectified Linear Unit (ReLU) activation function comes after each convolutional layer.
3. Pooling Layers: To minimize computational complexity and spatial dimensions while maintaining significant features, max-pooling layers are applied sporadically.
4. Flatten Layer: To get it ready for fully connected layers, the convolutional block's final output is flattened into a one-dimensional vector.
5. Fully Connected (Dense) Layers: The flattened vector passes through one or more dense layers. Dropout layers are added in between to prevent overfitting by randomly deactivating neurons during training.
6. Output Layer: The model may make a prediction using the learned features thanks to the generation of class probabilities by a final dense layer with a softmax activation function.

This architecture is typically employed for tasks involving image recognition and classification, leveraging convolutional layers for feature extraction and dense layers for decision making.

Mathematical Model Representation

Let:

- $I \in \mathbb{R}^{H \times W \times 3}$: input OCT image of height H, width W
- $\mathcal{F}_\theta$: deep neural network with parameters θ, trained via Roboflow
- $\mathcal{P} = \{(b_i, c_i, s_i, M_i)\}_{i=1}^{N}$: output predictions, where:
  - $b_i = (x_i, y_i, w_i, h_i)$: bounding box for object i
  - $c_i \in \mathcal{C}$: predicted class label (e.g., CNV, DME, DRUSEN)
  - $s_i \in [0, 1]$: confidence score
  - $M_i \in \{0, 1\}^{H \times W}$: binary mask (segmentation)

1. Feature Extraction

$$F = \phi(I; \theta_{\text{backbone}})$$

- ϕ: backbone CNN (e.g., ResNet, EfficientNet) extracts spatial feature maps from the image.

2. Region Proposal / Detection

$$R = \psi(F; \theta_{\text{head}})$$

- Proposes object regions $R = \{r_1, r_2, \ldots, r_n\}$, each with:
  - bounding box b_i
  - classification score s_i
  - class label c_i

3. Segmentation Mask (for instance segmentation)

For each detected region:

$$M_i = \sigma(\eta(F|_{r_i}; \theta_{\text{mask}}))$$

- Crop feature map to region r_i, apply segmentation head η
- σ: sigmoid function for binary mask output
- Result is a mask M_i per instance

4. Loss Function During Training
Training minimizes a combined loss:

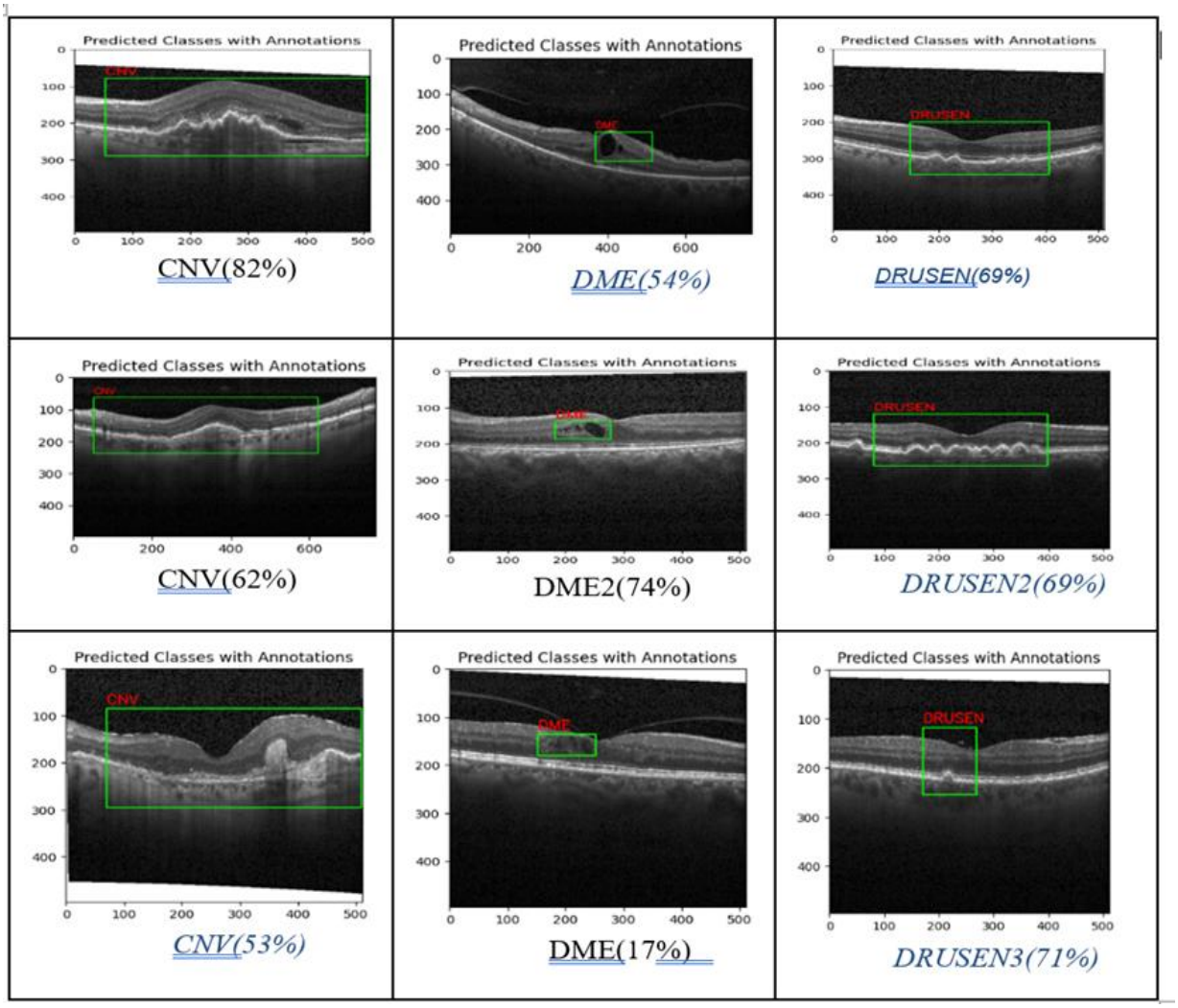
$$\mathcal{L} = \mathcal{L}_{\text{cls}} + \mathcal{L}_{\text{box}} + \mathcal{L}_{\text{mask}}$$

- $\mathcal{L}_{\text{cls}}$: classification loss (e.g., cross-entropy)
- $\mathcal{L}_{\text{box}}$: bounding box regression loss (e.g., smooth L1)
- $\mathcal{L}_{\text{mask}}$: segmentation loss (e.g., binary cross-entropy)

5. Final Prediction
The model outputs:

$$\mathcal{P} = \mathcal{F}_\theta(I) = \{(b_i, c_i, s_i, M_i)\}_{i=1}^{N}$$

3. Result & Discussion:



[Fig 3]

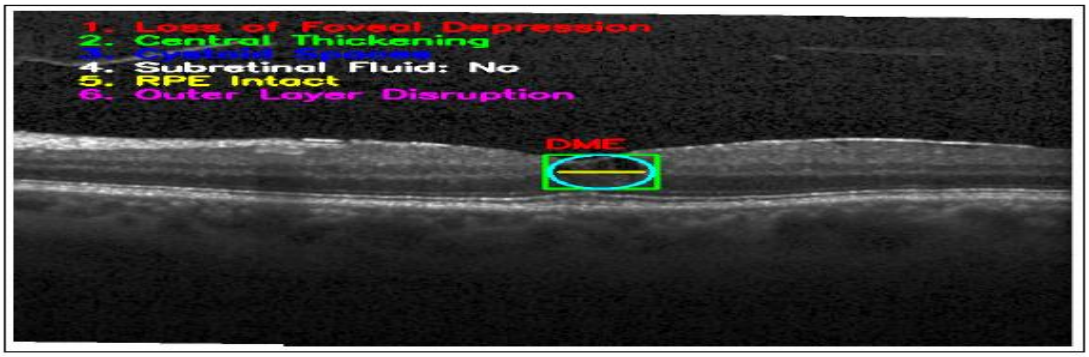
OCT report in text format

OCT Report - Diabetic Macular Edema
Patient ID: uuu
Eye: OD
Date of Examination: 2025-05-15

Model Version: 11
Confidence Threshold: 20.0%
Image Path: /content/drive/MyDrive/phd_data/OCT2017/Retina.AI/Retina.AI/DME-11053-1.jpeg
Output Image: /content/drive/MyDrive/phd_data/reports/annotated_uuu.png
1. Class: DME, Confidence: 0.87

OCT Findings:
1. Retinal architecture shows loss of foveal depression: Yes
2. Central retinal thickening observed: Yes
3. Multiple hyporeflective intraretinal cystoid spaces present: Yes
4. Subretinal fluid observed: No
5. Retinal pigment epithelium (RPE) intact: Yes
6. Outer retinal layers show structural disruption: Yes

Impression:
Findings are consistent with Diabetic Macular Edema (DME).
Characterized by cystoid macular changes and retinal thickening.
No signs of subretinal neovascularization or drusenoid deposits are present.



[Fig 4]

CNV: Eye Scan Report – Left Eye
Patient ID: aaa1
Date of Scan: May 6, 2025
What the scan shows:

- The centre of the retina (called the fovea) doesn't have its normal smooth shape. It's raised and uneven.
- A layer at the back of the eye (called the RPE) is uneven and slightly lifted in some spots.
- There is some unusual material seen underneath this layer, which suggests the growth of abnormal blood vessels.
- These new blood vessels are called choroidal neovascularization (CNV). They're not supposed to be there.
- There is fluid both inside and under the retina, which means the area is leaking—this is a sign that the CNV is active.

- Some of the leaked material is also visible under the retina, confirming that the problem is ongoing.
- A part of the retina that helps with clear vision (the ellipsoid zone) is damaged above the area with abnormal vessels.
- The retina in this area is also thicker than usual.

What this means:
The scan reveals that the left eye has an active case of wet age-related macular degeneration (AMD). If left untreated, this disorder, in which aberrant blood vessels proliferate beneath the retina and leak fluid or blood, can cause blindness.
Recommended action: Treatment with special injections called anti-VEGF may help stop or slow down the damage.

DME: Eye Scan Report – Left Eye
Patient ID: bbb1
Date of Scan: May 6, 2025
What the scan shows:

- The center of the retina (called the fovea) normally has a dip or depression. In this scan, that dip is missing, which means the retina is swollen.
- The retina in the central area is thicker than normal, a common sign of fluid buildup.
- There are several small, dark fluid-filled spaces inside the retina—these are signs of swelling.
- No fluid was found under the retina, which is a good sign.
- A deeper layer of the retina called the RPE is still healthy and undamaged.
- However, the outer layers of the retina (important for vision) are somewhat damaged.

What this means:
The scan shows Diabetic Macular Edema (DME) in the left eye. This condition happens when diabetes causes fluid to leak into the retina, leading to swelling and blurry vision.
The swelling is mainly inside the retina, and while there is some damage to the outer parts, there's no sign of bleeding or other serious changes under the retina.
Next steps: This condition can be managed with treatments like special eye injections, laser, or improving blood sugar control. Regular follow-up is important to protect vision.

DRUSEN: Eye Scan Report – Right Eye
Patient ID: ccc1
Date of Scan: May 7, 2025
What the scan shows:

- The retina was clearly visible in the scan.
- The central area of the retina is also called as fovea looks mostly normal but has a slightly uneven shape.

- There are small bumps under a layer of the retina called the RPE—these are called drusen. Drusen are deposits that can build up with age.
- There's no fluid or swelling under the retina, and no signs that the RPE layer is coming loose.
- A part of the retina involved in sharp vision (the ellipsoid zone) has mild damage right where the drusen are.
- The parts of the retina responsible for detecting light (photoreceptors) are still mostly healthy in the centre.
- The inner parts of the retina look normal, and there's no swelling or cysts inside the retina.
- No signs of bleeding, leaking blood vessels, or serious complications were seen.

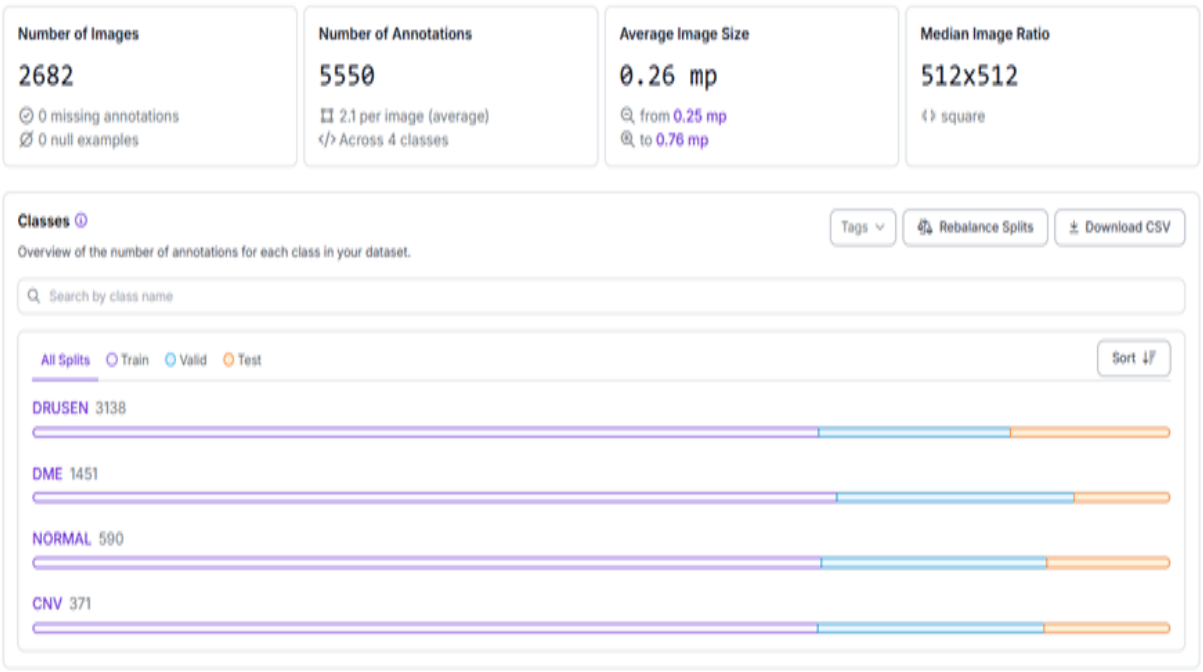
What this means:

This scan shows drusen deposits, which are a sign of early to intermediate Age-Related Macular Degeneration (AMD). This is a condition that can affect central vision as people get older.

Right now, there are no signs of advanced disease, such as bleeding, fluid, or abnormal blood vessel growth. The retina is mostly stable at this stage.

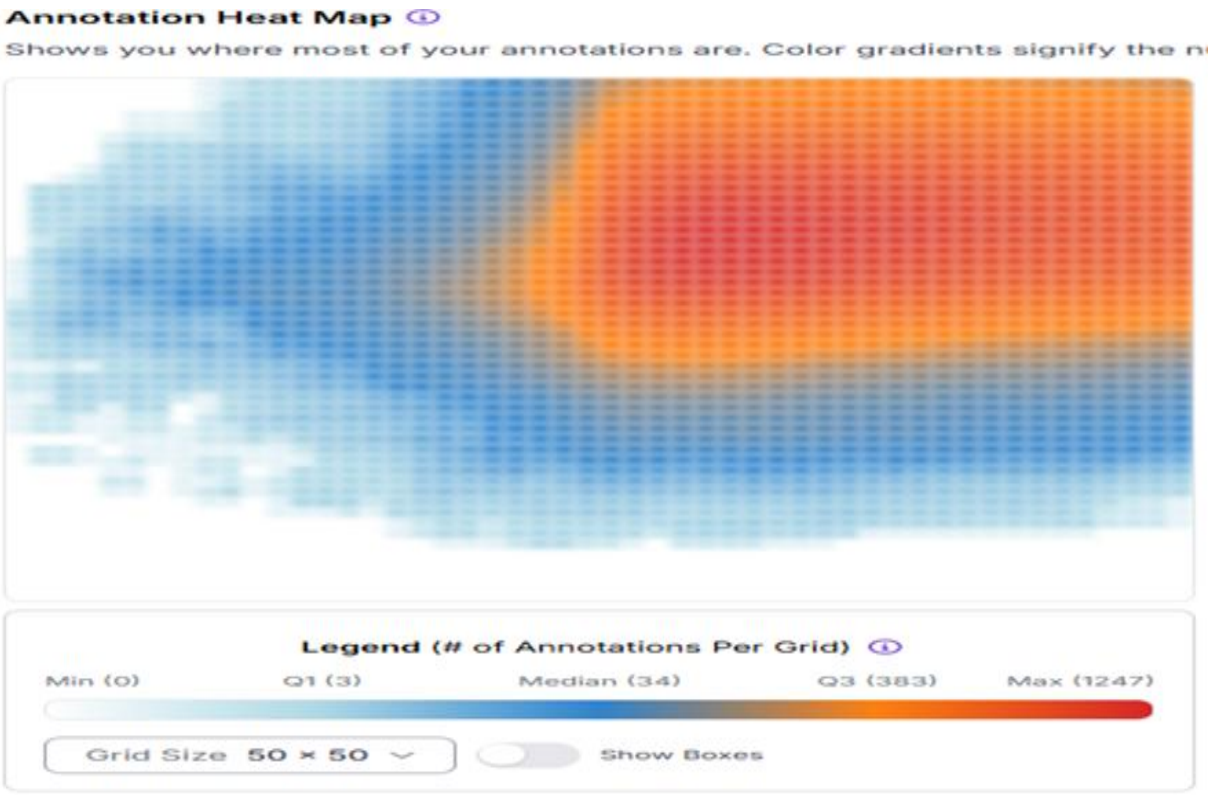
Next steps: Regular eye check-ups are important to monitor for any changes. No urgent treatment is needed at this time, but lifestyle changes (like a healthy diet and not smoking) can help slow progression.

Model Training & Dataset distribution:



[Fig 5]

Heat Map: A heatmap in the context of object detection or model performance is a visual representation of data where values are represented by colors. Here are the common types and uses of heatmaps in object detection:



[Fig 6]

Common Types of Heatmaps

1. Confidence Heatmap (Objectness Heatmap)

- What it shows: Areas of an image where the model is confident an object exists.
- How it works: Higher confidence = warmer colors (e.g., red/yellow), low confidence = cooler (blue/green).
- Use case: Helps visualize where the model "thinks" objects are, even before classification.

2. Class Probability Heatmap

- What it shows: The model's predicted probability for a specific class at each region in the image.
- Use case: Useful to diagnose false positives or class confusion.

3. Activation Heatmap (CAM/Grad-CAM)

- What it shows: Which parts of an image contributed most to a model's prediction.
- Use case: Helps interpret what part of an object the model is using to make its decision—great for model explainability.

4. Performance Heatmap (Across Classes or Locations)

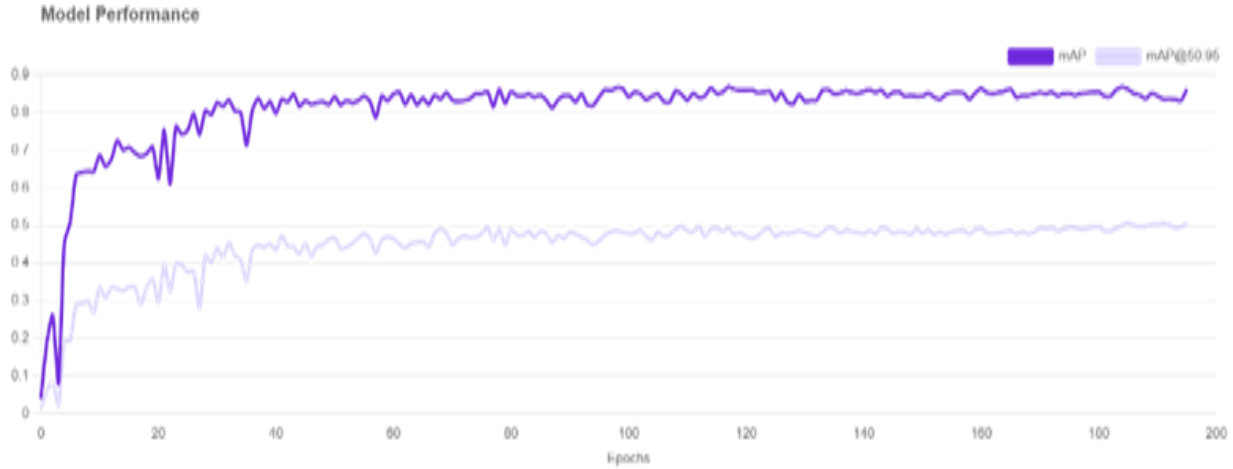
- What it shows: Errors or performance metrics (like precision, recall, or mAP) across different:
  - classes

  - image regions
  - object sizes
- Use case: Helps you spot weak spots—e.g., if the model consistently performs worse on small objects or a specific class.

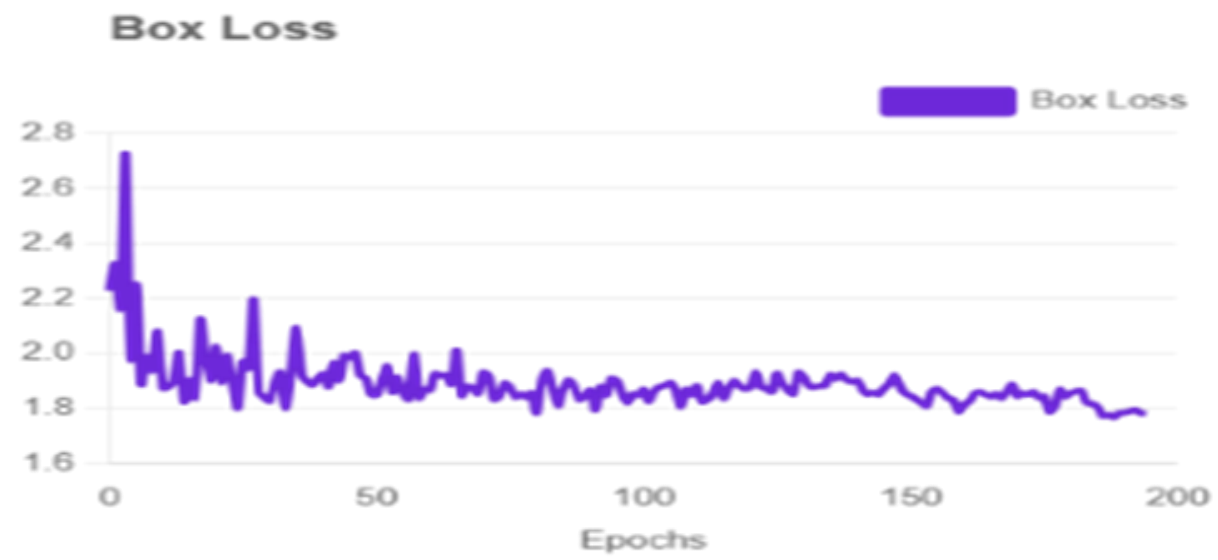
[Fig 7]

When training object detection models (like those on Roboflow), model performance is typically evaluated using mAP (mean Average Precision), which is the gold standard for detection accuracy. mAP stands for mean Average Precision and measures how well the model detects objects (localization + classification). There are two main flavors:

- mAP@0.5 – uses an IoU threshold of 0.5 (i.e., predicted box must overlap with ground truth by ≥50%)
- mAP@[.5:.95] – the COCO-style mAP, averaging over IoU thresholds from 0.5 to 0.95 in 0.05 increments (more strict, more comprehensive)

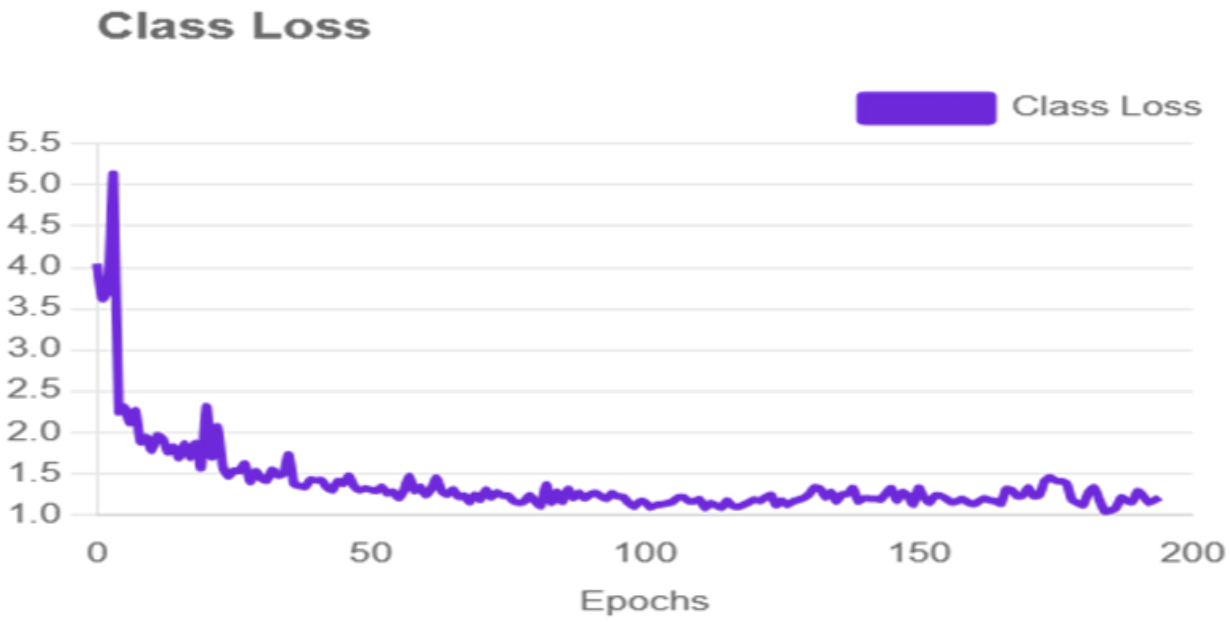


[Fig 8]



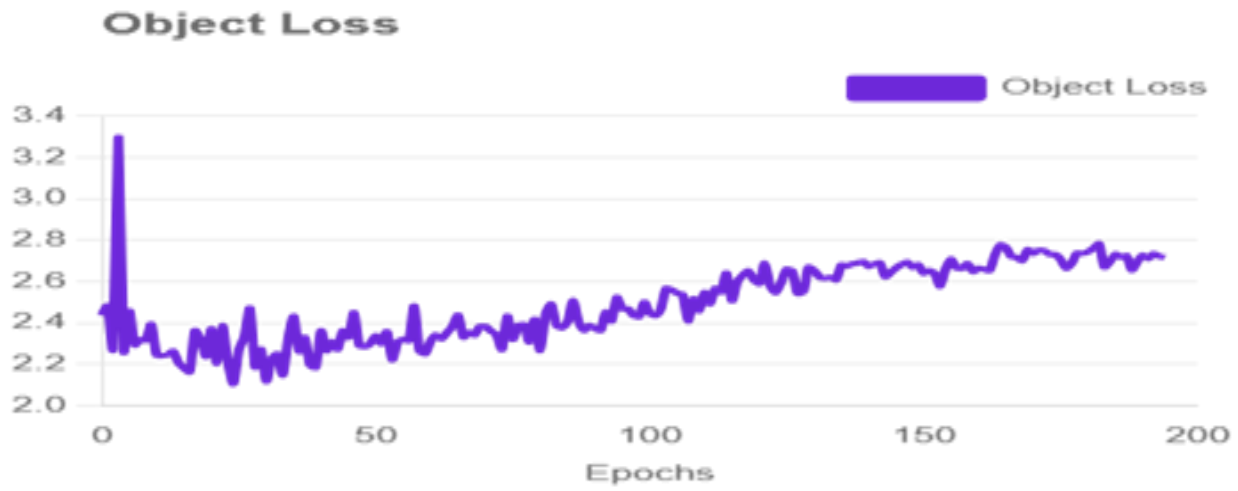
[Fig 9]

Box Loss: It measures how accurately the predicted bounding box matches the ground truth box i.e. the real object location in the image. It is used to minimize the difference in size, shape, and position between predicted and actual boxes.



[Fig 10]

Class Loss: Evaluates how well the model predicts the correct class given in your trained model for each detected object. Typically uses cross-entropy loss or binary cross-entropy. Improve the model's ability to correctly classify the detected objects.



[Fig 11]

Object Loss: Measures how confident the model is that an object exists in a particular location or anchor box. Often uses binary cross-entropy between the predicted objectness score and the actual presence/absence of an object. Ensure the model assigns high scores where objects are present and low scores where they aren't (reducing false positives and negatives)

IV. CONCLUSION

This paper offers a strong deep learning-based method for employing OCT imaging to automatically detect and report retinal illnesses like Drusen, Choroidal Neovascularization, and Diabetic Macular Edema (DME). Utilizing Convolutional Neural Networks (CNNs) and object identification models such as YOLO, the suggested system exhibits improved diagnostic precision and reliability. By eliminating subjectivity and variability in interpretations, the incorporation of a natural language generation component for converting OCT results into structured textual summaries helps standardize clinical reporting. Additionally, the technology facilitates the early identification of retinal anomalies that pose a threat to vision, allowing for prompt intervention and better patient outcomes.

This AI-assisted system helps ophthalmologists handle massive amounts of OCT scans with accuracy by drastically lowering clinician workload and improving diagnostic efficiency. Overall, our work advances the delivery of retinal care in clinical and community settings by laying the groundwork for scalable, real-time, and explainable AI tools in ocular diagnostics.

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Legends of the figures

Fig1: Image acquisition done by eye

Fig2: Proposed model of image to text formation

Fig3: Three samples output a) CNV b) DME c) DRUSEN

Fig4: Three samples output Text a) CNV b) DME c) DRUSEN

Fig 5: Distribution of data training and testing

Fig 6: Hit map of system

Fig 7: Average precision by class

Fig 8: Model performance

Fig 9: Box loss

Fig 10: Class Loss

Fig 11: Object loss

Evolution of Waste Management Policies in India (2000–2024): A Narrative Review

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Abstract- This narrative review examines the evolution of waste management policies in India between 2000 and 2024, a period marked by rapid urbanization, rising consumption, and increasing waste complexity. Drawing on government policy documents, national reports, international assessments, and peer-reviewed literature, the review traces regulatory developments across municipal solid waste, plastic waste, biomedical waste, e-waste, construction and demolition waste, and hazardous waste. The analysis highlights a clear shift from fragmented, disposal-oriented approaches to integrated frameworks emphasizing segregation, Extended Producer Responsibility (EPR), circular economy principles, and digital monitoring systems. Despite sophisticated reforms particularly after 2016 implementation challenges persist due to limited municipal capacity, inadequate funding, weak enforcement, and insufficient inclusion of informal waste workers. The review identifies recurring gaps and synthesizes policy evolution into a conceptual understanding of governance, stakeholder responsibilities, and implementation outcomes.

Index-Terms: Waste Management Policy, Informal Waste Sector, Implementation Challenges, Governance.

I. INTRODUCTION

India has undergone rapid urbanization, significant population growth, and extensive industrial diversification over the past two decades, resulting in a substantial increase in municipal solid waste (MSW) and other waste forms, such as electronic waste, plastic waste, biomedical waste, and construction and demolition debris. Estimates of India's annual MSW generation vary widely,

with figures ranging from approximately 62 million tonnes during 2011–2014 to around 58 million tonnes per year in 2021 (about 160,000 tonnes per day). Projections anticipate that MSW generation could reach between 277 and 300 million tonnes by 2047 and escalate to as high as 436 million tonnes by 2050, driven primarily by ongoing urban population growth and increased per capita waste production (Pal & Bhatia, 2022; Shahab & Anjum, 2022). According to the World Bank (2018), India generated over 277 million tonnes of municipal solid waste annually, underscoring the pressing need for effective waste management policies. Poorly managed waste significantly contributes to environmental degradation, including air and water pollution, greenhouse gas emissions, soil contamination, and increased incidences of vector-borne diseases. These impacts disproportionately affect vulnerable urban populations, particularly the urban poor (Abubakar et al., 2022; Kitole et al., 2024; Ferronato & Torretta, 2019).

In response to these challenges, India's policy landscape has evolved to reflect changing governance priorities, advances in technology, and alignment with global sustainability frameworks. The foundational legal framework began with the Municipal Solid Waste (Management and Handling) Rules of 2000, which focused largely on waste collection, transportation, and disposal. While these early rules established a basis for urban waste governance, they lacked enforcement rigor and failed to incorporate effective strategies for recycling, source segregation, or community participation. Subsequent legislation, including the Plastic Waste Management Rules (2011), the E-Waste (Management and Handling) Rules (2011), and the revised Solid Waste Management Rules (2016), progressively incorporated extended producer responsibility (EPR), emphasized waste segregation at source, encouraged decentralized waste processing, and integrated circular economy principles. Despite these progressive policy reforms, implementation challenges remain formidable. Urban local bodies often grapple with limited financial and technical resources, and insufficient capacity-building initiatives constrain effective execution. Additionally, informal sector workers, who contribute significantly to recycling and material recovery, continue to be marginalized within formal governance structures. Compliance with EPR frameworks is uneven, hindered by systemic governance deficiencies and behavioural barriers.

This narrative review critically examines the evolution of waste management policies in India from 2000 to 2024, emphasizing regulatory milestones, policy shifts, implementation gaps, and emerging governance trends. It seeks to provide a comprehensive understanding of how waste governance is adapting amid rising waste volumes and increasingly complex waste streams, with implications for sustainable development.

II. METHODOLOGY

This narrative review synthesizes India's waste management policy evolution from 2000 to 2024 using scholarly literature. Key materials included peer-reviewed articles from Scopus, and selected for relevance to municipal solid waste, plastic, e-waste, biomedical waste, construction debris, and hazardous materials.

Inclusion criteria encompassed English-language documents published 2000–2024 addressing policy frameworks, governance, or implementation; exclusions comprised local circulars, non-official commentary, and non-peer-reviewed opinions. Data extraction focused on thematic codes such as regulatory shifts, Extended Producer Responsibility (EPR), decentralization, stakeholder roles, and challenges, aligned with the review's emphasis on urbanization-driven waste growth. An iterative narrative synthesis identified policy milestones, patterns, and gaps ensuring evidence-based insights into transitions from dump-centric to integrated, circular economy models.

III. RESULTS

Early Phase (2000–2010): Foundational Policies and Fragmented Governance

The period from 2000 to 2010 established the foundational architecture of India's waste management governance amid escalating municipal solid waste (MSW) generation, estimated at approximately 62 million tonnes annually, driven by early urbanization trends (Pal & Bhatia, 2022; Mani & Singh, 2016). This phase was characterized by fragmented, sector-specific regulations that prioritized basic collection, transportation, segregation, and landfilling, with minimal attention to waste reduction, recycling, or circular economy principles (Sharholy et al., 2008).

The cornerstone policy, the Municipal Solid Waste (Management and Handling) Rules, 2000, represented India's first comprehensive national framework, mandating urban local bodies (ULBs) to implement source segregation into biodegradable and non-biodegradable fractions, construct sanitary landfills, develop composting and vermicomposting facilities, and progressively eliminate open dumping practices. Despite these progressive stipulations, the Rules suffered from critical shortcomings: absence of stringent enforcement mechanisms, financial penalties for non-compliance, Extended Producer Responsibility (EPR) provisions, or incentives for resource recovery. Consequently, compliance remained nominal, with most ULBs continuing reliance on inadequate landfills and open dumps

Parallel sector-specific regulations operated in silos, lacking integration with municipal systems. The Biomedical Waste (Management and Handling) Rules, 1998 (amended 2003), introduced categorized treatment, segregation, and incineration protocols for healthcare waste to mitigate infection risks, while the Hazardous Waste (Management and Handling) Rules, 2008, regulated industrial effluents and hazardous substances through treatment, storage, and disposal facility requirements. Implementation faltered due to ULB chronic capacity deficits technical expertise, infrastructure, and funding shortages compounded by the absence of monitoring technologies or centralized data systems

Urban disparities were stark: metropolitan areas like Delhi, Mumbai, and Bengaluru struggled with collection inefficiencies and legacy waste accumulation, while smaller cities and towns faced existential resource constraints (Sharholy et al., 2008). Public engagement was negligible; source segregation mandates were largely ignored by households, and informal waste pickers who recovered 20-30% of recyclables operated outside formal governance, unrecognized and

unsupported. Technological interventions were virtually absent, perpetuating linear waste flows toward landfills.

Year	Policy	Key Provisions	Limitations
2000	MSW (Management & Handling) Rules	Source segregation, sanitary landfills, composting mandates	Weak enforcement, no EPR, no recycling incentives
1998/2003	Biomedical Waste Rules	Categorized treatment, incineration protocols	Siloed from MSW systems, compliance monitoring gaps
2008	Hazardous Waste Rules	TSD facilities for industrial waste	ULB capacity deficits, no tracking tech (CPCB reports)

This phase embedded accountability and sustainability but revealed nascent gaps in scalability and enforcement, setting the stage for further refinements. (UNEP, 2020; World Bank, 2018).

Key Reforms (2011–2016): Toward Segregation, Recycling, and Producer Responsibility

The 2011–2016 period signified a transformative transition in India's waste management policies, evolving from landfill-centric models to multi-stakeholder frameworks emphasizing segregation, recycling, and Extended Producer Responsibility (EPR), amid MSW generation reaching ~58 million tonnes annually by 2021 (Shahab & Anjum, 2022).

Key interventions included the Plastic Waste Management Rules, 2011 (amended 2015), which banned thin carry bags, set recycling targets, mandated labelling and producer collection responsibilities, and aligned with global plastic pollution concerns. The E-Waste (Management and Handling) Rules, 2011 (revised 2016) introduced India's inaugural EPR regime, obligating producers to establish collection centres, meet recycling quotas, and ensure authorized disposal, though enforcement lagged due to inconsistent reporting and monitoring deficits. The Solid Waste Management Rules, 2016 consolidated advances by mandating household source segregation (wet/dry/reject), decentralized composting/biogas, EPR for bulk generators, user fees, and legacy waste remediation, integrating circular economy norms (Mayanti, B., & Helo, P., 2023; Szamek, G. 2024)

Municipal awareness campaigns under state authorities and National Green Tribunal pilots promoted citizen duties, yet behavioural uptake faltered in smaller towns due to infrastructure gaps and low mobilization. Advances encompassed decentralized processing and informal sector linkages, but challenges persisted: uneven compliance, technological silos, and persistent landfilling.

Aspect	Pre-2011 (MSW Rules 2000)	Post-2016 Reforms
Segregation	Recommended	Mandatory (wet/dry/reject); fines
Producer Role	Absent	EPR (plastics/e-waste/bulk)
Processing	Centralized landfills	Decentralized recovery/biogas
Citizen Engagement	Minimal	Awareness campaigns, penalties

This phase embedded shared accountability but exposed scalability gaps, informing 2016's comprehensive overhaul.

Reform Phase (2016): Comprehensive Overhaul of Waste Rules

The year 2016 marked a watershed in India's waste governance, transitioning from fragmented policies to integrated, sustainability-driven regulations. The Ministry of Environment, Forest and Climate Change (MoEFCC) comprehensively revised the Solid Waste Management (SWM) Rules, Plastic Waste Management Rules, E-Waste (Management) Rules, Biomedical Waste Rules, and Construction & Demolition (C&D) Waste Rules, embedding accountability, technological monitoring, decentralization, and circular economy principles.

The SWM Rules, 2016 mandated source segregation (biodegradable/recyclable/hazardous) for households and institutions, promoted decentralized composting, bio methanation, and material recovery facilities (MRFs), integrated informal waste workers, introduced user fees, and encouraged waste tracking technologies. Parallel reforms expanded Extended Producer Responsibility (EPR): Plastic Waste Rules (amended 2018–2022) imposed phased single-use plastic reductions, centralized reporting, and recycling mandates; Biomedical Rules incorporated barcode tracking; C&D Rules required recycling facilities and debris reuse.

Rule (2016)	Key Innovations
SWM	Segregation, MRFs, informal integration, user fees
Plastic	EPR expansion, single-use phase-out
Biomedical/C&D	Tracking/barcodes; 100% reuse mandates

Consolidation Phase (2017–2024): Digital Integration and Circular Economy Advancement

The 2017–2024 period consolidated the 2016 reforms amid MSW projections of 277–436 million tonnes by 2050, emphasizing digital transformation, universal Extended Producer Responsibility (EPR), and circular economy operationalization (Pal & Bhatia, 2022; Ferronato & Torretta, 2019). Key Policy Advancements included targeted amendments: Construction & Demolition (C&D) Waste Rules (amended 2017/2022) mandated 100% reuse/recycling through dedicated processing

sites; Hazardous & Other Wastes Rules (2019 update) enforced pretreatment and transboundary controls; Plastic Waste Management Rules (2022/2024 amendments) universalized EPR across all producers with phased recycling targets (50–80% by 2027–28), microplastic prohibitions, and mandatory digital compliance portals; E-Waste Rules (2022) established centralized record-keeping for end-to-end tracking. Swachh Bharat Mission (Urban) 2.0 catalysed innovations GPS-enabled vehicles, mobile apps for citizen reporting, AI waste sorting, waste-to-energy plants, and formal cooperatives for informal recyclers directly supporting SDG 11 (sustainable cities) and 12 (responsible consumption) (Fang et al. 2023; Miranda et al. 2020; Kasinja, C., & Tilley, E. 2018) Citizen and Behavioural Progress saw sustained awareness campaigns yield segregation rates exceeding 50% in metro cities with active monitoring (e.g., Indore model), alongside circular economy embedding through bio methanation, compostable alternatives, and material recovery facilities (MRFs), reducing landfill dependency.

IV. DISCUSSION

The evolution of India's waste management policies from 2000 to 2024 demonstrates a clear progression from fragmented, disposal-centric regulations toward integrated and sustainability-driven governance aligned with global frameworks such as SDG 11 and SDG 12. Early policies (2000–2010) relied heavily on landfilling and basic collection systems, revealing gaps in enforcement, institutional capacity, and producer accountability. Fragmented rules for plastic, biomedical, and hazardous waste, combined with limited technological infrastructure, constrained coordinated implementation (Sharholy et al., 2008). A transitional shift occurred between 2010 and 2016, marked by the introduction of recycling-oriented provisions, source segregation, and the initial adoption of Extended Producer Responsibility (EPR) through the 2011 Plastic Waste and E-Waste Rules. While these policies initiated shared responsibility and multi-stakeholder engagement, compliance was inconsistent, largely due to municipal capacity deficits and weak monitoring mechanisms. The 2016 reforms represent the most transformative phase, offering a comprehensive overhaul across all major waste streams. Mandatory segregation, decentralized waste processing, strengthened EPR frameworks, inclusion of informal recyclers, and the introduction of digital tracking mechanisms signalled a paradigm shift toward circular economy governance (Murthy, V., & Ramakrishna, S. 2022; Srivastav et al. 2023; Fiksel et al. 2021). Between 2017 and 2024, policy consolidation further expanded digital compliance portals, encouraged material recovery facilities, promoted bio methanation, and strengthened reuse mechanisms for construction and demolition waste. Despite significant regulatory advancement, persistent challenges hinder full realization of policy intent. Urban local bodies continue to face financial, human resource, and infrastructural constraints, limiting enforcement and service delivery. Integration of informal waste workers central to India's recycling ecosystem remains partial, affecting both equity and operational efficiency. EPR compliance gaps, limited data transparency, and uneven citizen participation in segregation further restrict systemic effectiveness.

Strengthening India's waste governance therefore requires a multipronged approach: enhancing municipal capacity, formalizing and supporting informal waste workers, expanding technology-enabled monitoring systems, and fostering sustained behavioural change among citizens. Future research should investigate effective models of informal sector integration and examine the socio-technical impacts of EPR and digital monitoring across diverse urban contexts.

Overall, India's waste management trajectory reflects substantial policy modernization aligned with global sustainability principles, yet underscores the continuing need for stronger governance, institutional coherence, and inclusive partnerships to fully achieve circular economy objectives.

V. RECOMMENDATIONS

To bridge identified policy-implementation gaps, targeted interventions are essential across governance levels. Allocate dedicated funding streams for urban local bodies (ULBs) to establish material recovery facilities (MRFs), bio methanation units, and waste-to-energy infrastructure, prioritizing smaller municipalities. Implement mandatory training programs for ULB staff on digital tracking tools, EPR compliance, and decentralized processing. Formalize waste picker cooperatives through legal recognition, social security provisions, and priority access to recyclables, enhancing recycling efficiency (>50% national recovery potential). Develop public-private partnerships linking informal workers to EPR supply chains. Strengthen centralized portals with AI-driven audits and real-time verification to curb under-reporting, mandating 80% compliance by 2027. Scale Swachh Bharat Mission ICT innovations (GPS, apps) nationwide for transparent waste monitoring. Launch sustained behaviours change campaigns integrating schools, RWAs, and digital nudges to achieve >70% source segregation, modelled on Indore's success.

VI. CONCLUSION

From 2000 to 2024, India's waste management policies underwent substantial transformation, evolving from foundational, disposal-centric rules to comprehensive frameworks emphasizing segregation, recycling, Extended Producer Responsibility, circular economy principles, and digital monitoring. The 2016 reforms represent a watershed moment, consolidating fragmented rules into integrated governance structures with clear responsibilities for municipalities, producers, and citizens. Subsequent amendments and consolidation efforts have strengthened EPR compliance, encouraged circular economy adoption, and enhanced monitoring through digital technologies. Despite these advancements, implementation gaps remain a critical concern. Municipal capacity limitations, insufficient infrastructure, uneven citizen participation, partial inclusion of informal waste workers, and inconsistent EPR compliance continue to impede the realization of policy objectives. Addressing these challenges will require coordinated action, including institutional strengthening, technological adoption, behavioural change initiatives, and inclusive engagement of the informal sector. Overall, India's experience demonstrates that regulatory sophistication must be complemented by robust governance capacity and multi-stakeholder collaboration to achieve

sustainable, SDG-aligned waste management outcomes. The lessons from this 24-year period provide valuable insights for other low- and middle-income countries grappling with urban waste challenges, highlighting the critical interplay between policy evolution, implementation capacity, and stakeholder engagement in achieving environmental sustainability.

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