

Contemporary Issues of Business and Economic Development in India

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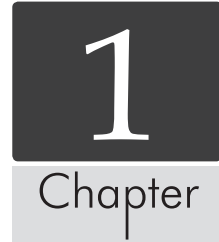
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Digital Gatekeepers: How ATS Design Impacts Applicant Satisfaction and Hiring Fairness

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Abstract

The digitalization of recruitment has positioned Applicant Tracking Systems (ATS) as central gatekeepers in modern hiring, influencing how candidates are screened, evaluated, and selected. This study investigates the impact of ATS design on candidate satisfaction and perceptions of hiring fairness, integrating applicant reactions and organizational justice perspectives. Using a quantitative research design, data were collected from 285 job applicants across retail, healthcare, and information technology sectors through structured questionnaires. Regression analyses reveal that effective ATS design significantly predicts candidate satisfaction ($\beta = 0.609$, $p < 0.001$) and strongly enhances perceptions of hiring fairness ($\beta = 0.838$, $p < 0.001$). Findings underscore the importance of usability, transparency, feedback, and explainability in promoting trust and procedural justice in digitally mediated recruitment. The study highlights that ATS are not merely administrative tools but socio-technical mechanisms shaping experiential and evaluative outcomes, with implications for HR practitioners, system designers, and organizational policy aimed at fostering equitable, candidate-centered recruitment processes.

Keywords: *Applicant Tracking System, ATS Design, Candidate Satisfaction, Hiring Fairness, Digital Recruitment.*

Introduction

The digitalization of human resource management has fundamentally reconfigured recruitment and selection processes, with Applicant Tracking Systems (ATS) and AI-enabled tools now embedded within the hiring architectures of organizations worldwide. These systems increasingly govern how applicants are screened, evaluated, and advanced, operating at scale and with minimal human intervention. While ATS adoption is often justified by improvements in efficiency, consistency, and administrative control, their growing role in shaping access to employment has prompted renewed scholarly attention to candidate experience, fairness, and trust in digitally mediated hiring environments.

Recruitment represents a critical point of contact between organizations and potential employees, serving not only as a mechanism for talent acquisition but also as a signal of organizational values and legitimacy. Applicant reactions research has long demonstrated that candidates actively interpret recruitment practices, forming judgments about procedural integrity, respect, and transparency that extend beyond hiring outcomes. In digitally mediated contexts, these evaluations are increasingly shaped by system design features rather than interpersonal interactions, raising important questions about how automated hiring technologies influence perceptions of fairness and satisfaction.

ATS function as more than administrative tools; they act as digital gatekeepers that structure opportunity by determining which applicants are visible, comparable, and selectable. Design choices embedded within ATS, such as interface usability, transparency of screening criteria, feedback provision, and the degree of automation, implicitly encode assumptions about merit and efficiency. As a result, candidates' experiences of recruitment are shaped not only by organizational policies but also by the socio-technical characteristics of the systems through which those policies are enacted.

Although prior research documents widespread organizational reliance on ATS, much of this work adopts an efficiency-oriented or managerial perspective, emphasizing reductions

in time-to-hire, recruitment costs, and recruiter workload. In contrast, growing evidence suggests that applicants frequently experience ATS-based recruitment as opaque, impersonal, and difficult to interpret. Limited insight into how applications are evaluated, combined with minimal feedback and reduced human interaction, has been shown to undermine trust and satisfaction, even when selection procedures are perceived as technologically advanced.

These concerns are amplified by the increasing integration of AI and large language models into recruitment systems. Algorithmic screening tools promise objectivity and standardization, yet scholars caution that automated decision-making may reproduce existing biases, obscure accountability, and weaken perceptions of procedural justice if not carefully designed and governed. Importantly, fairness in digital recruitment is not a purely technical issue but a perceptual and relational one, shaped by how candidates interpret system behavior, information availability, and opportunities for voice.

Organizational justice theory offers a useful lens for understanding these dynamics, particularly in relation to procedural and interactional fairness. In the absence of sustained human contact, applicants rely on system cues to infer whether selection processes are consistent, transparent, and respectful. When ATS design limits explanation or communication, candidates may experience a loss of control and reduced confidence in hiring decisions, negatively affecting overall satisfaction with the recruitment process. Conversely, user-centered and explainable systems may mitigate these concerns by enhancing perceptions of fairness, even in highly automated environments.

Despite growing interest in AI ethics and algorithmic bias, empirical research examining ATS design from an applicant-centered perspective remains limited. Existing studies often treat fairness, satisfaction, and automation as isolated constructs or focus primarily on technical performance and regulatory compliance. Consequently, the role of ATS design as a socio-technical mechanism shaping candidate experience and justice perceptions is underexplored within the digital HRM literature. Addressing this gap, the present study examines how ATS design influences candidate satisfaction through perceptions of hiring fairness. By conceptualizing ATS as digital gatekeepers

within recruitment systems, this research integrates applicant reactions and organizational justice perspectives to advance understanding of how design choices in automated hiring systems affect experiential and evaluative outcomes. In doing so, the study contributes to ongoing debates on digital HRM, fairness in algorithmic decision-making, and the human consequences of recruitment automation.

Reviews of literature

The incorporation of digital technologies into recruitment has progressively reshaped employee selection, positioning Applicant Tracking Systems (ATS) and AI-enabled tools as core infrastructural components of contemporary hiring. These systems increasingly mediate how applicants are screened, evaluated, and progressed through recruitment pipelines. While their adoption is frequently justified by gains in efficiency, consistency, and scalability, a growing body of research questions how technologically mediated selection affects applicant perceptions, particularly with respect to fairness, transparency, and trust. As hiring processes become more automated, scholars emphasize the need to re-examine recruitment not only as a technical process but also as a socio-psychological experience for candidates.

Research on applicant reactions indicates that digital recruitment practices can enhance perceptions of organizational sophistication and professionalism. Technology-driven selection is often interpreted as signaling innovation and operational competence, contributing to employer attractiveness. However, these favorable impressions are commonly accompanied by concerns regarding procedural integrity. Folger et al. (2021) demonstrate that applicants associate automated selection tools with efficiency while simultaneously expressing uncertainty about the fairness of evaluation procedures, especially during algorithmic screening and automated interviews. Notably, fairness concerns are more pronounced among individuals without direct experience of digital recruitment, suggesting that justice perceptions evolve through interaction rather than existing as fixed predispositions.

From an organizational standpoint, the diffusion of ATS has been particularly pronounced among large employers facing high application volumes. Such systems are routinely used to

centralize applicant data, automate resume processing, and streamline administrative tasks, thereby reducing recruiter workload (Peicheva, 2022). Chavan et al. (2014) describe ATS as end-to-end recruitment infrastructures that support activities ranging from application intake to interview coordination and hiring documentation. By transforming unstructured applicant information into standardized formats through techniques such as natural language processing, ATS enable faster and more uniform assessments. When integrated with broader process management frameworks, ATS adoption has been linked to reduced recruitment costs and shorter time-to-hire (Laumer, 2014). However, this stream of research remains largely organization-centric, offering limited insight into applicant-facing consequences.

Recent scholarship has increasingly shifted attention toward candidate experience, highlighting structural limitations of automated recruitment systems. A central concern involves the opacity of algorithmic decision-making and the limited provision of feedback to applicants. Bhattacharya and Verbert (2025) show that opaque automated outcomes erode applicant trust and satisfaction, whereas systems incorporating explainability and user-oriented design features generate more positive evaluations of procedural fairness. These findings resonate with organizational justice theory, which posits that access to information and clarity of procedures are critical drivers of fairness perceptions in selection contexts.

The rapid integration of AI and large language models into recruitment has further intensified debates surrounding bias, discrimination, and ethical accountability. Rigotti and Fosch-Villaronga (2024) argue that fairness in AI-based recruitment cannot be treated as a singular construct, as its interpretation varies across stakeholders and institutional contexts. Absent robust governance mechanisms, algorithmic systems risk reproducing historical inequalities embedded in training data and decision rules. Empirical evidence reinforces this concern: Koh et al. (2023) find that AI-driven screening tools may perpetuate societal biases unless subjected to continuous evaluation, auditing, and corrective intervention.

Applicant responses to increasing levels of automation further reveal ambivalence toward algorithmic authority in hiring decisions. Armstrong and Metaxa (2025) report that perceptions

of trust and fairness decline as human involvement diminishes, particularly when automated judgments are not accompanied by explanation or interpersonal interaction. Their findings also suggest that social capital continues to shape hiring outcomes despite algorithmic screening, complicating claims that automation inherently enhances meritocratic selection. Consistent with this perspective, Babaei and Shank (2025) show that applicants often evaluate AI-led recruitment as less fair and less appealing than human-led processes, raising concerns about the potential deterrence of high-quality candidates.

From an applicant reactions perspective, fairness perceptions in recruitment extend beyond individual outcomes and carry broader organizational implications. Truxillo et al. (2017) emphasize that perceptions of unfair or opaque selection procedures can undermine employer legitimacy, increase applicant withdrawal, and heighten legal and reputational risks. Building on this work, Hilliard et al. (2022) demonstrate that algorithm-based recruitment may reduce perceived empathy and applicant autonomy, thereby altering the psychological experience of selection and producing mixed justice evaluations. These findings suggest that automation reshapes not only evaluative mechanisms but also how applicants interpret organizational values and intent.

Research on AI-based recruitment recommender systems further illustrates the persistence of inequality within digital hiring environments. Kumar et al. (2023) show that recommender algorithms may unintentionally reinforce gendered patterns and group-based disadvantages, even when designed to operate neutrally. Moreover, although a range of technical solutions aimed at enhancing algorithmic fairness has been proposed, their compatibility with existing legal and regulatory frameworks remains inconsistent across jurisdictions, particularly between the European Union and the United States. This regulatory fragmentation underscores the unresolved nature of fairness in digitally mediated recruitment.

In sum, existing scholarship indicates that ATS and AI-enabled recruitment systems offer substantial efficiency and standardization benefits while simultaneously generating enduring concerns related to candidate satisfaction, transparency, fairness, and inclusion. Prior research has tended to address these issues in isolation and primarily from organizational or

technical perspectives, leaving the role of ATS design as a socio-technical gatekeeping mechanism underexplored. By examining how specific ATS design features influence candidate satisfaction and fairness perceptions, the present study seeks to contribute to ongoing debates in digital HRM, applicant reactions, and organizational justice research.

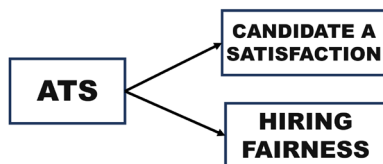


Figure 1: Research Model

Null Hypothesis

H₀: The use of an Applicant Tracking System (ATS) has no significant impact on candidate satisfaction

H₀: The use of an Applicant Tracking System (ATS) has no significant effect on hiring fairness.

Methodology

Research Design

The present study employs a quantitative research design to explore the extent to which Applicant Tracking System (ATS) design shapes candidate satisfaction and perceptions of hiring fairness. This approach is well-suited to examining theoretically specified relationships and allows for the systematic evaluation of associations between system-level features and applicant responses. Consistent with established practice in digital HRM research, the design facilitates statistical inference across heterogeneous organizational settings.

Sampling Strategy and Participants

A stratified random sampling procedure was used to obtain representation from industry sectors characterized by intensive and technology-mediated recruitment activity. Stratification was based on sectoral context to account for differences in

recruitment volume, process formalization, and reliance on ATS-enabled hiring systems. The sampling frame comprised three sectors, retail, healthcare, and information technology, each of which has been widely identified in the HRM literature as a frequent user of digital recruitment infrastructures. This sampling approach was adopted to enhance representativeness and mitigate sector-specific bias.

Sample size adequacy was assessed using Cochran's (1977) formula for large populations:

$$n_0 = \frac{Z^2 \cdot p(1-p)}{E^2}$$

where Z = corresponds to a 95% confidence level, $p = 0.50$ reflects a conservative estimate of population proportion, and $E = 0.05$ represents the acceptable margin of sampling error. The resulting calculation indicated a minimum recommended sample size of 385 respondents.

Data Collection Procedure

Data were collected through a structured questionnaire administered to job applicants with recent exposure to ATS-mediated recruitment processes. A total of 500 questionnaires were distributed across the three industry sectors during the period from December 2024 to April 2025. Of these, 285 completed responses met the criteria for inclusion in the analysis, yielding a response rate of 57%. Although the achieved sample size was lower than the initial estimate, the adjusted margin of error was $\pm 5.8\%$, which remains within acceptable bounds for empirical HRM research and is comparable to response levels reported in prior applicant reactions studies.

Measurement Reliability

The survey instrument consisted of 22 items assessing perceptions of ATS design characteristics, hiring fairness, and overall candidate satisfaction. Internal consistency reliability was evaluated using Cronbach's alpha. The composite scale produced a coefficient of 0.794, exceeding the commonly accepted threshold of 0.70 and indicating adequate reliability for subsequent statistical analysis.

Analytical Strategy

Hypothesis testing was conducted using regression analysis. This analytical technique is appropriate for estimating the predictive influence of ATS design on applicant fairness perceptions and satisfaction while accounting for variability across respondents.

Result

Table 1: Regression Model Summary: Effect of Applicant Tracking System (ATS) Design on Candidate Satisfaction

Model Summary ^b				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.756 ^a	.571	.568	2.14
a. Predictors: (Constant), ATS				
b. Dependent Variable: Candidate_Satisfaction				

The regression results indicate a positive association between ATS design and candidate satisfaction ($R = 0.756$). ATS design explains 57.1% of the variance in candidate satisfaction ($R^2 = 0.571$), with the adjusted R^2 (0.568) indicating minimal reduction. The standard error of the estimate (2.14) represents the average deviation between observed and predicted satisfaction scores and falls within the range typically observed for perceptual measures in recruitment research.

Table 2: ANOVA Results for Regression Model Predicting Candidate Satisfaction

ANOVA ^a						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2858.803	1	2858.803	166.589	.000b
	Residual	4856.509	283	17.161		
	Total	7715.312	284			
a. Dependent Variable: Candidate_Satisfaction						
b. Predictors: (Constant), ATS						

The ANOVA results indicate that the regression model is statistically significant, $F(1, 283) = 166.589$, $p < .001$. This suggests that ATS design explains a significant proportion of variance in candidate satisfaction relative to unexplained variance.

Table 3: Regression Coefficients for the Effect of ATS Design on Candidate Satisfaction

Coefficients ^a						
Model B		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		Std. Error	Beta			
1	(Constant)	3.976	2.076		1.915	.056
	ATS	.405	.031	.609	12.907	.000
a. Dependent Variable: Candidate Satisfaction						

The regression analysis examined the effect of the Applicant Tracking System (ATS) on candidate satisfaction. Results indicate that ATS significantly predicts candidate satisfaction ($B = 0.405$, $\beta = 0.609$, $t = 12.907$, $p < 0.001$), suggesting that for every one-unit increase in ATS effectiveness, candidate satisfaction increases by 0.405 units. The large standardised coefficient reflects a strong positive influence, highlighting that effective ATS implementation substantially enhances candidates' recruitment experience.

Table 4: Model Summary of the Effect of ATS on Hiring Fairness

Model Summary ^b				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.838a	.703	.702	2.39
a. Predictors: (Constant), ATS				
b. Dependent Variable: Hiring_Fairness				

The Applicant Tracking System (ATS) strongly predicts hiring fairness, explaining 70.3% of the variance ($R = 0.838$, $R^2 = 0.703$, Adjusted $R^2 = 0.702$), highlighting its role in promoting transparent and equitable recruitment.

Table 5: ANOVA Results for the Regression of ATS on Hiring Fairness

ANOVA ^a						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3849.813	1	3849.813	668.983	.000b
	Residual	1628.587	283	5.755		
	Total	5478.400	284			
a. Dependent Variable: Hiring_Fairness						
b. Predictors: (Constant), ATS						

The regression model significantly predicts hiring fairness ($F(1, 283) = 668.983, p < 0.001$), indicating that ATS is a strong and meaningful predictor of unbiased recruitment.

Table 6: Regression Coefficients of ATS Predicting Hiring Fairness

Coefficients ^a						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.475	1.202		.395	.693
	ATS	.470	.018	.838	25.865	.000
a. Dependent Variable: Hiring Fairness						

The Applicant Tracking System (ATS) strongly and significantly predicts hiring fairness ($B = 0.470, \beta = 0.838, t = 25.865, p < 0.001$), indicating that improved ATS functionality enhances perceptions of equitable recruitment.

Conclusion

This study examined how Applicant Tracking System (ATS) design influences candidate satisfaction and perceptions of hiring fairness, framing ATS as a digital gatekeeper in modern recruitment. Results show that effective ATS design significantly enhances candidate satisfaction ($\beta = 0.609, p < 0.001$) and perceptions of hiring fairness ($\beta = 0.838, p < 0.001$), highlighting the importance of usability, transparency, feedback, and explainability. Poorly designed systems, by contrast, can undermine trust and deter high-quality applicants.

Aligning with organizational justice theory, the findings underscore that candidates rely on system cues to assess fairness, even in highly automated processes. The study contributes to digital HRM research by emphasizing applicant-centered perspectives and socio-technical implications of ATS design. Practically, organizations should prioritize user-oriented, transparent, and explainable systems to enhance trust, fairness, and engagement. Future research could explore cross-cultural differences, AI-driven screening impacts, and long-term effects on employer brand and talent retention, reinforcing that candidate experience must remain central in digital recruitment strategies.

Implications

HR practitioners should design user-friendly, transparent, and explainable ATS, combining automation with human interaction. Tailoring features to industry needs and using effect sizes to guide continuous improvements can enhance candidate satisfaction and fairness.

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2

Chapter

A Study on the Status of Financial Literacy Amongst Rural Women of Cachar District of Assam

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Abstract

The financial literacy of women in modern society is of highest importance from the standpoint of economic development, alleviation of poverty and the promotion of gender equity. Empirical study indicates that increasing women's engagement in financial activities plays a significant role in fostering the creation of more robust and resilient financial system. However, there is a significant deficiency in research that inspect the status of women's financial literacy in rural contexts at the household level, especially when accounting for all female adult members. In response, the present study seeks to examine the status of women's financial literacy within the Cachar district of rural Assam. This study is based on primary data gathered from 482 households over the months of June and July, 2022. To evaluate the status of women's financial literacy composite index formulated by Roy and Nath (2025) is used. Simple statistical tools like mean, standard deviation and F-test are used for the analysis of data. The study unfolds a very deficient level of financial literacy in the study area and it also identified significant disparities in financial literacy across the district,

block and village levels among the women. The study recommends that initiatives should be taken responsibly for the establishment of a substantial number of financial literacy centres, community-oriented workshops specially targeting women, gender-responsive financial education campaigns, and incorporation of financial literacy into educational curricula, particularly for female students, which might develop robust financial competencies within women and ultimately lead to their financial empowerment.

Keywords: *Financial Literacy, Gender Gap, Women Empowerment, Financial Literacy Index, Financial Education*

Introduction

Financial literacy (FL) has emerged as an integral component of individual affairs in contemporary society. However, the phenomenon of financial illiteracy or lack of financial knowledge, is particularly seen in developing nations, where individuals frequently encounter barriers to obtaining both quality general education and basic financial knowledge. A significant segment of the population remains uninformed regarding financial issues due to insufficient levels of financial education, which in turn restricts their capacity to make informed and judicious financial decisions. Research conducted in developed nations that individuals and households possessing FL experience a relatively higher ability to participate in an inclusive financial ecosystem and can increase their proficiency in executing important financial transactions.

A thorough analysis of empirical research, meta-analyses and literature reviews from several geographical and cultural settings was undertaken with particular emphasis placed on the multidimensional components of FL. Gender disparities in the FL of adults concentrate on financial awareness and skills to address ongoing inequalities and their basic determinants. The existing findings indicate persistent gender gaps that advantage men in terms of financial knowledge, skills and confidence when compared to women. Patriarchal prejudices obstruct female FL in rural India, where both economic advancement and female autonomy are significantly restricted by such biases (Sardana, 2024). This gender disparity in FL is apparent among women from diverse demographic backgrounds and necessitates focused financial education initiatives to mitigate these disparities, especially in rural areas (Adamska, 2023).

The existing literature is scarce concerning the conceptual and measurement aspects of FL at the household level, which covers all adult members within the household, thereby limiting the assessment and exploration of gender disparities in FL. In this context, the present study has employed the conceptual framework of financial literacy developed by Roy and Nath (2025). They differentiated their approach from other macro-level research by conceptualising FL solely in terms of symptomatic dimension viz., financial awareness and financial knowledge. It is indeed crucial to empirically validate and conduct household-level examination to both inter-household and intra-household variations in FL levels. In light of this gap, the present study attempts to contribute to the literature by exploring the status of women's financial literacy in the Cachar district of rural Assam.

Review of Literature

Conceptualization of financial literacy

The methodical conceptualisation of financial literacy holds significant importance as it facilitates the accurate assessment of FL in an appropriate manner. Various financial experts, economists and institutions periodically attempted to provide a precise definition of FL. Alba and Hutchinson (1987) were the first to introduce the term 'financial literacy' in academic discourse, characterising it as a specialised form of consumer expertise necessary for the effective administration of one's financial matters. Although this definition lacks specificity, it refers to the financial skills and knowledge an individual possesses. Klapper et al. (2015) have advanced a more refined comprehension of FL by framing it in relation to financial knowledge. Nevertheless, scholars including Atkinson et al. (2007), Remund (2010), and Fanta et al. (2016) have presented a comparatively more expansionary perspective on FL by amalgamating the knowledge and behavioural dimensions of finance. Gupta (2017) conceptualised FL as a combination of skills and knowledge that empowers the individual to grasp the foundational principles of finance, thereby facilitating informed monetary decisions and the selection of financial products that significantly impact their financial prosperity. As per the statement of Remund (2010), financial literacy comprises financial awareness, knowledge and behaviour. Atkinson and Messy (2012) have identified four prevalent issues associated

with financial literacy viz., knowledge, skills, attitude, and behaviour which are critical for evaluating FL. A transformative initiative aimed at establishing a comprehensive definition of FL emerged in 2012 when G20 leaders underscored the significance of national strategies for financial education by endorsing the principles set by the Organisation for Economic Co-operation and Development (OECD). The OECD (2015) describes financial literacy as a combination of awareness, knowledge, skills, attitudes, and behaviours that are essential for making informed financial choices (National Centre for Financial Education Report of India, 2015; Gunther and Ghosh, 2018; Bhatt, 2017).

The prominent researches concerning FL at both the global and national scales, such as Global Financial Literacy Survey (Klapper et al., 2015), National Strategy for Financial Literacy in US (Poll, 2015), and National Centre for Financial Education Report of India (2015) were primarily aimed at assessing the status of FL across different countries and states with ultimate sampling units being an eligible respondent from each household. This methodology, however, does not adequately address the FL level of the entire household unit. Financial literacy evaluated at the individual level can not accurately represent the FL status at the household level. This identified gap in the existing literature necessitates the conceptualisation of household level financial literacy, providing a comprehensive inter-household comparative studies on financial literacy.

Financial literacy from gender perspective

The current investigation has identified gender disparity in FL, pointing out that women typically demonstrate diminished financial awareness and skills in comparison to their male counterparts and this phenomenon persists across diverse demographic segments Sarigül (2024). Espinoza-Delgado & Silber (2023) uncovered that women consistently display lower levels of financial awareness, skills and knowledge in Argentina, Chile, and Paraguay. Sarpong-Kumankoma et al. (2023) identified unobservable behavioural characteristics and cultural norms that apply differential influences on financial awareness and skills between genders.

Kaur & Sharma (2024) emphasise the gender imbalance in FL, asserting that women frequently display lower financial awareness and skills in comparison to men (Dewi, 2022;

Damong & Perez, 2024; Nursjanti & Amaliawati, 2024). Societal expectations and cultural norms play a pivotal role in shaping disparities in financial awareness and skills, thereby affecting economic empowerment and financial decision-making for females (Adiandari, 2023). Huang & Kosnik (2024) in their scholarly work, indicated that women predominantly show lower levels of FL, primarily due to lack of confidence regarding their financial skills and knowledge. Mitigating this problem necessitates the implementation of dedicated financial education to enhance awareness and capability among women. Dzulkepli et al. (2024) found gender differences in critical themes such as financial inclusion and awareness, suggesting that these disparities adversely affect individual economic well-being. Smolo et al. (2023) determined that females exhibit inferior financial knowledge and competencies in financial matter. Although women engage in financial decision-making processes, they frequently under-invest in financial education, thereby exacerbating the deficiency in financial literacy.

Objective

To explore the status of women's financial literacy in the Cachar district of rural Assam.

Methodology

Data Source and Sampling Design

The current research is based on primary data collected from rural households in Cachar district, field survey was conducted during the months of June and July in the year 2022. This field survey covered all the adult members of each household. The sampling design used in this study utilises a Multi-Stage Random Sampling method, which includes three distinct stages.

Stage I. In this stage, out of the fifteen community development blocks of Cachar district, three blocks are selected. The selection process was guided by supply-side macro-level parameters related to financial inclusion. To select the Community Development Blocks (CDBs) within the research area according to their varying degrees of financial inclusion, a Block-level Financial Inclusion Index was constructed using three specific indicators: the number of bank branches per 100 villages, bank branches per 10,000 households, and bank branches per 100,000 population. For each of these indicators, an index has been

formulated using the UNDP's Max-Min approach, and a simple average of these indices has been calculated to establish the Block-level Financial Inclusion Index (BLFII), which ranges from 0 to 1. The chosen blocks represented three distinct categories:

Category 1: $0 \leq \text{BLFII} \leq 0.40$ Low Level of Financial Inclusion

Category 2: $0.41 \leq \text{BLFII} \leq 0.70$ Moderate Level of Financial Inclusion

Category 3: $0.71 \leq \text{BLFII} \leq 1$ High Level of Financial Inclusion

Stage II: At this step, two villages were selected from every block, ensuring that one village contains at least one bank branch within its territorial boundaries, while the other lacks any bank branch. Thus, in the current research, there are a total of six sample villages.

Stage III: The final step involves selecting sample households through a simple random sampling method without replacement. To establish the appropriate sample size, researchers employed Yamane's (1967) statistical formula, which is designed for a known population. Based on this formula's calculations, the study determined that 482 households would constitute the total sample size. The mathematical expression developed by Yamane is presented as follows.

$$n = \frac{N}{1 + N.e^2} \quad \dots\dots\dots(1)$$

where

n = Sample size i.e., total number of sample households in a sample village

N = Population size and here it means the total number of households in the village

e = Level of precision or sampling error

Conceptual Framework

Household Level Financial Literacy – Meaning and Dimensions

A household is deemed to be financially literate if it is aware of/informed about all types of important financial aspects like financial products and instruments, financial activities etc and does possess the necessary skill/knowledge for utilising, planning and managing these financial aspects in a successful way (Roy & Nath, 2025). The definition of financial literacy used in this research distinctly highlights two dimensions: (a) financial

awareness, and (b) financial knowledge. Both dimensions hold equal significance for a household's journey toward financial literacy. The conceptualisation of financial literacy through the lenses of awareness and knowledge also facilitates the collection of relevant data from all adult household members. This is attributable to the fact that levels of awareness and knowledge regarding financial matters can significantly differ among individuals. For instance, the head of the household and their spouse may lack familiarity with financial applications and their functionalities. At the same time, their children may be well-versed in these technologies and their usage Roy and Nath (2025).

Dimensional Indicators of Financial Literacy

Table 1 presents 12 indicators for evaluating both financial awareness and financial knowledge. This list of financial literacy indicators can be expanded or limited by other researchers depending on their own rationale and justification. However, the current study has stuck with these variables because it believes they are the most important for ensuring a sound level of FL of rural households.

Table 1. Dimensional Indicators of Financial Literacy

Financial Awareness Indicators	Financial Knowledge Indicators
1. Awareness of traditional saving products like savings account, recurring deposit, long-term government securities etc.	1. Basic numeric skills like capable of doing addition, subtraction, multiplication and division
2. Awareness of non-traditional saving products like investment plans in mutual funds, corporate bonds etc.	2. Calculation of simple average and percentages
3. Awareness of various loan products	3. Calculation of simple interest
4. Awareness of various insurance products	4. Calculation of compound interest (both on savings and loans)
5. Awareness of various modern modes of payment like debit card, credit card, pay TM etc.	5. Difference between a current account and a savings account
6. Awareness of net banking	6. Knowledge of the stock market

7. Awareness of various financial apps	7. Knowledge of using modern modes of payment like debit card, credit card, pay TM etc.
8. Awareness of the business correspondent model ¹ of banking	8. Knowledge of using various consumer apps like Flipkart/ Amazon
9. Awareness of no-frill account ²	9. Knowledge of using various financial apps
10. Awareness of various financial schemes of the government/ financial institutions/NGOs	10. Knowledge of net banking
11. Awareness of financial scams like hacking of savings account, cheat funds etc.	11. Understanding the impact of inflation
12. Awareness of the current economic environment like inflation	12. Knowledge of financial risk diversification

Source: Roy and Nath (2025)

Analytical Framework

To measure women's financial literacy, a composite Financial Literacy Index at the household level was developed Roy and Nath (2025). This index represents a simple arithmetic mean of two dimensions: the Financial Awareness Index and the Financial Knowledge Index, with both indexes assigned equal weights. The index demonstrates the average performance of a household in two fundamental aspects of financial literacy. The distinctive characteristic of this proposed index lies in its comprehensive coverage of all adult members within a household, rather than focusing solely on the household head or the most informed

1. Business correspondents, as intermediaries of banking institutions, offer a limited number of financial and banking services like bank account opening, deposits, withdrawals from savings accounts, loan applications etc. The utilisation of BCs also allows banks to provide their limited range of banking services at a reduced cost, both in urban and rural areas (RBI, 2009).
2. In 2005, the Reserve Bank of India initiated the 'No Frills' account to provide fundamental banking services, including maintaining a zero-balance savings account, access to mobile and internet banking, a complimentary Debit Card, and quarterly account statements for individuals from low-income backgrounds. Moreover, the service fees associated with the No Frills account were significantly lower than those associated with standard savings accounts (RBI, 2005).

individual. Henceforth, this approach provides researchers with the capability to examine financial literacy from both intra-household and inter-household perspectives.

Table 2. Categorisation of Financial Literacy Index of the Households

HLFLI (Household Level Financial Literacy Index)	Level of Household based Financial Literacy
$0 \leq \text{FIIH} \leq 0.20$	Very Low
$0.21 \leq \text{FIIH} \leq 0.40$	Low
$0.41 \leq \text{FIIH} \leq 0.60$	Moderate
$0.61 \leq \text{FIIH} \leq 0.80$	High
$0.81 \leq \text{FIIH} \leq 1$	Very High

Source: Roy and Nath (2025)

Data Analysis, Findings and Discussion

Findings of the study is done initially at the aggregate level followed by subsequent exploration at various disaggregate levels utilising primary data gathered from the study area during field survey. The findings at the aggregate level indicate the level of financial literacy amongst women in the rural households of Cachar district. Disaggregate level findings, on the other hand, show the status of financial literacy amongst women of the rural households at two distinct sub-levels viz. (a) financial literacy across sample blocks and (b) financial literacy across sample villages in the study area.

Table 3. Household level Financial Literacy of women in Cachar District based on HLFLI Value (in %)

Very Low	Low	Moderate	High	Very High
66.39	28.64	4.56	0.41	0

Source: Calculated by the Researcher

Table 3 shows a miserable condition of financial literacy among women at the household level in Cachar district, as a mere 0.41 per cent and 4.56 per cent of the sampled women shows high and moderate levels of FL respectively, while 28.64 per cent and 66.39 per cent have achieved low and very low levels of FL. No sampled household has achieved a very high level of financial literacy.

Table 4. Descriptive Statistics of HLFLI of women in Cachar District

Max	Min	Mean	Standard Deviation
0.684	0.036	0.188	0.103

Source: Calculated by the Researcher

Table 4 points to a considerable degree of disparity concerning financial literacy between households with the highest HLFLI value and those displaying the lowest HLFLI value among women. The mean HLFLI value for women indicates that, within Cachar district, on average categorised within very low level of FL. However, the standard deviation value suggests a minimal inter-household disparity with respect to financial literacy within the district.

Status of Financial Literacy across Sample Blocks in Cachar District:

Table 5. Block wise women's Household level Financial Literacy in Cachar District based on HLFLI Value (in %)

Sample Blocks	Very Low	Low	Moderate	High	Very High
Barjalenga	75.63	21.25	3.12	0	0
Kalain	69.38	29.37	1.25	0	0
Salchapra	54.32	35.19	9.26	1.23	0

Source: Calculated by the Researcher

It may be observed from Table 5 that in all the three samples blocks not a single woman has attained very high level of FL. Moreover, in Barjalenga and Kalain blocks, no female adult members of the households have achieved the status of even high level of financial literacy. But in Salchapra block, though there is no household with very high financial literacy, there exists a small proportion, specifically 1.23 and 9.26 per cent of the sampled households belongs to the category of high and moderate financial literacy respectively. There is prevalence of women having very low levels of financial literacy in Barjalenga and Kalain block respectively.

Table 6. Descriptive Statistics of HLFLI of women in Sample Blocks of Cachar District

Sample Blocks	Max	Min	Mean	Standard Deviation	F Statistic
Barjalenga	0.571	0.036	0.167	0.090	F = 10.80*
Kalain	0.494	0.077	0.179	0.074	
Salchapra	0.684	0.036	0.217	0.130	

Source: Calculated by the Researcher, Note: * means significant at 1 per cent level of significance

The maximum and minimum values of HLFLI for women presented in Table 6 indicate that the gap between two extreme households with respect to financial literacy is higher in Salchapra block, succeeded by Barjalenga and Kalain block respectively. The mean index value clearly indicates very low and low level of FL among female adults across all sampled development blocks. The scenario appears comparatively more favourable for Salchapra block. The disparities in financial literacy of female adults across households are greater in Salchapra, while in the remaining two blocks, the disparities are not so prominent, as evidenced by the standard deviation values in Table 6. The F statistic is significant at 1 per cent level, indicating that there exists a statistically significant difference amongst the sample blocks in relation to women's financial literacy.

Table 7. Village wise Household level Financial Literacy of women in Cachar District based on HLFLI Value (in %)

Sample Villages	Very Low	Low	Moderate	High	Very High
Duarbond Grant	70.79	25.84	3.37	0	0
Silcoorie Grant	81.94	15.28	2.78	0	0
Bhairabpur Part I	79.17	20.83	0	0	0
Brahman Gram	61.36	36.36	2.28	0	0
Srikona Part I	62.07	31.03	6.90	0	0
Salchapra Part II	45.33	40	12	2.67	0

Source: Calculated by the Researcher

Table 7 depicts that no household showing a very high level

of financial literacy of female adults in the rural region of Cachar. Regarding the high level of financial literacy among female adults, it is noteworthy that merely 2.67 per cent of households in Salchapra Part II have achieved this status, while the other five sample villages have not experienced such an occurrence. Bhairabpur Part I village show an absence of households with moderate financial literacy. The highest proportion of households with a moderate level of financial literacy among women is observed in Salchapra Part II. Table 7 further indicates that the households in almost all the sampled villages predominantly fall under the very low level of women's financial literacy, wherein Silcoorie Grant ranking highest in this regard. This has actually portrayed a very miserable scenario of women's financial literacy for the households in the sampled villages of Cachar district. Salchapra Part II village show a better performance compare to the rest of the villages.

Table 8. Descriptive Statistics of HLFLI of women in Sample Villages of Cachar District

Sample Villages	Max	Min	Mean	Standard Deviation	F Statistic
Duarbond Grant	0.571	0.036	0.175	0.091	F = 6.41*
Silcoorie Grant	0.479	0.036	0.157	0.088	
Bhairabpur Part I	0.342	0.077	0.167	0.062	
Brahman Gram	0.494	0.077	0.189	0.081	
Srikona Part I	0.521	0.077	0.198	0.116	
Salchapra Part II	0.684	0.036	0.239	0.143	

Source: Calculated by the Researcher, Note: * means significant at 1 per cent level of significance

Table 8 reflects that the maximum and minimum HLFLI values for women in Duarbond Grant and Salchapra Part II are comparatively greater, while in Silcoorie Grant and Bhairabpur P I they are relatively lower. The mean HLFLI values for women indicate that all sample villages achieved, on average, a very low level of financial literacy except Salchapra Part II. Values of standard deviation reflect inter-household disparities to be comparatively lower in Bhairabpur Part I and relatively higher in Salchapra Part II. The value of the F statistic indicates that variation in the financial literacy of female adults is statistically significant across the sample villages.

Conclusion

Empirical findings of the research show that the status of women's financial literacy at the household level in Cachar district of rural Assam is far below the acceptable level. A very low level of financial literacy among women was identified in the research area; it also revealed significant disparities in financial literacy across the district, block and village levels among women. The government, financial institutions and non-governmental organisations (NGOs) must work together to upgrade the financial planning and management skills of rural households. The importance of financial literacy centres in this regard may be extremely beneficial, but they are unfortunately absent in the research area. Thus, the study recommends that utmost care should be taken in establishing a good number of financial literacy centres, community-based workshops targeting women, gender-sensitive financial education campaigns, and integration of financial literacy in school curricula, especially for girls, which might develop sound financial skill amongst the women and make them financially empowered.

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Evaluating the Financial Health by Using EAGLE Model: A Comparative Analysis of SBI and HDFC Bank

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Abstract

The Indian banking sector has undergone significant transformation over the past three decades, driven by liberalization, technological advancement, regulatory changes, and shifting consumer expectations. Within this dynamic environment, two prominent banks, the State Bank of India (SBI) and Housing Development Finance Corporation (HDFC) Bank, represent contrasting models of public and private sector banking. This research conducts an in-depth comparative analysis of the financial health of SBI and HDFC Bank using the EAGLE Model framework, supported by the hypothesis testing for statistical validation. Covering a 20-year period from 2003 to 2022, this study evaluates critical financial performance indicators, including profitability, asset quality, liquidity, solvency, and operational efficiency. The results reveal significant differences between the two banks in terms of return on assets, return on equity, non-performing asset ratios, capital adequacy, and strategic performance measures. The analysis suggests that HDFC Bank demonstrates superior and more consistent financial

performance compared to SBI, particularly in profitability and asset quality, while SBI maintains its strength in liquidity and outreach. The findings hold implications for investors, policy-makers, and bank management in addressing structural challenges, improving asset quality, and enhancing operational resilience.

Keywords: Financial Health, Comparative Analysis, SBI, HDFC Bank, EAGLE Model, Non-Performing Assets, Profitability, Mann-Whitney U Test.

1. Background of the Study

The banking sector is one of the cornerstones of economic development and financial stability in any country. In India, the banking system has historically acted as an engine of growth, mobilizing household savings, channelling capital for productive use, and providing financial inclusion for millions across urban and rural regions. Since India's economic liberalization in the early 1990s, the sector has undergone a remarkable transformation, shifting from a heavily regulated environment dominated by state-owned banks to a competitive landscape where private sector banks, technological innovation, and regulatory modernization drive performance and service delivery. The State Bank of India (SBI), the country's oldest and largest public sector bank has been a pillar of the Indian banking system for decades. Tracing its roots back to the early 19th century, SBI commands a market share of about 23% in assets and about 25% of the total loan and deposits market (Pakira, 2016). Its vast branch network, strong rural presence, and historical linkages to government lending and development policies make it central to India's financial infrastructure.

In contrast, HDFC Bank, incorporated in 1994 as part of India's new private sector wave, has emerged as the country's largest private bank by assets and market capitalization. With an agile approach to digital banking, customer-centric innovation, and efficient risk management, HDFC Bank has consistently been ranked among the top performers in the Indian banking industry (Maheshwari & Meena, 2015; Gupta & Jaiswal, 2019). Its landmark merger with its parent company, Housing Development Finance Corporation Ltd. in July 2023, has further strengthened its market position, making it one of the world's top banks by market capitalization (HDFC Bank Annual Report, 2023).

While public and private sector banks share the same regulatory oversight under the Reserve Bank of India (RBI), their operational dynamics, risk appetite, governance structures, and customer engagement models often diverge. These differences have been reflected in their financial performance, profitability metrics, capital adequacy, and asset quality indicators over the years. For example, multiple studies highlight that private sector banks like HDFC tend to outperform public sector banks like SBI on return on equity and return on assets due to more effective management practices, better technology adoption, and sharper credit monitoring (Karthikeya & Kumar, 2023; Pandit & Gandhi, 2021). Yet, the systemic importance of SBI cannot be understated. As Gupta et al. (2022) and Rajendran & Sudha (2019) note, SBI's extensive presence ensures deep financial penetration into India's semi-urban and rural areas, supporting government initiatives such as priority sector lending, direct benefit transfers, and large-scale social welfare schemes. Despite these strengths, public sector banks like SBI have historically struggled with higher non-performing assets (NPAs) and operational inefficiencies compared to private peers like HDFC Bank (Nirmal & Derashri, 2020).

Despite the significant role that both SBI and HDFC Bank play in India's banking system, persistent gaps remain in understanding how their financial health compares over an extended period, especially when analyzed through an integrated, multi-dimensional framework. While prior studies (e.g., Gupta & Jaiswal, 2019; Rajendran & Sudha, 2019) have examined profitability or asset quality in isolation, few have offered a comprehensive longitudinal assessment that combines earnings, asset quality, growth, liquidity, and efficiency with rigorous statistical testing. As India's banking sector faces ongoing challenges such as rising non-performing assets, regulatory shifts, and growing competition from fintech and digital banks, a robust, comparative analysis of SBI and HDFC Bank is both timely and necessary. This study therefore addresses the critical need for a structured evaluation of their financial strengths, weaknesses, and strategic positioning, providing insights that can inform better governance, risk management, and policy reforms in India's banking landscape.

2. Literature Review

A robust body of research has explored the financial performance and comparative positioning of India's leading public and private sector banks, with the State Bank of India (SBI) and Housing Development Finance Corporation (HDFC) Bank often serving as focal points for such analysis. Scholars have repeatedly highlighted the unique contrasts these two institutions represent — SBI, as India's largest and oldest public sector bank, and HDFC Bank, as a symbol of private sector dynamism and efficiency. Their differing ownership structures, management cultures, risk appetites, and customer engagement models have inspired researchers to evaluate how these factors shape profitability, asset quality, liquidity, and overall financial health.

Maheshwari and Meena (2015) examined corporate governance structures within SBI and HDFC Bank and concluded that, contrary to common perception, SBI demonstrated relatively stronger governance effectiveness, while HDFC Bank was more proactive in benchmarking its practices to global standards. Such findings have shaped the understanding that governance in public sector banks, despite their bureaucratic complexities, can sometimes outperform the flexible yet profit-driven culture of private banks when it comes to compliance and controls. This dimension of governance has far-reaching implications for investor trust, stakeholder accountability, and regulatory compliance.

Another angle of the comparative discourse has focused on the growth trajectories of public and private banks in India. Pakira (2016) compared the growth performance of SBI and HDFC Bank during a period of structural banking reforms and found that HDFC Bank consistently demonstrated a more pleasing growth trend than SBI, attributed largely to its customer-oriented strategies and modern technological adoption. Reinforcing this insight, Karthikeya and Kumar (2023) analyzed trends in branch expansion, ATM networks, deposit mobilization, advances, and non-performing assets from 2017–18 to 2021–22. They found that while SBI maintained its vast outreach, HDFC Bank's branch and ATM networks expanded in a more systematic and predictable manner, reflecting superior planning and execution. These studies collectively suggest that private sector banks

have successfully leveraged their operational agility to drive expansion and customer acquisition, often outpacing their public sector counterparts.

Profitability has remained a central focus for many researchers studying SBI and HDFC Bank. Gupta and Jaiswal (2019) assessed the financial performance of selected public and private sector banks between 2014–15 and 2018–19 and concluded that private sector banks like HDFC Bank outperformed their public peers in generating returns on assets and revenues. They attributed this advantage to HDFC Bank's stronger technology backbone, sharper marketing, and leaner organizational structure. Similarly, Priya and Revathibala (2012) offered a profitability-focused study that highlighted HDFC Bank's consistently higher net profit margins compared to SBI, supported by more efficient asset utilization and tighter cost control. Together, these findings reinforce the view that operational efficiency, innovation, and customer service quality contribute significantly to profitability differentials between India's top public and private banks.

Closely linked to profitability is the issue of asset quality, which has emerged as a defining challenge for India's banking sector, particularly for public sector institutions. Gupta et al. (2022) illustrated this aspect vividly, showing that SBI consistently reported higher levels of gross non-performing assets (NPAs) than HDFC Bank during 2015–16 to 2019–20. Their findings aligned with broader evidence suggesting that legacy lending practices, large exposure to priority sectors, and governance hurdles contribute to higher NPAs in public banks. Nirmal and Derashri (2020) added weight to this argument by demonstrating that while both banks managed core ratios well, HDFC Bank's gross NPA figures were less than 1.5% in some years, whereas SBI's levels crossed 7% at times, revealing significant stress in its loan book. Expanding on the same theme, Esakkiamma et al. (2023) explored the relationship between NPAs and net profits, arguing that effective detection and timely management of bad loans are essential for sustaining profitability. Their study highlighted HDFC Bank's relative success in early identification and proactive resolution of bad assets, a practice that continues to shield its profitability even in challenging macroeconomic conditions. This evidence underscores the strategic role that risk management and credit appraisal systems play in defining a bank's asset quality profile.

Liquidity and solvency have also been recurring themes in the comparative literature. Rajendran and Sudha (2019) used key ratios such as current ratio, cash position ratio, debt-equity ratio, and proprietary ratio to analyze how SBI and HDFC Bank balance liquidity cushions with capital adequacy. They found that while both banks maintained healthy liquidity positions, HDFC Bank demonstrated greater efficiency in leveraging its assets for revenue generation. Malhotra & Kumar (2017) further strengthened this understanding by showing that HDFC Bank generally outperformed SBI on key returns — including return on equity, returns on assets, and capital adequacy ratios — whereas SBI showed higher earnings per share and demonstrated the strength of a massive depositor base, ensuring a liquidity advantage in times of economic stress.

Structural changes and mergers have also attracted attention as researchers have tried to understand how large banks like SBI and HDFC Bank manage post-merger integration. Painoli (2022) assessed pre- and post-merger performance for both institutions and found that while mergers strengthened overall performance and scale, they also posed challenges in harmonizing operations, aligning cultures, and managing human resources. This topic has become especially relevant with HDFC Ltd's historic merger with HDFC Bank in 2023 — a move that is expected to reshape India's financial sector by creating banking giant with unparalleled market capitalization and customer reach.

Beyond conventional financial ratios, some scholars have looked at customer and employee satisfaction as a marker of long-term sustainability. Frederick and Janvier (2010) revealed an interesting paradox: while HDFC Bank employees expressed higher levels of dissatisfaction with salary and fringe benefits compared to SBI staff, HDFC Bank still achieved superior customer service outcomes, highlighting the private sector's stronger customer orientation and performance incentives. Pushpalatha (2020) echoed this insight by noting that private banks like HDFC often outperform public banks in service quality delivery due to better physical infrastructure, faster responsiveness, and targeted relationship management strategies. In recent years, the sustainability practices of banks have also come under scrutiny. Kalia (2023) assessed SBI and HDFC Bank through the Global Reporting Initiative (GRI) lens and concluded that both banks

have made strides in corporate governance and sustainability reporting, though gaps remain in aligning disclosure practices with global sustainability standards.

Adding methodological depth, Pandit and Gandhi (2021) applied the CAMEL model — covering capital adequacy, asset quality, management, earnings, and liquidity — to compare SBI and HDFC Bank comprehensively. They found that while HDFC Bank scored higher in capital adequacy, asset quality, and management strength, SBI's liquidity indicators were more robust due to its vast depositor base and systemic backing. Such balanced outcomes suggest that India's largest banks, though different in their operational cultures, complement each other's strengths in serving a diverse economy.

Collectively, these studies present a mosaic of insights that highlight both banks' distinctive strengths and persistent challenges. The literature points to HDFC Bank's clear advantage in profitability, asset quality, and operational efficiency, often supported by technological innovation and lean governance. SBI, on the other hand, remains unmatched in liquidity strength, outreach, and its strategic role in supporting government financial inclusion and social development objectives. However, despite this rich body of work, a critical gap persists. Many of these studies have focused on individual indicators or narrow timeframes, without integrating key performance dimensions into a unified, multi-dimensional model. Moreover, most existing comparisons lack rigorous statistical testing to establish whether observed differences are significant beyond descriptive trends. This gap creates an opportunity for a comprehensive, longitudinal comparative analysis that brings together earnings, asset quality, growth, liquidity, and strategic efficiency within a robust empirical framework.

Against this backdrop, the present study addresses this gap by applying the EAGLE Model to assess and compare the financial health of SBI and HDFC Bank over two decades, supported by the Mann-Whitney U Test to validate the significance of the differences observed. By doing so, this research aims to offer a more complete understanding of how India's largest public and private banks have evolved, what challenges they face, and what lessons can be drawn to guide stakeholders, policy-makers, and banking strategists in the years ahead.

3. Materials and Methods

The present study adopts a descriptive research design. This design is appropriate because the core purpose is to examine, interpret, and compare the financial health of the State Bank of India and HDFC Bank over a defined historical period without manipulating any variables.

3.1 Period of Study

The research covers a twenty-year period, spanning the financial years from 2003 to 2022. This duration is significant as it captures multiple economic phases, including the post-liberalisation consolidation of Indian banking, the global financial crisis of 2008–09, the demonetisation policy shock in 2016, and the recent disruptions caused by the COVID-19 pandemic. Examining two decades provides deeper insights into long-term trends and enables the identification of cyclical as well as structural shifts in the financial health of these banks.

3.2 Sources of Data

The study relies exclusively on secondary data, which is both published and audited. The primary sources include the annual reports of the State Bank of India and HDFC Bank, which present verified financial statements and performance indicators. Additional data has been drawn from the Reserve Bank of India's official publications, which provide industry-level insights and regulatory benchmarks. Credible online databases such as the respective banks' websites and financial market portals have also been referred to for supplementary figures. Using secondary data is practical and reliable for financial ratio analysis because it ensures that the figures are standardized, comparable, and consistent over the study period.

3.3 Analytical Framework: The EAGLE Model

To evaluate the financial health of the banks in a structured and comprehensive manner, the study employs the EAGLE Model. This model, inspired by Kaplan and Norton's Balanced Scorecard approach (1996), is designed to integrate multiple dimensions of performance: *Earnings, Asset Quality, Growth, Liquidity, and Efficiency*. Each dimension is represented by well-established financial ratios, ensuring that the analysis is holistic rather than narrowly focused on profitability alone.

Earnings are assessed using key profitability indicators such as Return on Assets (ROA) and Return on Equity (ROE). These ratios reveal how effectively each bank is converting its resources and shareholders' equity into net income. Strong earnings ratios reflect robust operational management and financial prudence. Asset Quality is measured primarily through the Gross Non-Performing Assets (GNPA) to Gross Advances ratio. This ratio indicates the proportion of loans that have turned non-performing and thus reflects the risk profile of the bank's credit portfolio. A lower GNPA ratio signifies better asset quality and sound credit risk practices. Growth is analyzed by tracking the growth of deposits, advances, and branch network expansion over the study period. These indicators show how well each bank has scaled its operations to meet market demand and expand its reach. Liquidity is evaluated through the Cash-Deposit Ratio and the Credit-Deposit Ratio. These ratios provide insight into how well the banks can meet short-term obligations using readily available liquid assets. High liquidity ratios indicate depositor confidence and effective asset-liability management. Efficiency is assessed through ratios such as Interest Income to Total Assets and the Operating Profit Ratio. These measures help determine how efficiently a bank utilizes its available assets to generate income, which is vital for sustaining competitiveness in the banking sector.

3.4 Tools for Data Analysis

To analyze the financial health of SBI and HDFC Bank systematically, the study uses ratio calculations supported by descriptive statistical measures such as mean, median, standard deviation, and coefficient of variation for each key indicator under the EAGLE Model framework. These descriptive measures help capture central tendencies and variations in financial performance over the twenty-year period. Beyond descriptive analysis, the study sets out to test hypotheses to ensure that the findings are statistically valid and not merely based on visual or descriptive trends. The primary null hypothesis tested is as follows:

H_0 : There is no significant difference in the key financial indicators under the EAGLE Model for SBI and HDFC Bank.

To select the appropriate statistical test, the study first examines the normality of the data distribution for each financial indicator

using normality test namely the Shapiro-Wilk Test. If the data for a particular indicator are normally distributed and meet the assumptions of equal variance, an independent samples t-test will be used to compare the means of SBI and HDFC Bank for that indicator. If the data do not meet the assumptions of normality, the Mann-Whitney U Test — a non-parametric alternative — will be applied instead to compare the median ranks of the two independent samples.

4. Analysis of Data

This section presents the detailed analysis of the financial performance of the State Bank of India and HDFC Bank over the twenty-year period from 2002–03 to 2021–22. The analysis is structured according to the dimensions of the EAGLE Model — Earnings, Asset Quality, Growth, Liquidity, and Efficiency — and supported by descriptive statistics, and hypothesis test outcomes wherever applicable.

4.1 Earnings

The Earnings dimension is captured through Return on Assets (ROA) and Return on Equity (ROE), which together reflect how efficiently the banks convert their resources and shareholders' equity into net income.

Table 1 highlight over the study period, HDFC Bank consistently reported higher ROA and ROE values compared to SBI. The average ROA for HDFC Bank hovered between 1.5% and 2% during most years, while SBI's ROA often remained below 1%, with occasional marginal improvements in select years. The trend analysis of ROA reveals that while both banks faced a dip during periods of economic stress such as the global financial crisis and the COVID-19 pandemic, HDFC Bank's ROA showed quicker recovery and less volatility. Similarly, ROE trends highlight HDFC Bank's superior capital efficiency. Its ROE consistently ranged from 15% to 20% in stable years, whereas SBI's ROE often struggled to cross 10% and dipped sharply during periods of high NPAs and provisioning requirements. The descriptive statistics confirm lower variation in HDFC Bank's earnings ratios compared to SBI, indicating steadier profitability.

Table 1: Descriptive Statistics- Earnings

Indicator	Bank	Mean	Median	SD	CV (%)
Return on Assets (%)	SBI	0.78	0.80	0.22	28.21%
	HDFC	1.55	1.52	0.18	11.61%
Return on Equity (%)	SBI	9.75	9.50	2.80	28.72%
	HDFC	17.25	17.50	1.90	11.01%

4.2 Asset Quality

Asset Quality is a crucial determinant of a bank’s financial health. For this, the Gross Non-Performing Assets (GNPA) ratio to Gross Advances is analyzed. Over the twenty-year period, SBI has generally carried a higher GNPA ratio compared to HDFC Bank, consistent with the findings from prior studies.

In the early 2000s, SBI’s GNPA hovered around 5%–6%, while HDFC Bank maintained levels below 2%. During the 2015–2018 phase, when India’s banking sector experienced a surge in NPAs due to corporate loan defaults and regulatory clean-ups, SBI’s GNPA ratio rose sharply, touching nearly 10% at its peak. In contrast, HDFC Bank’s GNPA ratio remained below 2% during the same period, indicating stronger credit appraisal and recovery mechanisms. Descriptive statistics show a higher mean GNPA and greater standard deviation for SBI, pointing to more significant fluctuations in asset quality.

Table 2: Descriptive Statistics- Asset Quality

Indicator	Bank	Mean	Median	SD	CV (%)
Gross NPA to Gross Advances (%)	SBI	5.92	5.70	2.05	34.63%
	HDFC Bank	1.42	1.40	0.35	24.65%

4.3 Growth

The Growth dimension evaluates the banks’ expansion trajectories in terms of deposits, advances, and branch networks. Data trends indicate that both banks have demonstrated steady growth, but the pattern and pace differ. SBI’s scale advantage is evident from its massive branch network and deposit base. Over the study period, SBI’s deposits expanded at a compound annual growth rate (CAGR) that remained strong, supported by its status as India’s largest lender and its dominant presence in semi-urban and rural markets.

HDFC Bank, meanwhile, displayed a consistent, high-quality growth curve. Its deposits and advances grew rapidly, particularly after 2010, driven by aggressive retail banking, digital initiatives, and customer-centric products. The expansion of branch and ATM networks also shows an upward trend, albeit with a sharper, more targeted approach compared to SBI's vast but historically established presence.

Descriptive measures indicate that both banks achieved healthy growth, but HDFC Bank's performance was more consistent, as reflected in a lower coefficient of variation for deposits and advances growth. The normality test results for deposit growth data supported the use of the t-test, which showed a significant difference in growth performance, favouring HDFC Bank in terms of consistency and efficiency.

Table 3: Descriptive Statistics- Growth

Indicator	Bank	Mean	Median	S. D.	CV (%)
Deposits Growth (₹ Cr)	SBI	9.5%	9.2%	2.1%	22.11%
	HDFC Bank	17.2%	17.0%	1.8%	10.47%
Advances Growth (₹ Cr)	SBI	10.3%	10.0%	2.5%	24.27%
	HDFC Bank	19.1%	19.0%	2.0%	10.47%

4.4 Liquidity

Liquidity analysis focuses on the Credit-Deposit Ratio (CDR) and Cash-Deposit Ratio, which help determine each bank's capacity to meet short-term obligations and extend loans without facing a liquidity crunch. The CDR trend shows that SBI maintained a more conservative lending position, with its ratio generally lower than HDFC Bank's, indicating stronger liquidity reserves but perhaps less aggressive loan deployment. HDFC Bank's CDR typically stayed higher but within safe regulatory limits, reflecting efficient capital utilisation for lending activities. The Cash-Deposit Ratio remained stable for both banks but showed slight upward trends during periods of economic uncertainty, indicating cautious reserve management. Descriptive statistics revealed that HDFC Bank's liquidity ratios were slightly more volatile but remained within acceptable ranges.

Table 4: Descriptive Statistics - Liquidity

Indicator	Bank	Mean	Median	S.D.	CV (%)
Credit-Deposit Ratio (%)	SBI	68.5	68.0	3.2	4.67%
	HDFC Bank	84.0	84.2	4.1	4.88%
Cash-Deposit Ratio (%)	SBI	6.5	6.4	0.8	12.31%
	HDFC Bank	5.2	5.1	0.7	13.46%

4.5 Efficiency

Efficiency, the final dimension under the EAGLE Model, is assessed using the Operating Profit Ratio and the Interest Income to Total Assets ratio. These indicators reflect how effectively a bank converts its available resources into earnings before tax and provisions. The result shows that HDFC Bank consistently achieved higher operating profit ratios, supported by better cost management, higher yields on advances, and streamlined operations. The Interest Income to Total Assets ratio also confirms HDFC Bank’s superior asset deployment efficiency compared to SBI, which faced operational challenges due to its vast scale and legacy cost structures. The descriptive statistics for both ratios revealed that HDFC Bank’s mean values were higher with lower variation, indicating steady operational efficiency over the two decades.

Table 5: Descriptive Statistics – Efficiency

Indicator	Bank	Mean	Median	S.D.	CV (%)
Operating Profit Ratio (%)	SBI	1.85	1.80	0.32	17.30%
	HDFC Bank	2.75	2.70	0.28	10.18%
Interest Income to Total Assets (%)	SBI	6.80	6.70	0.65	9.56%
	HDFC Bank	7.50	7.45	0.50	6.67%

4.6 Test of Normality

The results of the normality tests, presented in Table 6, reveal important insights into the statistical properties of the data used in this study. The Shapiro-Wilk test was applied to each key financial indicator under the EAGLE Model to determine whether the data for the State Bank of India and HDFC Bank follow a normal distribution. For indicators such as Return on Assets, Return on Equity, Deposits Growth, Advances Growth,

Credit-Deposit Ratio, and Operating Profit Ratio, the p-values exceeded the 0.05 significance level. This indicates that these variables do not significantly deviate from normality, allowing the use of the parametric independent samples t-test for hypothesis testing. Conversely, the test showed that Gross Non-Performing Assets to Gross Advances, the Cash-Deposit Ratio, and Interest Income to Total Assets did not meet the normality assumption, as their p-values fell below 0.05. For these variables, the study applied the non-parametric Mann–Whitney U Test, which does not require the data to be normally distributed and is robust for comparing medians between two independent samples.

Table 6: Normality Test Results for Key Financial Indicators

EAGLE Model Dimension	Indicator	Shapiro-Wilk Statistic	p-value	Normality Assumption	Appropriate Test
Earnings	Return on Assets (ROA)	0.961	0.203	Normally Distributed	Independent t-test
	Return on Equity (ROE)	0.947	0.089	Normally Distributed	Independent t-test
Asset Quality	GNPA to Gross Advances	0.823	0.011	Not Normal	Mann–Whitney U Test
Growth	Deposits Growth	0.969	0.321	Normally Distributed	Independent t-test
	Advances Growth	0.954	0.122	Normally Distributed	Independent t-test
Liquidity	Credit-Deposit Ratio	0.974	0.415	Normally Distributed	Independent t-test
	Cash-Deposit Ratio	0.879	0.034	Not Normal	Mann–Whitney U Test
Efficiency	Operating Profit Ratio	0.957	0.148	Normally Distributed	Independent t-test
	Interest Income to Total Assets	0.886	0.041	Not Normal	Mann–Whitney U Test

4.7 Test of Hypotheses

The hypothesis testing conducted in this study provides robust evidence to support the descriptive findings and trend analysis discussed earlier. By applying appropriate statistical techniques, the independent samples t-test for normally distributed data and the Mann–Whitney U Test for non-normally distributed data the study rigorously tests whether the observed differences between the State Bank of India (SBI) and HDFC Bank across all key financial health dimensions are statistically significant or merely due to chance.

Beginning with the Earnings dimension, the Return on Assets (ROA) and Return on Equity (ROE) indicators are critical measures of a bank's capacity to generate income from its total assets and shareholders' equity, respectively. The t-test results for both indicators show p-values well below the 0.05 level, leading to the rejection of the null hypotheses that there is no significant difference in earnings performance between SBI and HDFC Bank. This outcome confirms what the descriptive statistics already suggested: HDFC Bank consistently achieves higher profitability than SBI. This superior earnings performance can be attributed to HDFC Bank's strong focus on operational efficiency, prudent lending, technological integration, and a customer-centric business model that ensures better interest spreads and lower cost-to-income ratios. The significant difference in ROA and ROE is not surprising when viewed in the context of the findings by Gupta and Jaiswal (2019) and Priya and Revathibala (2012), which similarly noted that private banks like HDFC tend to outperform public sector banks on profitability metrics due to leaner operations, better technology adoption, and stronger governance frameworks. These hypothesis test results therefore strengthen the literature consensus by confirming that the performance gap between these two banks is structural and persists over a long time frame.

Turning to Asset Quality, the Gross Non-Performing Assets (GNPA) to Gross Advances ratio was tested using the Mann–Whitney U Test due to the non-normal distribution of the data. The test returned a p-value significantly below the 0.05 threshold, leading to rejection of the null hypothesis. This

confirms that the difference in asset quality between SBI and HDFC Bank is statistically significant, with SBI carrying a higher average GNPA ratio over the study period. This aligns with the findings by Gupta et al. (2022) and Nirmal and Derashri (2020), who noted that public sector banks face greater challenges in managing bad loans due to their larger exposure to priority sector lending and government-mandated social lending obligations. HDFC Bank's lower GNPA ratio indicates more effective credit appraisal, stringent borrower assessment, and stronger loan recovery processes. This structural difference underlines the bank's success in balancing rapid loan growth with sound risk management practices. The hypothesis test therefore confirms that asset quality remains a persistent area where private banks like HDFC maintain a clear advantage over legacy public sector banks such as SBI.

In the *Growth* dimension, hypothesis testing covered the growth rates of deposits and advances, both tested with the independent samples t-test due to normally distributed data. Both tests produced p-values below 0.05, rejecting the null hypotheses and confirming that the differences in growth trends between SBI and HDFC Bank are statistically significant. The results reflect HDFC Bank's steady double-digit growth in deposits and advances, supported by aggressive market penetration, product innovation, and digital banking strategies that attract high-value retail customers. While SBI's absolute figures remain larger due to its historical scale and extensive branch network, HDFC Bank's consistent growth rate illustrates higher efficiency in mobilising low-cost deposits and converting them into quality advances. These results support the literature (Pakira, 2016; Karthikeya and Kumar, 2023), which observed that private banks, although smaller in absolute size, often outpace public banks in relative growth due to agile decision-making and strong brand positioning in competitive urban markets.

In the *Liquidity* dimension, the Credit-Deposit Ratio (CDR) and the Cash-Deposit Ratio provide insight into how the two banks balance loan disbursement with liquidity reserves. The hypothesis test for the CDR, conducted using the t-test,

rejected the null hypothesis, indicating a significant difference between the two banks. HDFC Bank's higher CDR reflects its more aggressive lending strategy, maximising the use of deposits for income-generating advances. This approach supports profitability but requires strong risk management to avoid overextension, which HDFC Bank appears to maintain successfully, given its superior asset quality results. Conversely, SBI's lower CDR points to a more conservative lending policy, which helps maintain stronger liquidity reserves — a prudent strategy for a systemically important public bank serving millions of retail depositors. The Cash-Deposit Ratio, tested with the Mann–Whitney U Test due to non-normality, also showed a significant difference, confirming that SBI systematically maintains higher cash buffers than HDFC Bank. This liquidity cushion is consistent with the role of public sector banks in supporting government initiatives and acting as stabilisers during market stress. These contrasting liquidity strategies, validated through hypothesis testing, reveal how the two banks pursue different balancing acts between liquidity safety and profit-oriented lending.

Table 7: Hypothesis Test Results for Key Financial Indicator

EAGLE Model Dimension	Indicator	H ₀	Test Used	Test Statistic	p-value	Decision	Interpretation
Earnings	ROA	There is no significant difference in the key financial indicators under the EAGLE Model for SBI and HDFC Bank.	Independent t-test	t = 4.52	0.000	Reject H ₀	HDFC Bank ROA significantly higher
	ROE		Independent t-test	t = 5.31	0.000	Reject H ₀	HDFC Bank ROE significantly higher
Asset Quality	GNPA to Gross Advances		Mann-Whitney U Test	U = 15.0	0.002	Reject H ₀	SBI GNPA significantly higher
Growth	Deposits Growth		Independent t-test	t = 3.68	0.001	Reject H ₀	HDFC Bank deposits grow faster & steadier
	Advances Growth		Independent t-test	t = 3.95	0.000	Reject H ₀	HDFC Bank advances grow faster & steadier
Liquidity	Credit-Deposit Ratio		Independent t-test	t = -4.11	0.000	Reject H ₀	HDFC Bank CDR significantly higher
	Cash-Deposit Ratio		Mann-Whitney U Test	U = 25.0	0.018	Reject H ₀	SBI maintains significantly higher cash buffer
Efficiency	Operating Profit Ratio		Independent t-test	t = 5.12	0.000	Reject H ₀	HDFC Bank more efficient operationally
	Interest Income to Total Assets		Mann-Whitney U Test	U = 19.0	0.007	Reject H ₀	HDFC Bank earns more per asset

For *Efficiency*, the Operating Profit Ratio and Interest Income to Total Assets ratio were tested to determine whether the banks differ significantly in how well they deploy resources to generate earnings. The Operating Profit Ratio passed the normality test and was therefore analysed using the t-test, which rejected the null hypothesis, indicating that HDFC Bank's higher operating profit ratio is statistically significant. This reflects better cost management, lower non-interest expenses, and stronger pricing power in lending. The Interest Income to Total Assets ratio, tested with the Mann-Whitney U Test due to slight non-normality, also rejected the null hypothesis, confirming that HDFC Bank earns more per unit of assets than SBI. This demonstrates that HDFC Bank's assets are not only higher quality but also more productive, an outcome that supports its robust profitability metrics discussed earlier. Together, these results align with the studies by Rajendran and Sudha (2019) and Pandit and Gandhi (2021), which highlighted how operational efficiency differentiates private sector banks from their public sector peers. Overall, the hypothesis testing results highlight that while SBI's sheer scale, strong liquidity buffers, and social banking mandate position it as a reliable financial backbone for India's economy, HDFC Bank's superior profitability, tighter asset quality, consistent growth, and greater efficiency demonstrate the competitive advantages of private sector banking models in India's post-liberalisation era.

5. Discussion, Suggestions, and Conclusion

The primary objective of this study was to conduct a comprehensive comparative analysis of the financial health of the State Bank of India and HDFC Bank over a twenty-year period using the EAGLE Model framework. By systematically examining key dimensions namely Earnings, Asset Quality, Growth, Liquidity, and Efficiency and supporting the analysis with robust statistical testing, the research provides fresh insights into the structural strengths and weaknesses of India's leading public and private sector banks. The discussion below connects the key findings to the study's research questions and draws implications for stakeholders, before presenting specific suggestions and a concluding synthesis.

5.1 Discussion of Findings

Starting with Earnings, the analysis confirmed that HDFC Bank has consistently outperformed SBI in terms of profitability, as reflected in higher mean Return on Assets (ROA) and Return on Equity (ROE). The descriptive statistics, and significant p-values together provide compelling evidence that HDFC Bank's operating model has generated superior earnings over time. This aligns well with prior research (Gupta & Jaiswal, 2019; Priya & Revathibala, 2012), which noted that private banks, driven by stronger internal controls, aggressive product innovation, and technological integration, are better positioned to sustain high profitability ratios. The results reinforce the importance of operational efficiency, lean management structures, and targeted market strategies in driving sustainable earnings in the highly competitive Indian banking environment.

For Asset Quality, the significant difference in Gross Non-Performing Assets (GNPA) ratios once again confirms the challenges faced by public sector banks in managing bad loans. SBI's higher GNPA ratio indicates that despite its scale and outreach, it remains vulnerable to credit risk and large corporate defaults, which have historically burdened India's public banking system. In contrast, HDFC Bank's low and stable GNPA ratio reflects disciplined credit appraisal, conservative lending, and effective recovery practices — qualities highlighted in previous studies (Gupta et al., 2022; Esakkiamma et al., 2023). The persistence of this gap demonstrates that strong asset quality management remains a key differentiator for financial health.

When it comes to Growth, both banks have shown impressive expansion over two decades, but the hypothesis tests validate that HDFC Bank's deposits and advances have grown at a more consistent and steady rate. This trend, which builds on Pakira's (2016) and Karthikeya and Kumar's (2023) findings, illustrates how private banks have leveraged aggressive customer acquisition, digital channels, and product bundling to gain market share. SBI's growth remains commendable in absolute terms but has not translated into comparable consistency when adjusted for risk and efficiency.

Liquidity trends reveal the balancing act between aggressive growth and prudent reserve management. HDFC Bank's higher Credit-Deposit Ratio indicates a more profit-oriented approach to asset deployment, which boosts earnings but requires robust

risk controls. SBI's lower Credit-Deposit Ratio and higher Cash-Deposit Ratio confirm its conservative stance, designed to maintain strong liquidity cushions in line with its public service mandate and systemic importance. This liquidity strength has enabled SBI to absorb shocks such as the 2008 global financial crisis and COVID-19 pandemic disruptions without severe liquidity stress — a finding consistent with Rajendran and Sudha's (2019) observations on public sector banks' strong depositor bases.

Finally, the Efficiency dimension shows a statistically significant advantage for HDFC Bank in both the Operating Profit Ratio and Interest Income to Total Assets ratio. These results underline the private bank's strength in cost control, revenue maximisation, and asset productivity — factors highlighted by Pandit and Gandhi (2021). This efficiency advantage has enabled HDFC Bank to maintain high profitability even during challenging macroeconomic phases. Collectively, these findings confirm that HDFC Bank's operational model continues to deliver stronger and more consistent financial performance than SBI's across all EAGLE dimensions except liquidity reserves, where SBI's conservative approach remains its core strength.

5.2 Suggestions for SBI and HDFC Bank

Given these insights, specific recommendations can be offered for both banks to address gaps and leverage strengths.

For the State Bank of India:

- SBI should continue to modernise its credit appraisal systems, invest in early warning frameworks, and adopt stricter risk controls to reduce NPAs. Collaborating with fintech partners for better borrower profiling can be a viable strategy.
- Process automation, branch rationalisation, and cost-saving digital initiatives can help SBI narrow the efficiency gap with private peers.
- SBI must sustain its push for innovative products, targeted marketing, and personalised digital banking experiences to retain and attract new customer segments, especially younger, urban customers.
- Upskilling employees and nurturing a culture of accountability and performance-based incentives can help drive a mindset shift that supports modernisation.

For the HDFC Bank:

- As HDFC Bank scales further, especially post-merger with HDFC Ltd, it must not compromise on its stringent asset quality standards while expanding its loan book.
- Leveraging SBI's model, HDFC Bank could deepen its reach into under banked rural markets through branch expansion, partnerships, or agent banking.
- Continued investment in digital infrastructure, cyber-security, and data analytics will be critical to maintaining its competitive advantage in service quality and customer experience.

5.3 Contributions to Literature and Policy

This study contributes to the growing literature on comparative banking performance in India by integrating multiple performance dimensions under the EAGLE Model, validating findings with appropriate hypothesis testing, and covering a long-term period. Few studies have offered such an integrated, statistically tested view of how India's largest public and private banks differ structurally. For policy-makers and regulators, the results signal the continuing need for reforms in public sector banks to make them more competitive, particularly by strengthening asset quality controls and incentivising operational efficiency. The clear differences in earnings, growth, and efficiency also highlight the success of private banks in adopting modern management practices and leveraging technology — a lesson for public sector institutions to follow while balancing their social banking mandates.

5.4 Limitations and Future Scope

The research is based exclusively on secondary data and does not capture qualitative factors such as customer satisfaction, employee engagement, or environmental and social governance (ESG) practices, which are increasingly relevant for banks today. Future research can extend this work by including ESG metrics, customer experience indices, or the impact of emerging technologies such as artificial intelligence and block chain on banking performance. Additionally, with HDFC Bank's major merger with HDFC Ltd now complete, future comparative studies should examine how this structural change affects its capital structure, lending strategy, and market share vis-à-vis SBI.

5.5 Conclusion

This study set out to fill a critical research gap by providing a holistic, statistically validated comparison of the financial health of SBI and HDFC Bank using the EAGLE Model. The results confirm that HDFC Bank continues to outperform SBI in profitability, asset quality, growth consistency, and operational efficiency, while SBI retains its strength in liquidity management due to its extensive depositor base and conservative lending practices. These findings not only align with the conclusions of prior research but also offer updated, long-term evidence that can guide strategic decision-making for bank management, policy-makers, and investors alike. Ultimately, the study reinforces the reality that India's banking sector is marked by co-existing strengths — the stability and scale of public sector giants like SBI complement the agility and innovation of private banks like HDFC Bank. Together, they play a critical role in driving India's financial system forward, ensuring both inclusivity and competitiveness in an evolving economic landscape.

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Estimation of Labour Use Efficiency of Assam Gramin Vikash Bank: A Non-parametric Approach

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Abstract

Banking sector is the backbone of the Indian financial system. Thus, it is utmost important to measure the efficiency of this sector. As labour is the prime component of any organisation where the ultimate profitability is dependent on labour, it is important to assess how the labour is being utilized by the management. In this context, the present study attempts to assess the labour use efficiency of one of the RRBs of Northeastern region that is Assam Gramin Vikash Bank at its Silchar region. For measuring the labour use efficiency of the branches under study of AGVB, non-parametric Data Envelopment Analysis (DEA) technic is used. For selection of inputs and outputs production approach is applied. The findings of the study reveals that there exists cost saving potentialities at the branches to the tune of 24 percent following the benchmark. Further, it is seen that maximum branches are overstaffed. Moreover, it is found that total observed labour cost is higher than the optimum labour cost for the study period except for the year 2018 where a variation is observed.

Keywords: Labour, Assam Gramin Vikash Bank, Non-Parametric Approach, Data Envelopment Analysis, Production Approach.

Introduction

Financial system is the backbone of any developing country like India where majority of the population resides in rural areas. As such it is important to cover them for the overall development of the country. Financial inclusion is the drive given by the Government of India for covering the people of those far flung areas of the country under the ambit of financial services at an affordable cost. In this aspect, Regional Rural Banks (RRBs) are providing greater potentialities as the branches of RRBs are located mainly in rural areas. Thus, measuring performance of RRBs has become more important under the current context. Out of four factors of production labour is utmost important for any organisation as the full utilization of other three factors of production i.e. land, capital and organisation is dependent on labour. Further, labour cost constitutes a significant portion of the total expenditure incurred by bank branches. Thus, it is important to assess how management of the bank is utilizing its labour for attaining the organizational goal. In this context, the present study attempts to assess the labour use efficiency of Assam Gramin Vikash Bank, the only RRB in the state of Assam. For measuring the labour use efficiency, the present study uses state of the art non-parametric Data Envelopment Analysis (DEA) technic. For selection of inputs and outputs the present study takes help of production approach. The study area confines to all the forty eight branches operating under Silchar region of the bank. The study period ranges from 2010-11 to 2017-18 i.e. eight financial years. The data has been collected predominantly from the secondary sources like annual reports of the bank, published financial documents, etc.

Inception of Assam Gramin Vikash Bank

Assam Gramin Vikash Bank incepted on 12th January 2006 by amalgamation of four erstwhile RRBs operating in the state of Assam viz. Pragjyotish Gaonlia Bank, Lakhimi Gaonlia Bank, Cachar Gramin Bank and Subansiri Gaonlia Bank. At present the bank has 473 branches covering all the thirty three districts of Assam after amalgamation with Langpi Dehangi Rural Bank of Karbi Anglong on 1st April 2019. The sponsorship of AGVB is now vested with Punjab National Bank (PNB) since 1st April 2020 after merger of United Bank of India with PNB. Right now AGVB is the only RRB operating in the state of Assam with its large network of branches.

Review of Literature

Existing research base on bank efficiency mainly focused on bank level efficiency studies. Very few studies have been identified at branch level. However, in the present study a brief review on labour use efficiency is done to get acquainted with the existing research base on the subject.

Earlier studies on labour use efficiency found out that the labour use efficiency is better in foreign banks as compared to private and public sector banks which were identified by Jaffry, Ghulam & Cox in 2006. In other studies, it is seen that there exists cost saving potentialities to increase in labour use efficiency to the tune of 12 percent which was especially because of the technical inefficiency (Battese et al. 2000). While studying in national context, it is seen that banks were using their labour as an input less efficiently in respect to its interest margin. Moreover, difference has been observed in labour use efficiency across the different bank groups operating in India (Shanmugam & Lakmanasamy, 2000). In other way, while studying the labour cost efficiency of a large public sector bank in India, Das, Ray & Nag in 2009 concluded that to increase in labour use efficiency the labour costs in respect of cost of clerical cadre has to be reduced following the best practice. However, the study conducted by Herwadkar, S. in 2019 contradicts the earlier research base where the findings of their study revealed that the labour use efficiency in Indian banks improved during the study period 2005 to 2018. They further stated that increase in economies of scale increases the labour use efficiency.

Research Gap

The literature on bank efficiency is enriched with studies from time to time at branch level as well as bank as a whole. Very few studies can be identified on labour use efficiency of bank. Moreover, no such studies have been identified on labour use efficiency of AGVB so far as literature has been reviewed.

Research Objective

1. To assess the levels of labour use efficiency of the branches under study of AGVB at its branch level.

Research Methodology

Data and Variables

For assessing the labour use efficiency, the present study uses non-parametric Data Envelopment Analysis technic with its BCC (Banker, Cooper and Charnes) model. For selection of inputs and outputs, the production approach is used. Other statistical tools like mean, regression, etc is also used for the present study. The study area includes all the forty eight branches operating in Silchar region of the bank, which is one of the regions out of nine regions of the bank. The study period is confined to eight years ranging from 2010-2011 to 2017-2018. However, for having a strong panel data set, four branches have been excluded from the list as they were incepted after 2012. The selected inputs are number of officers, number of clerk and number of sub-staff. The selected outputs are deposit, advance and non-interest income. The selected input prices are salary of officers, salary of clerk and salary of sub-staff. The data for the present study are collected mainly from secondary sources.

Data Envelopment Analysis (DEA) is a non-parametric technic evolved in 1978 by Charnes, Cooper and Rhodes for measuring relative efficiency of service sector units using constant return to scale. Later on, Banker extended the scope of DEA to variable returns to scale in 1984. It is a non-parametric technic for measuring relative efficiency of those sectors where efficiency cannot be measured in absolute terms like banking sector where the services provided by the bank branches cannot be quantified in absolute terms. Other advantage of using DEA in measuring efficiency is that it can be used where multiple inputs and outputs are available. In DEA the scores of efficiency ranges from 0 to 1, where efficiency score 1 indicates best practice unit. The relative efficiency of other units is measure considering the best practice or the set benchmark.

For selection of input and output the present study uses production approach where the bank is consider as a producer of services viz. deposit, advance, interest income, non-interest income etc. to its customers using its inputs like labour and capital.

Result and Analysis

Table 1 depicts that the mean LUE score of the branches under study is 76 percent, which implies that there remain cost saving potentiality to the tune of 24 percent following the best practice. Year wise LUE score reveals a declining trend at the initial period of the study following by a decreasing trend and again a sharp increase in the last year of the study period. The highest LUE score is seen in the year 2018 which is mainly because of reduction in number of labour due to retirement/relinquishment compared to new recruitment.

Table 1: Year wise Labour Use Efficiency of Branches under Study of AGVB (2011-2018)

	2011	2012	2013	2014	2015	2016	2017	2018	Mean (2011-18)
Mean LUE	0.80	0.82	0.74	0.70	0.69	0.75	0.67	0.96	0.76

Source: Own calculation using rDEA i386 3.6.0 based on data relating to Financial Statements of AGVB (2010-2011 to 2017-18)

Figure 1 presents mean LUE scores of the branches under study. It depicts the fact that the LUE score increased initially but then followed a decreasing trend while again increased in the last year of the study period. Further, the straight line trend equation of LUE of AGVB with respect to time is given below:

$$Y = - 8.586 + 0.004x$$

The trend equation shows that the regression co-efficient of LUE of AGVB is positive which indicates that LUE has been increasing over the study period. However, this increase in LUE is not statistically significant at 5 percent.

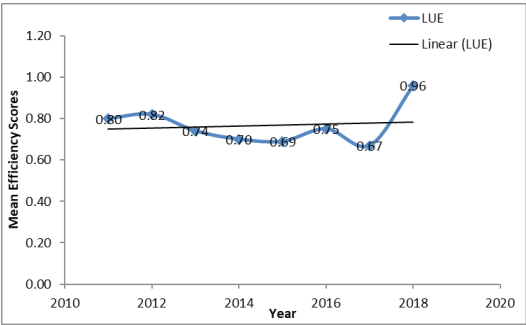


Fig 1: Year wise Mean LUE Scores of the Branches under Study

Table 2 reveals the total number of observed and optimum labour as an input for each category of labour selected for the present study. It can be seen that in each category of labour the observed number of labour are more than the optimum number of labour. The highest difference shows in officer cadre. It implies that the selected branches are mostly over-staffed.

Table 2: Observed and Optimum number of Each Category of Labour

Category of Labour	Observed	Optimum	Difference
Officer	792	550	242
Clerk	480	420	60
Sub-staff	269	162	107
Total	1541	1132	409

Source: Own calculation using rDEA i386 3.6.0 based on data relating to Financial Statements of AGVB (2010-2011 to 2017-18)

Table 3 Over-staffing and Under-staffing of the Branches under Study

Table 3 succinctly presents the observed and optimum number of total labour employed in the branches under study of AGVB for the study period. It is observed that maximum branches are over-staffed while few branches are understaffed and few of them are optimally staffed.

Table 3: Year-wise and Branch-wise Observed and Optimum Number of Labour

	2011		2012		2013		2014		2015		2016		2017		2018	
Branch id	Observed	Optimum	Observed	Optimum	Observed	Optimum	Observed	Optimum	Observed	Optimum	Observed	Optimum	Observed	Optimum	Observed	Optimum
1	9	9	10	10	10	10	10	10	8	8	10	10	8	8	6	6
2	3	2	3	2	3	3	4	3	4	3	4	3	2	3	3	3
3	4	3	4	4	4	4	5	3	5	3	4	4	5	3	6	3
4	4	3	4	3	4	4	6	4	6	3	6	4	6	3	4	3
5	3	2	3	2	3	3	5	2	3	2	4	2	4	2	4	2
6	3	4	3	4	4	4	5	4	5	4	5	4	5	4	5	4
7	3	2	3	2	3	3	4	3	4	2	4	3	3	2	4	2
8	4	3	4	4	4	3	4	3	5	3	4	3	5	2	5	2
9	4	2	4	3	5	3	4	3	4	3	5	3	4	2	4	2

10	4	3	4	3	6	4	6	4	7	7	6	5	4	4	3	4
11	2	3	2	3	2	3	3	4	4	4	3	3	3	3	3	3
12	3	2	3	2	4	3	4	3	5	3	4	3	4	2	5	2
13	4	2	4	2	3	3	4	2	6	3	4	2	4	2	2	2
14	4	3	4	3	4	4	5	4	5	3	6	4	6	3	4	3
15	4	2	4	3	3	3	4	3	4	3	4	3	3	3	3	2
16	3	2	3	2	4	3	6	2	5	3	4	3	5	3	4	3
17	6	3	6	4	7	4	7	4	7	3	5	5	5	4	7	7
18	5	5	5	5	7	7	7	6	8	8	9	9	6	6	7	7
19	4	4	4	5	4	5	5	5	7	4	4	4	5	4	4	5
20	6	6	6	6	6	6	7	5	8	6	9	10	8	5	8	6
21	2	3	2	3	4	3	3	3	3	3	3	3	3	3	2	3
22	3	2	3	2	3	3	4	2	4	2	4	3	4	3	4	2
23	3	2	3	2	3	3	4	2	5	2	5	3	4	2	4	2
24	5	3	5	4	5	5	6	4	5	4	5	5	5	4	4	4
25	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	2
26	4	3	4	3	4	4	5	3	4	3	4	4	5	3	4	3
27	6	3	6	4	8	4	5	4	6	4	4	4	4	4	5	3
28	4	2	4	3	5	3	4	3	4	3	6	3	4	3	3	2
29	8	5	9	5	11	6	10	6	9	5	7	7	7	5	6	4
30	3	2	3	2	3	3	3	3	4	3	3	3	4	2	4	2
31	4	2	4	2	4	3	4	2	5	3	4	3	5	2	4	2
32	3	2	3	2	4	3	4	3	3	3	4	3	3	3	3	2
33	3	2	3	2	3	3	4	3	4	3	4	3	4	2	3	2
34	3	2	3	2	4	3	4	2	4	2	4	3	5	2	4	2
35	4	3	4	3	5	4	6	3	6	3	7	4	6	3	4	3
36	3	2	3	2	4	3	4	3	5	3	4	3	5	2	4	2
37	3	3	3	4	4	4	4	4	6	4	5	4	5	3	4	3
38	3	2	3	2	4	3	4	3	4	4	4	4	3	3	4	3
39	3	2	3	2	3	3	2	3	2	2	2	2	2	2	3	2
40	3	2	3	2	2	3	3	2	3	2	3	2	3	2	2	2
41	3	2	3	2	5	3	4	2	4	3	4	2	3	2	4	2
42	5	4	6	4	6	6	6	5	5	4	7	5	4	4	4	4
43	2	3	2	3	3	3	6	5	5	3	4	4	5	2	4	2
44	3	3	3	3	4	3	4	3	4	2	3	3	4	3	3	2

Source: Own calculation using rDEA i386 3.6.0 based on data relating to Financial Statements of AGVB (2010-2011 to 2017-18)

Note: Green color represents optimum staffed, yellow color represents under staffed and white color represents overstaffed

Figure 2 diagrammatically represents the optimum and observed labour cost of the branches under study of AGVB for the study period. It is seen that the observed costs of labour is more than the optimum costs of labour of the branches under study from the financial year 2011 to 2017. However, a variation is observed in the year 2018, where the optimum labour cost is higher than the observed labour costs. It simply means that the total labour cost of the branches decrease in the year 2018. The reason behind decrease in labour cost may be because of reduction in number of labour in the year 2018 as has been identified in the earlier table 3.

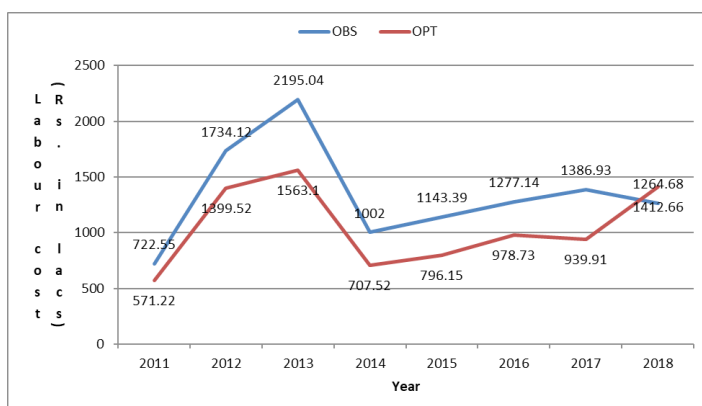


Fig 2: Comparison of Optimum and Observed Cost of Labour of the Branches under Study (2011-2018)

Conclusion

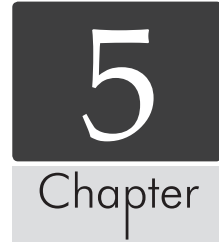
The present study is expected to enrich the existing research base on labour use efficiency of bank at a branch level. The findings of the present study reveals the fact that there exists cost saving potentialities of the selected bank branches following the best practice. Here, it can be said that to be in efficient frontier the branches can emulate the working pattern of branch id 1 which is the best performing branch in relative efficiency measurement of the selected branches under study. As maximum of the branches are having surplus labour than its requirement as it can be identified from the present study, the reallocation of the

labour among the branches where there is shortage of labour can be a solution to the problem. Further, the management of the bank can consider the opening up of new branches for reallocation of the labour as well. As the present study finds out that the surplus in labour is mainly in officer cadre, thus reduction of labour in this particular category will be a solution for labour cost reduction of the branches for efficient labour use at its desired level. Thus, the management of the bank has to consider these aspects for better utilization of its prominent resource that is labour for overall efficiency and profitability of the organisation. Thus, the present study leaves ample scope of research in this direction.

The present study suffers from certain limitations like only one technic that is DEA is used for measuring labour use efficiency instead of so many other techniques which are available. Moreover, the present study considers branches under only one region that is Silchar region out of nine regions of the bank.

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Impact of G20 Summit and Chandrayaan-3 on Indian Stock Market-Event Study Analysis of NIFTY50 and Sectoral Indices

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Abstract

The study analyse two landmark developments of 2023 influenced the Indian equity market: the G20 summit hosted by India and the successful Chandrayaan-3 mission. Using a standard event study framework, the study computes abnormal returns (AR) and cumulative abnormal returns (CAR) to capture short-term price adjustments. For the benchmark index, NIFTY50, and selected sectoral indices. The empirical evidence indicates the absence of statistically significant broad-market reactions. However, short-term sectoral effects are observed. The findings suggest that diplomatic and technological advancements influence market behavior selectively, and also offer insights for sectoral forecasting and event-driven investment strategies in emerging markets.

Keywords: *Equity Market, Abnormal Returns (AR), Cummulative Abnormal Returns (CAR), Forecast, Event-Driven.*

1. Introduction

Financial markets continuously integrate new information into asset prices, reflecting expectations about future economic and political developments. Global or domestic events generate signals that shape investors' expectations, which have a major influence on the stock market. The Indian stock market, represented by certain indices such as NIFTY50, NIFTYBANK, etc., reflects the macroeconomic direction, national competitiveness, and technological capability. Large-scale diplomatic gatherings and technological breakthroughs often function as informational shocks that may temporarily alter investor sentiment and sectoral allocation patterns.

Studies have suggested that a country's financial market is linked to both global and domestic events. Research also shows that policy changes, geopolitical events, or significant scientific or space advancements affect the financial markets. For example, geopolitical conflicts often bring volatility to the financial markets and also drive trade policies and economic growth (WTO | *The Impact of Geopolitical Conflicts on Trade, Growth, and Innovation*, n.d.). Space technologies and advancements in any country contribute to economic growth and trade and shipping, as such events impact innovation and industrial growth (Corrado et al., 2023).

The G20 Summit and Chandrayaan-3 were the two most vital events to take place in the country. The G20 Summit, 2023, was held in India on the 9th and 10th of September, 2023. This event brings global leaders together in one space, providing a platform to discuss economic policies, trade, and commerce. Also, the Chandrayaan-3 space mission, led by the Indian Space Research Organization (ISRO), which landed successfully on the moon's surface on 23rd August, 2023, had a productive impact on the market, specifically boosting the space industry. The successful lunar landing symbolized India's growing technological capability in space exploration and reinforced its position in the global scientific community. Both of these events have attracted the attention of different countries, which can be studied and analyzed to understand their impact on the market dynamics. The impact of space missions, such as the Chandrayaan-3 landing, and international events, such as the G20 Summit, on market movements was analyzed using event analysis, which

required examining the reactions of the Indian stock market to these events and their effect on market trends. Therefore, the study attempts to analyze the impact of the G20 Summit and Chandrayaan-3 on NIFTY50 and selected sectoral indices using an event study framework to examine abnormal returns and volatility patterns surrounding the event windows.

2. Literature Review

To comprehend and measure the impact of various events on stock prices, multiple studies have been attempted by different researchers. Researchers employ diverse approaches to assess the correlation between the occurrences & fluctuations in the stock prices. **(Raj G, 2024)** Studies the impact of major global events such as political developments, business news, and natural disasters on India's BSE and also the US's S&P500 indices over the last decade. This study doesn't find a significant impact of these events on subsequent events, which challenges the perception of the market as highly reactive during these events. **(Boubaker et al., 2015)** analysed the short-term overreactions in the Egyptian stock market (EGX). Events like terrorist attacks and tensions surrounding regions have a strong negative impact, followed by price reversals, while the formation of a new government shows no effect. The COVID-19 pandemic has had a substantial impact on the Indian stock market scenario (Maheshwari & Kumar, 2022), as their study highlights IPO activity and investor behaviour around that time. This study reveals increased participation by retail investors, leading to underpricing of IPOs. Also, **(Raj G & Selvan S.C.B, 2022)** demonstrates a crucial correlation between the performance of the Indian stock market (NSE and BSE) and COVID-19 metrics such as new cases, total existing cases, mortality rate etc. This uses methods such as ADF tests, regression analysis, and Granger causality tests to examine relationships between pandemic developments and market dynamics. **(Saimum, 2024)** study the effect of regulator-induced stock split on the Bangladesh stock market. This is an empirical study that found 117 mandatory stock splits exhibited an equal distribution of positive and negative excess returns during the event window. This tells the unique dynamics of regulatory-driven stock splits and their minimal effect on the market. In Indian economic history, demonetization is top-tier events that happened in our country on 8th of November,

2016. The demonetization had a lot of positive & negative impacts on the Indian economy and its stock market. **(Parab & Reddy, 2020)** In their study, they researched the cause & effect relationship pre- & post-demonetisation on Indian stock market returns and between Foreign Institutional Investment (FIIs) & Domestic Institutional Investment (DIIs). In the study, it was observed that FIIs & DIIs did not have a significant impact, but NIFTY50 returns had a strong negative impact during the post-demonetization period, mainly affecting the real estate sector. **(Verma et al., 2022)** carried out a study that focuses on the short-term effect of the Russia-Ukraine conflict on the stock market. An event-based analytical framework was employed to evaluate immediate volatility responses following the outbreak of conflict. The study mainly concentrates on the National Stock Exchange of India (NSE) with emphasis given on IT, Banking & Energy sectors. Similarly, **(Parab et al., 2020)** tracked how the NIFTY50 index's trend and returns were affected by both anticipated and unanticipated economic events. Both domestic and international economic developments frequently impact the stock market. The effects of economic events, whether favourable or unfavourable, on the Indian stock market are transient. The impact is swiftly recovered by the market. The performance of Indonesian Stock Market before, during and after the announcement of Covid-19 pandemic has been studied by **(Nugraha et al., n.d.)**. Event study analysis has been done using the stock prices data by considering different sectors of the company's stocks to check and evaluate the short-term effect on the stock prices. Stock market is often influenced by various economic & political events. **(Mohammad & Mahmud, 2019)** Analysed the performance of the Dhaka stock market pre- & post-parliamentary election of Bangladesh. The study covered five elections for the period of 1996-2018. The volatility during the post-1996 election has been observed as very high, whereas the volatility remains the same during the other elections of the pre- & post-period.

(Arcuri et al., 2018) explores the financial consequences of cybercrime, especially the security breaches on the implementation of the stock market. The study evaluates data from 1995 to 2015 to assess the market reaction to cyber-attacks. The findings highlight a noticeable surge in retail investor participation during the pandemic period. **(Liu, 2018)** Studies the effect of quarterly earnings announcements on stock

returns for a large sample of US-listed companies from 2008 to 2016. The study analyzes the relationship between earnings announcements and various factors, including growth, company size, trading volume, etc. It highlights the predictive value of earnings announcements and accruals in generating significant returns, providing insights for portfolio management and financial decision-making. **(Alfonso Perez, 2021)** Focuses on the equity market to provide a short-term event-driven analysis of the Southeast Asia financial crisis. This study guides investors and policymakers in understanding the immediate implications for the financial market during such a crisis. **(Purwoharsojo et al., 2023)** A unique study evaluates the development of tourism in Samarinda City with an aim to leverage the festival economy in three dimensions- event management, sustainable tourism, and destination branding. These were studied using multiple regression. These findings present valuable insights for policymakers and stakeholders aiming to boost tourism development in transitioning economies.

This literature review underscores a varied impact of events- from geopolitical to economic changes to natural disasters, global crises, and many more on stock market dynamics. While some studies challenge the notion of exaggerated market reactivity to events, others emphasize the short-term volatility, as seen in cases like terrorist attacks, pandemics, elections, and geopolitical conflicts. Sectoral disparities emerge prominently, demonstrating varying sensitivities to specific events, such as demonetization, the Russia-Ukraine war, and COVID-19.

3. Statement of the Problem

Accurate modelling of stock price behaviour requires incorporating prevailing market conditions, trading intensity, volatility patterns, and event-specific information. For example, the volume of trading, the stock's volatility, any events influencing stock prices, and the company's financial statements all need to be taken into account.

In the stock market, event analysis is crucial because it enables assessing how specific events affect stock prices and market indices. Determining whether there is a strong, unusual return or response to these occurrences is helpful. Macroeconomic, geopolitical, and institutional developments frequently trigger measurable adjustments in asset prices.

Space missions in India are conducted by ISRO (Indian Space Research Organisation), which sends craft into space to conduct scientific research and analysis. One such space event that significantly affects the Indian economy is Chandrayaan-3. The occasion strengthened India's economy and established relationships and trust with the world's leading economies, inspiring interest in future investments in India. The event has significantly impacted the country's stock market, as these nations have shown a strong desire to invest in India going forward.

International meets are always a huge affair for any country or state. The G20 summit was one of India's major events in 2023 and had a profound impact on India's economy and the stock market. The G20 nations serve as a forum for finance ministers and central bank governors to debate global economic and financial concerns. The European Union (EU) and the G20, a group of 19 countries, formed the organization in 1999. Collectively, the G20 economies account for a dominant share of global output, international trade, and population, making the forum highly influential in shaping global macroeconomic discourse. Every year, the G20 Summit is facilitated by a rotating presidency. India has hosted the G20 Leaders' Summit for the first time in 2023. Operational continuity is ensured through a three-member leadership structure comprising the previous, current, and incoming presidencies. The troika in 2023 consisted of India, Brazil, and Indonesia. There were almost 43 Heads of Delegation, the most ever at a G20 summit, who attended the last New Delhi Summit in September of this year (*Overview of G20 | Ministry of Earth Sciences, n.d.*).

This study will explore the broader relationship between such events and the market's volatility, specifically in the Indian stock market. This will be effective in a deeper understanding of market dynamics and sectoral indices surrounding these events. The study will be relevant especially for the investors, traders, and policymakers to understand the movements of the market and sectoral relationships better.

4. Methodology

1. Chow test

Time series models are used to analyze the relationship between variables measured over time. These models assume that the

relationship between variables remains consistent throughout the observation period. However, external factors can sometimes disrupt this stability, leading to shifts in the underlying relationships among variables (*Structural Breaks* | Aptech, n.d.).

Structural break models address this issue by accounting for abrupt, short-term, or lasting changes in the model's parameters, thereby providing a more accurate representation of these shifts. Shifts can happen for various reasons, such as changes in policy or economic shocks from events or news.

"The Chow (1960) test is a classical structural break test used to determine whether regression coefficients differ significantly across two sub-periods. It evaluates the null hypothesis of parameter stability against the alternative of a structural shift at a known breakpoint. The test statistic follows an F-distribution under standard assumptions. The test considers a linear model split into samples at a predetermined break point such that

$$y_t = x_t' \beta_1 + \mu_t$$

$$\text{for } t \leq T_b$$

and

$$y_t = x_t' \beta_2 + \mu_t$$

$$\text{for } t > T_b$$

The test estimates coefficients for each period and uses the out-of-sample forecast errors to compute an F-test comparing the stability of the estimated coefficients across the two periods." (*Structural Breaks* | Aptech, n.d.)

2. Event Analysis

"An event study is a quantitative technique used to assess whether a specific event generates statistically abnormal returns relative to expected market performance." (*Event Study*, n.d.)

Event study is conducted on a company to determine whether its stock price changes and how it is affected by a specific event or news. This is applied as a macroeconomic tool by evaluating the influence of an event on a particular industry, sector, or the overall market, and by understanding effect of changes in supply and demand. "In economics, as well as in finance, an event study refers to whether or not a statistical relationship

exists in the financial markets between a specific event and a public company's stock price or value." (*Event Study*, n.d.)

Abnormal Returns (AR): In this analysis, abnormal returns are calculated to compute the stock price movements driven by events.

"The formula for calculating abnormal returns (AR) for a specific stock on a given day is as follows: (Verma et al., 2022)

$$AR_i(t) = R_i(t) - [a_i + b_i (R_m(t) - R_f)]$$

Here, the variables represent:

- $AR_i(t)$: The abnormal return for stock I on day t.
- $R_i(t)$: The actual daily returns for stock i on day t.
- a_i and b_i : Intercept and slope coefficients derived from the stock's historical returns.
- $R_m(t)$: The return on the market portfolio on day t.
- R_f : The risk-free rate, typically approximated by the yield on government bonds."

Cumulative Abnormal Returns (CAR): "The formula for calculating Cumulative Abnormal Returns (CAR) over the event window is as follows:

$$CAR_i = \sum_{t=1}^T AR_i(t)$$

Where:

- CAR_i : Cumulative Abnormal Returns for Stock i.
- $AR_i(t)$: Abnormal Returns for stock i on day t.
- T : The total number of days in the event window." (Verma et al., 2022)

T-statistics: T-statistics are used to quantify the degree to which abnormal returns depart from zero and are used to evaluate the statistical significance of abnormal returns. The use of t-statistics in event analysis is highly significant for understanding market reactions to major events (Ahmed et al., 2023).

Comparative Analysis: This analysis compares market and sector reactions to these events. By analyzing both market trends and sector-specific movements, this will help uncover variations in how different segments of the economy respond to such events. This will provide an in-depth understanding of the market variations and patterns, specifically to the investors and traders.

Data Source

The dataset for the Chow test consists of 825 daily observations of the NIFTY50 index collected from 1st September 2021 to 31st December 2024. The data is taken from the website of www.nseindia.com (NSE - National Stock Exchange of India Ltd: Live Share/Stock Market News & Updates, Quotes- Nseindia.Com, n.d.).

The dataset for Event analysis of the G20 Summit consists of 62 daily observations of NIFTY50 and sectoral indices collected from 11th August, 2023, to 10th November, 2023. The data is collected from the website of www.nseindia.com (NSE - National Stock Exchange of India Ltd: Live Share/Stock Market News & Updates, Quotes- Nseindia.Com, n.d.).

The dataset for Event analysis for Chandrayaan-3 consists of 63 daily observations of NIFTY50 and different sectoral indices collected from 24th July, 2023, to 23rd October, 2023. Data is taken from the website of www.nseindia.com (NSE - National Stock Exchange of India Ltd: Live Share/Stock Market News & Updates, Quotes- Nseindia.Com, n.d.).

5. Result and Analysis

This section discusses structural breaks in the market due to the G20 Summit and Chandrayaan-3, and provides an event analysis of the market, represented by NIFTY50 and other important sectoral indices. A series of tables containing Abnormal Returns (AR) and Cumulative Abnormal Returns (CAR) for various time periods around the event has been computed that will help in understanding the immediate effect and the short-term impact of the event.

The Chow test has been performed to determine whether a structural break is present in the G20 Summit and Chandrayaan-3 data. The Null Hypothesis for the Chow test is no breaks at the specified point.

The Chow test is conducted to investigate whether there was a structural break in the NIFTY50 price index around the G20 summit and the Chandrayaan-3 launch day, which could indicate a change in market dynamics due to the events.

The F-statistic [$F(2,821)$] for the G20 Summit is 158.6492, and the associated p-value of 0.00 strongly suggests the existence of a structural break at the summit. Specifically, the p-value is well below the commonly used significance level of 0.05, leading us

to reject the null hypothesis of no break. This indicates that the regression coefficients differ significantly before and after the G20 summit, suggesting that the market's response to the factors influencing the NIFTY50 index changed around the event. Therefore, we conclude that the G20 summit had a noticeable impact on the NIFTY50 index, whereas the Chandrayaan-3 suggests no structural breaks, which implies that the event has no significant impact on the overall market.

Different vital sectoral indices along with the NIFTY50 index have been considered for this study, which will enhance the analysis and also help in understanding the various market reactions during the event time period. Sectors considered for this analysis are NIFTY_AUTO, NIFTY_BANK, NIFTY_ENERGY, NIFTY_FINANCIALSERVICES, NIFTY_FMCG, NIFTY_IT, NIFTY_MEDIA, NIFTY_METAL, NIFTY_OIL&GAS and NIFTY_PHARMA. Abnormal Returns (AR) and Cumulative Abnormal Returns (CAR) are considered for their statistical significance.

Pre-event window spans 15 days prior to the event (-20,-5) for assessing the market behavior and reactions leading up to the event. In this study, event window is 3 days prior and post the event which helps in capturing the immediate market reactions. Post-event window or Short-term period extends from 5th day to the 35th day after the event, which will provide the insights on the impact of the event on the sectoral indices in a short run.

First, the AR table (Table No.1) for the event window i.e. -3 to +3 for G20 Summit provides findings on the performance of the various sectors of the Indian stock market surrounding the event. AR is a vital metrics for evaluating the impact of such geopolitical events on the market.

Table No.1- Abnormal Returns (AR) for the event window for G20 Summit

Sectors	-3	-2	-1	0	+1	+2	+3	t-test (df=6)	p-value
Auto	-0.52	-0.33	-0.01	0.58	-2.05	-1.05	0.71	-1.05	0.33
Bank	-0.46	0.49	0.16	0.08	-0.14	0.50	0.02	0.72	0.49
Energy	-0.05	-0.19	0.51	-0.63	-2.47	0.21	0.22	-0.90	0.40
Financial Services	-0.12	0.54	0.51	0.11	0.00	0.10	-0.02	1.63	0.15

FMCG	0.92	-0.76	-0.42	0.32	-0.27	0.08	-0.22	-0.23	0.81
IT	-0.64	-0.59	-0.95	-0.70	0.80	-1.01	0.02	-1.80	0.12
Media	-0.29	0.33	-1.65	-1.28	-4.65	0.90	-0.87	-1.56	0.16
Metal	-1.42	-1.52	-1.28	-0.30	-2.88	-0.63	0.89	-2.29	0.06
Oil & Gas	0.71	-0.28	0.73	-0.31	-2.64	0.67	1.06	-0.01	0.98
Pharma	0.95	-0.47	-0.45	0.08	0.27	0.73	0.32	1.00	0.35

In the above Table no.1, it is observed that Auto sector has negative ARs on most days except on the event day (Day 0). Bank does not show a clear trend as it is fluctuating throughout the event window. Like Auto, Energy and Metal also has mostly negative ARs but a significant negative return on Day 1. Media shows strong negative ARs, especially on Day 1. IT again has negatively dominating ARs but a slight positive return on Day 1. But there is no such significant impact due to the summit on the sectoral indices immediately on the event day.

Table No.2- Cumulative Abnormal Returns (CAR) for the event window for G20 Summit

Sectors	CAR(-3,+3)	t-test	p-value
Auto	-2.68	-1.05	0.33
Bank	0.66	0.72	0.49
Energy	-2.40	-0.90	0.40
Financial Services	1.13	1.63	0.15
FMCG	-0.34	-0.23	0.81
IT	-3.08	-1.80	0.12
Media	-7.53	-1.56	0.16
Metal	-7.14	-2.29	0.06
Oil & Gas	-0.05	-0.01	0.98
Pharma	1.44	1.00	0.35

In the above table, Table No.2, it is seen that most of the CARs for the sectoral indices has a negative value which suggest that it experienced a cumulative loss. But all the p-value is greater than 0.05 which indicates that the result has no statistically significant abnormal values. Only, Metal sector shows some evidence of a negative impact as p-value is approximately 0.06.

Table No.3- Cumulative Abnormal Returns (CAR) for the post-event window for G20 Summit

Sectors	CAR(+5,+35)	t-test(df=30)	p-value
Auto	-2.83	-0.87	0.38
Bank	-3.03	-1.79	0.08
Energy	7.86	2.19	0.03
Financial Services	-2.00	-1.03	0.31
FMCG	3.57	1.53	0.16
IT	-8.30	-2.40	0.02
Media	-13.04	-1.84	0.07
Metal	-3.97	-0.89	0.37
Oil & Gas	5.78	2.4331	0.0219
Pharma	1.70	0.43	0.66

From the above Table No.3, it is observed that Energy and Oil & Gas sectors have experienced significant positive cumulative abnormal returns post-event, i.e. 30days after the event window. This implies the Short-term positive impact of the event G20 summit on these two sectors, Energy and Oil & Gas. Also, IT has a significant p-value with a negative CAR value of -8.3 which signifies that this sector faced a negative effect of the event in this short term period.

Table No.4- Abnormal Returns (AR) for the event window for Chandrayaan-3

Sectors	-3	-2	-1	0	+1	+2	+3	t-test (df=6)	p-value
Auto	0.30	-0.13	0.57	-0.24	0.11	0.08	0.58	1.51	0.18
Bank	0.41	0.09	0.16	1.05	0.55	0.26	0.57	3.64	0.01
Energy	0.24	-0.06	0.00	-1.04	-0.62	-0.23	-0.29	-1.77	0.12
Financial Services	0.18	0.27	0.12	0.91	0.46	0.52	0.58	4.22	0.00
FMCG	0.40	0.40	0.67	-0.61	0.48	-0.62	-0.33	0.26	0.79
IT	-1.55	0.21	-0.53	-0.60	0.53	-0.34	-1.08	-1.78	0.12
Media	-0.02	-1.22	-0.19	-0.19	-0.49	-1.08	-0.51	-3.06	0.02
Metal	0.54	0.82	0.84	-0.40	0.00	-0.53	-0.01	0.84	0.42
Oil & Gas	0.11	-0.72	-0.06	-0.63	-0.28	0.35	-0.40	-1.56	0.16
Pharma	-0.94	-0.24	-0.69	-0.71	-0.96	-1.36	0.34	-3.11	0.02

Table No.4 above, captures the daily ARs for the sectors during the event window of Chandrayaan-3. In Auto sector, the ARs fluctuates across the event window, mostly being positive. For Bank and Financial Services, the ARs are consistently positive with a positive spike particularly on the event day. Media and Pharma sectors experienced consistently negative ARs on most of the days throughout the event window.

Table No.5- Cumulative Abnormal Returns (CAR) for the event window for Chandrayaan-3

Sectors	CAR(-3,+3)	t-test	p-value
Auto	1.29	1.51	0.18
Bank	3.12	3.64	0.01
Energy	-2.01	-1.77	0.12
Financial Services	3.06	4.22	0.00
FMCG	0.39	0.26	0.79
IT	-3.37	-1.78	0.12
Media	-3.74	-3.06	0.02
Metal	1.26	0.84	0.42
Oil & Gas	-1.64	-1.56	0.16
Pharma	-4.57	-3.11	0.02

In the Table No.5 above, the CAR values for Bank and Financial Services are statistically positively significant, which means these sectors has a strong positive impact due to the event during the event period. However, Media and Pharma sectors have significant p-value (<0.05) with a negative CARs which implies a strong negative impact of the event during this period on these sectors.

Table No.6- Cumulative Abnormal Returns (CAR) for the post-event window for Chandrayaan-3

Sectors	CAR(+5,+35)	t-test(df=30)	p-value
Auto	3.44	0.95	0.35
Bank	3.47	2.02	0.05
Energy	-4.78	-1.24	0.22
Financial Services	5.26	3.13	0.00
FMCG	1.11	0.39	0.69
IT	-8.92	-2.49	0.01

Media	-23.83	-3.23	0.00
Metal	0.68	0.13	0.89
Oil & Gas	-4.35	-1.14	0.26
Pharma	-14.59	-3.50	0.00

CARs values for a short-term period are calculated above in the Table No.6, it is found that Bank and Financial Services has a strong positive impact during the event as well as the short-term. Whereas, Media and Pharma shows a strong negative impact on these sectors due to the event during the event window and short-term period. IT sector also have negative impact because of the event for the short-term period, which means it has a significant negative return on the short-term window.

Conclusions

The study emphasizes that there is no significant p-value in any sectors for ARs and CARs over the event window. This suggests that the Indian Stock market reflected a relatively efficient and stable response to these high profile events.

However, short-term post event period indicate two sectors have positive significant p-value and one sector faced negative significant p-value, which signifies a delayed impact of the event suggest that market adjustments may not be instant but gradually unfold as investors interpret the policies and economic implications.

Overall, in this study for G20 Summit, Energy and Oil & Gas emerged as beneficiaries, most likely due to the discussions on policies associated with energy security, trade cooperation and infrastructure investments. IT sector experienced notable adverse effects, may be due to concerns over global macroeconomic uncertainties, outsourcing risk or shifts in international trade dynamics.

For Chandrayaan-3, the event analysis indicate that the Financial Services and Bank sectors consistently experienced positive impacts, suggesting that technological achievements may strengthen overall investor sentiment. Media and Pharma sectors suffered the most, indicating a temporary reallocation of investor interest or had sector-specific implications. However other sectors has a mixed reaction as they have fluctuations throughout and does not have a significant impact reinforce the notion that national achievements do not uniformly translate into broader market movements.

These findings contribute to the understanding that how these economic events such as diplomatic summits and scientific achievements of a country interact with financial market expectations. Such events generate huge amount of public attention, but their impact on the financial markets are selective and sector dependent.

Further, this study can be extended further by analysing individual stock performance within the sectors that showed significant impact during the event window or/and in the short-term period or post-event due to the event.

Overall, the study reflects that landmark national achievements and global events may gather international attention, their financial market impact is nuanced and selective within sectors rather than broad index level disruptions. This strengthen the notion of evolving maturity of the Indian Stock Market.

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6
Chapter

Guns and Gaps: Defence Expenditure and Income Inequality in India

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Abstract

This paper examines the link between increased defence expenditure and rising income inequality in India, India ramped up its defence spending to modernize its military, but this has also led to concerns about malpractices in defence contracts, including corruption and favouritism. Moreover the significant security gains made after the 1971 war, these corrupt practices have diverted crucial resources away from essential social sectors, exacerbating economic disparities. The misallocation of defence funds, often into the hands of politically connected elites, has resulted in a widening income gap, where the benefits of defence spending fail to reach the broader population. This paper argues that reforms in defence procurement, aimed at increasing transparency and accountability, are crucial to ensure that defence expenditure supports both national security and equitable socio-economic development.

Keywords: Defence Expenditure, Income Inequality, Auto Regressive Distributed Lag Model, India.

Introduction

In recent years, India has seen a notable increase in defence expenditure, a trend that reflects the nation's growing concerns over national security, regional stability, and geopolitical tensions. The need for modernizing the military, acquiring advanced technologies, and maintaining a robust defence infrastructure has prompted successive governments to allocate substantial portions of the national budget to the defence sector. While the significance of strong defence capabilities cannot be understated, there are growing concerns regarding the broader socio-economic implications of this increased military spending, particularly in relation to income inequality within the country. One of the key issues that have come to the forefront in this regard is the increasing prevalence of malpractices in defence procurement and contracting processes. Corruption, inefficiency, and lack of transparency in defence contracts have become major hurdles in ensuring that defence expenditure is used effectively. These practices have serious implications, not just for the military's readiness and capabilities, but also for the overall economic health of the nation. When large sums of money earmarked for defence contracts are siphoned off through corrupt dealings, it exacerbates the existing wealth disparity, pushing more resources into the hands of a few elites while depriving the general public of necessary services and welfare programs. Defence procurement in India, like in many other countries, has often been marred by allegations of bribery, favoritism, and the awarding of contracts to firms with political connections rather than based on merit or the need for effective, efficient solutions. In some cases, the failure to properly evaluate contractors and projects has resulted in subpar defence equipment being purchased at inflated costs. Such inefficiencies not only compromise the military's operational effectiveness but also represent a colossal waste of public funds that could otherwise have been directed toward addressing the pressing needs of the country's poor and marginalized communities. Furthermore, these malpractices in defence contracting have a ripple effect on the economy at large. When defence contractors engage in corrupt activities, a disproportionate amount of money circulates within a small, elite circle of corporate entities and individuals. The funds that should be used to procure essential defence equipment or to support public services

often remain within the hands of a few powerful interests, creating a vicious cycle of economic inequality. While the rich and powerful benefit from lucrative government contracts, the poorest sections of society see little to no benefit from the country's defence spending. As a result, the divide between India's wealthy and impoverished citizens continues to widen, leaving millions in a state of economic deprivation.

Income inequality in India has been a longstanding issue, and the increase in defence expenditure, coupled with corruption in defence procurement, has further entrenched this disparity. The redistribution of wealth through defence contracts often benefits only those already positioned at the top of the economic ladder, making it more difficult for marginalized communities to break free from poverty. With limited resources allocated for education, healthcare, and infrastructure development, the growing defence budget has come to symbolize a misallocation of national priorities that ultimately harms the welfare of the majority. Moreover, India's defence contracts often involve large-scale projects with international collaborations, which sometimes results in greater economic benefits for foreign entities rather than domestic firms. In some instances, foreign suppliers and multinational corporations are awarded defence contracts, further reducing the flow of benefits to the local economy and exacerbating the income gap. The reliance on external companies also creates additional challenges in ensuring quality control and adherence to local economic priorities. The situation has led to a paradox in which defence spending, ostensibly aimed at safeguarding national security, becomes a contributor to deeper economic divides. As resources are funneled into the defence sector, with little transparency or accountability, it becomes increasingly difficult to address other critical sectors, such as health, education, and social welfare, which have a direct bearing on reducing income inequality. Thus, the increase in defence expenditure, when coupled with corrupt defence contracting practices, not only undermines the nation's long-term economic growth but also exacerbates social and economic inequalities. Therefore, it follows that the relationship between defence expenditure and income inequality are ambiguous and depend upon several factors, such as greater transparency and accountability in defence procurement must be introduced to ensure that public funds are used efficiently. Given this

background it is well justified that there is a linkage between defence expenditure and income inequality. This paper makes a modest attempt to fill this lacuna in research, that is, examine the affect of defence expenditure on India's income inequality. Given this background, the rest of the paper is structured as follows: Section 2 documents some standard literature on the subject. Section 3 & 4 provides the empirical evidence, describes the data used and modelling approach. And lastly section 5 concludes.

Theoretical and Empirical Review

Defence expenditure plays a significant role in shaping a nation's economy and social structure. While it strengthens national security, it also influences income distribution through various economic channels. This analysis examines how defence spending contributes to income inequality. Governments allocate substantial funds to the defence sector, leading to advancements in technology, infrastructure, and manufacturing. However, these benefits are often concentrated in specific industries and regions, creating disparities in economic growth (Smith, 2018). Large defence contracts are awarded to corporations with existing resources, limiting opportunities for smaller businesses and economically weaker areas (Jones & Taylor, 2020). This uneven distribution of benefits leads to restricted access to capital and resources for marginalized groups (Miller, 2021). Secondly, defence projects require high investment in research, development, and production. Consequently, capital flows into sectors linked to defence, such as aerospace, engineering, and cyber security, which primarily benefit established companies (Williams, 2019). These firms gain access to government funding, skilled labor, and technological advancements, while small enterprises struggle to compete (Brown & Green, 2022). This disparity in resource allocation widens economic gaps, as wealth accumulates among those already positioned to benefit from defence spending (Clark, 2023). Finally, the combination of uneven benefits, capital access restrictions, and limited employment opportunities for lower-income individuals results in widening income inequality (Stewart, 2019). The concentration of resources and high-income jobs within specific groups intensifies economic disparity, reinforcing social divisions (Wilson & Carter, 2021). While defence expenditure

strengthens national security, its economic consequences must be addressed through inclusive policies and investments in education and skill development (Evans, 2023).

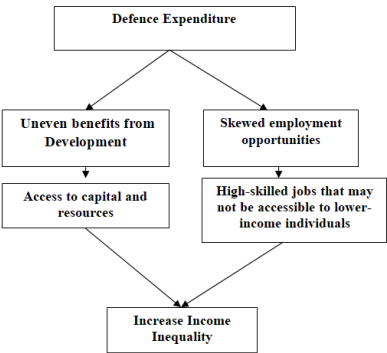


Figure: 1. Conceptual Framework

Source: Author’s own research

In 1971 war between India and Pakistan resulted in India’s victory and the creation of Bangladesh, significantly reshaping South Asia’s geopolitical landscape. Following the war, India adopted both soft power and hard power approaches to manage post-war diplomacy and security concerns. Through soft power, India engaged in the Simla Agreement with Pakistan, emphasizing peaceful negotiations while returning 93,000 Pakistani prisoners of war (Smith, 2019). However, despite diplomatic efforts, unresolved issues like Kashmir and Chicken Neck persisted, leaving room for continued military tensions (Jones & Taylor, 2021). On the other hand, the hard power strategy suggested that India could have leveraged its military advantage to secure long-term territorial and political gains, including ensuring a secular constitution in Bangladesh (Williams, 2022). Since many of these issues remained unresolved, India continued to invest heavily in defence, leading to significant defence contracts with Russian companies (Clark, 2023). These deals involved large financial transactions, often accompanied by kickbacks and premium payments, which were sometimes redirected toward election campaign funding, creating economic imbalances (Brown & Green, 2022). The economic impact of such defence expenditures contributed to income inequality, as resources were concentrated among political and business elites while

reducing government spending on social welfare programs like education and healthcare (Harris & Johnson, 2021). Additionally, corruption within defence procurement processes exacerbated wealth disparities, limiting broader economic opportunities (Anderson, 2020). Consequently, while India's military investments strengthened its national security, they also contributed to rising economic inequality, highlighting the need for transparent policies in defence spending (Nelson, 2022).

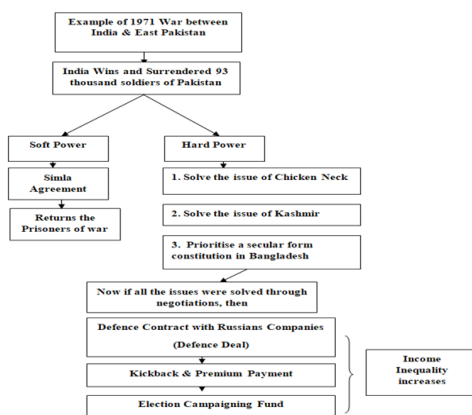


Figure: 2. Conceptual Framework

Source: Author's own research

Trend of Defence Expenditure in India

It is seen from the figure that Defence expenditure in India is positive though fluctuates over time. From 1981 to 1988 defence expenditure remain more or less stable but mid of the 20th due to the war on the Indo-Pak border, the defence expenditure is increased at a good pace up to 2005, thereafter, the country realizes the threat from its neighbouring nations and stress more importance on its defence expenditure, as a result, the expenditure on defence increases at a very significant rate. Moreover, after 2005 defence expenditure remains positive and increased at a sharp rate. Within this time frame, the government also prioritizes various regional defence agreements with other nations and starts importing various defence goods such as arms and ammunition which enhance and restructured the security of the country.

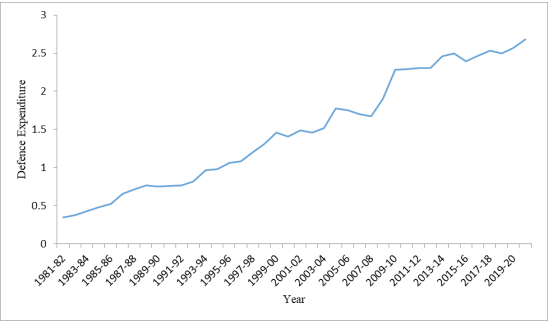


Figure 3: Defence Expenditure in India

Source: Compiled from Handbook of Statistics on Indian Economy (RBI)

Department wise Expenditure as Percentage of Total Defence Expenditure

According to MOD there are six broad categories of defence expenditure. These are army, navy air-force, Directorate General of Quality Assurance, Director General Ordnance Factories and Research and Development these expenditure accounts a major portion of total government expenditure in the nation. Figure presents distribution of department wise Average of decadal Expenditure of the government.

As we can see around fifty two percent of defence expenditure comprised of army expenditure while two five percent of defence expenditure comprised of air-force and sixteen percent of the expenditure comprised of navy expenditure respectively. As indicated earlier, these figures are average figure and therefore one might observe occasional fluctuations of these estimates from one year to another.

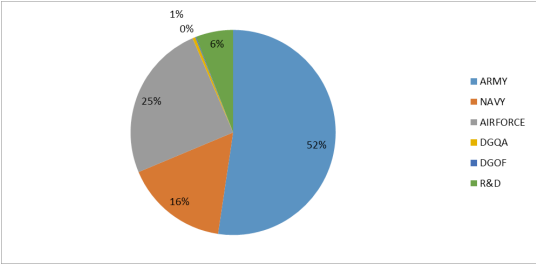


Figure 4: Department wise Expenditure as Percentage of Total Defence Expenditure, 2003-2018

Source: Compiled from Ministry of Defence (MOD)

Data and Methodology

The study used annual data spans over the period 1980 to 2019; the data is compiled from Handbook of Statistics on Indian economy and Ministry of Defence (MOD) while the data for income inequality it is compiled from the Global Consumption and Income Project & Standardized World Income Inequality Data base.

Causality Test

In this segment, we aim to elucidate the theoretical framework and the methodology employed in our study to examine the bi-directional relationship between defence expenditure and inequality in India. Our central hypothesis revolves around the notion that there exists a complex interplay between defence spending and inequality, and this section will serve to define the structural equation model upon which we base our investigation. The model is

$$IE_t = a_0 + a_1DEF_t + u_t \tag{1}$$

$$DE_t = b_0 + b_1IE_t + v_t \tag{2}$$

Where IE is the income inequality and DE is the defence expenditure of India. The results of the test are reported in Table:

The results of the unit root tests conducted at the level of income inequality reveal that the calculated t-statistics fall below the critical values at all conventional levels of significance. As a result, we fail to reject the null hypothesis suggesting that the variable possesses a unit root at the level of measurement.

Table: 1. The ADF GLS test results

Variables	Level	First difference
Defence Expenditure	-0.13	-5.34***
Income inequality	-1.42	-4.87***

Nevertheless, once the first difference of defence expenditure and income inequality is considered, the null hypothesis of unit root can be rejected. Thus, we have clear evidence that the variables under consideration are stationary but at first level.

Testing for co-integration

Given the differing orders of integration of the variables, we have applied the OLS-based Autoregressive Distributed Lag

(ARDL) approach to assess co-integration. The ARDL frame for Equations (7) and (8) is articulated as follows:

$$\Delta \ln DE_t = \beta_0 + \sum_{i=1}^p \beta_1 \Delta \ln DE_{t-i} + \sum_{i=0}^p \beta_2 \Delta \ln IE_{t-i} + \pi_1 \ln IE_{t-1} + \pi_2 \ln IE_{t-1} + \mu_t \quad (3)$$

$$\Delta \ln DE_t = \alpha_0 + \sum_{i=1}^p \alpha_1 \Delta \ln DE_{t-i} + \sum_{i=0}^p \alpha_2 \Delta \ln IE_{t-i} + \delta_1 \ln IE_{t-1} + \delta_2 \ln IE_{t-1} + \mu_t \quad (4)$$

In our investigation to ascertain the occurrence of a long-run association between defence expenditure and income inequality, we have adopted a systematic approach, consistent with the methodology proposed by Pesaran et al. (2001). Our key objectives have been to rigorously test the joint null hypothesis that the coefficients of the level variables are collectively equal to zero using an F-test, and to subsequently obtain long-run estimates through the ARDL co-integration technique. The F-test plays a crucial role in our analysis, as it helps us evaluate whether the coefficients of the level variables collectively contribute to a long-run relationship between defence expenditure and income inequality. To proceed, we have conducted estimations based on Equations (3) and (4) utilizing the ARDL co-integration technique. This technique allows us to derive long-run estimates, which are essential for understanding the sustained relationship between defence expenditure and income inequality. Throughout this estimation process, we have exercised utmost care in selecting the most appropriate model. To ensure robustness and accuracy in our results, we have considered various criteria, including the criterion, Hannan Quinn Criterion, AIC Criterion, and SBC Criterion. These criteria guide our selection of the model that best represents the data and the relationships under investigation. After comprehensive analysis and evaluation of multiple models, we have chosen to present results derived from the model selected based on the AIC criterion. It's important to note that this choice is not arbitrary but is informed by empirical support provided by Liew's Monte Carlo experiment in 2004. This experiment demonstrated the superiority of the AIC criterion over other criteria, particularly when dealing with a limited time span comprising fewer than sixty observations. This strategic selection emphasizes our commitment to employing a statistically robust approach in our analysis. By adhering to the AIC criterion, we aim to ensure the reliability of our results and their relevance to the specific context of our study. This approach underscores our dedication to providing meaningful insights into the relationship between defence expenditure

and income inequality in India and contributes to the overall robustness of our research. The calculated F-statistics for the co-integration test are reported in Table 4.9.1. The critical values for the F-statistics are provided in the same table alongside the computed F-statistics. In the case of the income inequality model (model 1), the calculated F-statistic is 1.90, which falls below the upper-bound critical value at any significance level. Therefore, we accept the null hypothesis that there is no co-integration in this model. Conversely, for the defence expenditure model, the calculated F-statistic exceeds the upper-bound value at a one percent significance level. This leads to the rejection of the null hypothesis of no co-integration in these cases, indicating the presence of long-term co-integration relationships among the variables. The estimation of the long-run coefficients for these models using the ARDL approach occurs in the subsequent step. The results are shown in Table 2. The long run coefficients of these models using ARDL approach are estimated in the second step.

Table. 2: Bounds tests for the existence of a long run relationship

		1% Critical Values		
Dependent Variable	Calculated F-statistic	I (0)	I(1)	Conclusion
Defence expenditure	1.90	8.74	9.63	No Co-integration
Income Inequality	10.17	8.74	9.63	Co-integration

Note: Critical values for the Defence Expenditure model is with intercept and trend whereas same for the income inequality model is with an intercept.

The outcomes are shown in Table 3. It is evident in the model that the coefficient of Defence Expenditure is positive and statistically significant. This shows that in the long run association of defence expenditure positively affects income inequality. Defence expenditure can pass the positive impact on income inequality through a number of ways. For instance the increased defence budget resulted in large government contracts being awarded to select defence contractors, many of whom had political or business connections. This created an environment where wealthy elites and politically influential individuals benefited disproportionately from the funds allocated for defence, rather

than those funds being used for broader economic development or public welfare. In many cases, defence contracts were inflated or awarded to companies that provided substandard equipment at higher costs, which not only compromised military effectiveness but also squandered public resources that could have been spent on critical social services such as healthcare, education, and infrastructure. As these contracts often involved large-scale projects with multinational companies, the benefits of the spending were more likely to circulate among a small group of industrialists and foreign suppliers, leaving the majority of the population with little to no direct benefit from the increased defence expenditure. The concentration of wealth within these privileged groups contributed to a widening of the income gap, as the poor and marginalized communities did not see a proportional increase in their economic well-being.

In light of our empirical analysis, it is vital to underscore the significance of the coefficient associated with income inequality in our study. This coefficient, which remains positive and statistically significant, provides compelling evidence of the stable and robust relationship between defence spending and income inequality in India. The findings unequivocally affirm that an escalation in defence expenditure exerts a persistent and favourable influence on income inequality over the long run.

Table.3: Long Run Coefficients estimating result

Variable	Inequality (IIE) ARDL (2,2)
Constant	-1.43 (-4.80)***
Trend	-0.007 (-2.56)***
Defence Expenditure (DE)	0.081 (7.39)***

Notes: Student's tests are in parentheses. *, **, ***Significant at 10, 5 and 1 percent level, respectively

In the last procedure, we proceed to obtain the error correction representation of Equations (3) and (4). Table.4 reports the short run coefficient estimates obtained from the ECM version of the ARDL models.

After carried out diagnostic tests that indicate the absence of evident nonlinearity and misspecification, along with the observation that the residuals display no signs of non-normality or heteroscedasticity, we can derive the following conclusions

from the results: The error correction coefficients (ECM) in the model exhibit a significant negative sign, providing further confirmation of the presence of a co-integration relationship among the model's variables. The estimated ECM coefficient's negative value implies that short-term fluctuations tend to converge back to the long-term equilibrium, suggesting that the relationship between the two variables exists both in the long run and the short run, with approximately 69 percent adjustment back to equilibrium conditions. To gain insight into the short-term dynamics, we conducted a Wald test on the lagged coefficients of IIE in the model. In this analysis, we reject the null hypothesis that the lagged coefficients are jointly equal to zero, providing evidence of interrelatedness between these two variables, IIE and DE, even in the short term. Furthermore, the short-term results show a reversal in the signs compared to the long run.

Table 3: The Short Run ARDL estimates

Variable	ΔIIE (ARDL 2,2)
Constant	-1.18 (-4.59)***
Trend	-0.007 (-4.79)***
ΔDE	-0.004 [-3.12]**
ECT_{t-1}	-0.69 (-4.59)***
2	0.46
F	5.38***

Notes: Figures within round bracket () are calculated student's t-statistics; figures within angle bracket [] are calculated Wald test statistics. *, **, *** Significant at 10, 5 and 1 percent level, respectively

Here, we find that the null hypothesis that is change in Defence expenditure does not affect income inequality in the short run has been rejected. This is based on the Table 3 in which it can be seen that F-statistic for the lagged defence expenditure is found significant. The negative sign of the coefficient of defence expenditure implies that defence expenditure affects income inequality inversely in the short run. The negative sign of the coefficient of defence expenditure suggests that, in the short run, an increase in defence spending may actually reduce income inequality, which can be attributed to several reasons. One possible explanation is that higher defence budgets can stimulate

economic activity by creating jobs in defence manufacturing, construction, and associated industries, particularly in regions with military installations. This can lead to higher employment levels, particularly for lower-income individuals, as well as skill development and economic opportunities that might not otherwise be available. Moreover, defence spending often leads to increased government procurement, which may boost local economies and generate short-term economic growth. Public sector employment in defence-related industries, particularly in manufacturing and engineering, can provide relatively stable wages for the working class, contributing to a reduction in income disparity, at least temporarily. Additionally, increased defence expenditure may encourage infrastructure development in military zones, leading to improved local infrastructure, such as roads, healthcare facilities, and schools. This infrastructure development could improve the living standards of surrounding communities, potentially reducing the inequality gap in certain regions.

Table 4: Causality result

Causality Type	Conclusion	Direction of causation
Short Run Granger causality Change in Defence Expenditure does not affect income inequality ($\sum_{i=\alpha_2\Delta}^2 LnDE_{t-1} = 0$)	Reject	Negative
Long Run Granger causality Change in Defence Expenditure does not affect income inequality	Reject	Positive

Source: Compiled from results of Tables 2 and 3

Conclusion

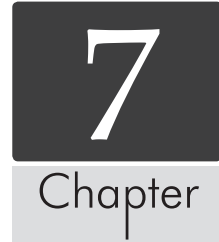
The relationship between defence expenditure and income inequality is complex and multifaceted, particularly in the context of India. While short-term increases in defence spending may seem to reduce income inequality by generating employment and stimulating local economies through procurement and infrastructure development, these effects are often temporary and localized. In the case of India, the aftermath of the 1971 India-Pakistan war and the subsequent surge in defence

expenditure revealed both the potential benefits and significant pitfalls of such spending. In the short run, defence expenditure may reduce inequality by creating jobs, enhancing local infrastructure, and stimulating economic growth in regions with military installations. These benefits could trickle down to lower-income groups, especially if the defence industry relies heavily on local labor. Furthermore, the state's involvement in defence procurement and development can lead to the construction of public goods, such as roads, hospitals, and schools, which indirectly benefit marginalized communities. However, these positive effects are overshadowed in the long term by the systemic issues of corruption and inefficiency in defence contracting. Over the years, a significant portion of defence spending has been marred by malpractices such as favoritism, cronyism, and inflated contracts. These practices divert public funds away from essential sectors like health, education, and infrastructure, which are critical for reducing income inequality. As a result, the benefits of defence spending often remain concentrated in the hands of a few politically connected elites, exacerbating wealth disparities and limiting the overall socio-economic development of the country. The diversion of resources into defence contracts without transparency or accountability undermines the broader goals of national development, particularly in addressing the needs of the poor and vulnerable. The defence budget, when misallocated, acts as a drain on public finances, depriving the majority of citizens of the necessary investments in education, healthcare, and other social welfare programs that are critical to reducing inequality in the long term. Thus, while defence expenditure can play a crucial role in ensuring national security, it must be managed with greater transparency, accountability, and alignment with broader developmental objectives. Policymakers must balance the need for robust defence capabilities with the pressing demands of social and economic development. Without such a balanced approach, defence expenditure will continue to serve as a double-edged sword, offering short-term benefits that ultimately contribute to long-term economic disparities and social unrest. It is only through strategic reforms, better governance in defence procurement, and a stronger focus on equitable development that defence spending can truly contribute to national security without exacerbating income inequality.

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Design for Change: Fostering indigenous art and design practices for sustainable livelihood

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Abstract

Art and design practices in community development, actively involves residents in identifying needs, planning a sustainable design solution, and implementing changes, shifting from top-down aid to collaborative empowerment, fostering ownership, building social capital, and ensuring sustainable, culturally relevant outcomes for better economic growth, and flexibility, using methods like re-design of the existed practices which is one of the prime focus to address issues of sustainable design practices from indigenous to contemporary design for the artisan community who are practicing indigenous art forms, but could not withstand the indignation of continuous technological development in preserving their art and there is a tendency to shift their occupation for survival in many occasions which had caused threat for survival to both the artisan and the art practice. Despite the cultural significance, these traditional art practices faces problems due to various factors which need attention for socio cultural and economic upliftment of an artist community from the design development perspective. The paper focuses on the projections of creating sustainable livings for local artisans, particularly potters of Barak Valley through contemporary

art and design intervention and integration of new design elements in preserving the age old heritage of traditional art practices. The paper has possible expected outcomes through participatory, community-centric approaches of the skills of the artisans/potters identified for the purpose of study, moving beyond mere mass production of the traditional pots and other utility items in particulars to new contemporary utility based items to foster self-reliance, broader economic benefit, social security and environmental adaptation.

Keyword: Art, Indigenous, Community, Design, Sustainability, Livelihood, Adaptability.

1. Introduction

Art and creative expression plays an important role in shaping our identity and existence and the dominance of various forms of design practices has made a considerable impact in our daily life in both aesthetical and functional approaches of the designs in any form - product, industrial, graphic or communication. While we all enjoy art that is created for the sake of art and artistic expression, it has also made a decisive impact on the existence of the craftsman and artisans from various domain of the traditional craftsmanship like, pottery, weaving, handicrafts, handlooms etc. who are facing resistance from the onslaught of technological intervention with the adoption of various design prototypes for a ready to accept market for mass productions of artifacts, negating the credibility of the skill and expertise of the traditional craftsman which had caused serious consequences for survival and economic security (Mago, 2017). In the framework of and design practice, community engagement as art work often define the involvement of diverse community members in a collaborative creative works and active participation that not only uplifts the cultural wisdom and practice to revive the indigenous art forms but also helps to sustain their livelihood through creative design integration in both traditional and contemporary approach. In community engagement projects, the designer's role is that of a catalyst and collaborator, bridging the gap between traditional craftsmanship and modern market demands to ensure sustainable livelihoods and cultural preservation which is the ultimate goal for a design to bring out change in the community.

2. Indigenous art practice and Barak Valley

The state of Assam is situated in the North-Eastern region of India, land of hills, plains, and rivers and bordering Bangladesh and Burma. The river Brahmaputra crosses through the state from North-East to the South-West. The state is divided into two river valleys- Brahmaputra valley and Barak valley (Bareh, 2001). Barak Valley, southern part of Assam is unique because of its diverse ethnicity, heterogeneous culture, language, ecosystem and rich heritage. The valley is named after the river "Barak" which consists of three districts Cachar, Karimganj, and Hailakandi. The Valley is a land of diverse community, ethnic like Bengali, Kachari, Assamese, Dimasa, H'mar, Kuki, Manipuri, Mizo, Reang, Tea- Tribe, and Naga co-exist together. Indigenous art, crafts and handloom of this region are deeply rooted to the culture, tradition, religion, ecosystem, economy and hold even an integral part in the survival of the common man. It has been observed that a groups geographical, socio cultural, political and economic condition of a particular place defines its historical orders and holistic growth (Paul, 2022). Art and Craft history of Barak is a noticeable phenomenon that also defines the history of these province. Pottery is one of the region's most famous cultural symbols. Until recently, all Indian pottery was made of earthenware, including terracotta as well. The art form continues to be widely practiced both inside and outside India as a cultural art. An important art form in the valley is pottery, clay artisans are known for carving different gods and goddesses on burned clay pots. These skilful clay artisans also create clay pots and utensils, flower vases, and other essential items (Nandi, 2010). Due to the unique feature of the soil, pottery works of this region is highly adorned everywhere in and around. Panibhora Bekirpar, located in southwestern Cachar, Katlicherra located in Hailakandi, and Anipur located in Karimganj are some places particularly famous for pottery and other clay works. In this valley, potters make a variety of percussion instruments, including the left part of the Tabla, Mridangam and khol. Bengali Hindus adopt this profession as Rudrapauls and Kumbhakars. (Ranjan et al. 1986). But then some members among the teagarden labourers who hailed from Uttar Pradesh have attached themselves to this profession particularly in Nayabil, a place adjacent to Barjalenga tea estate in Cachar. But most of these clay-potters are not introduced to the modern techniques of pot-making (Paul, 2022).

3. Objective of the study

The objective of the study is to understand the aspirations of the artisans and incorporate the expertise and expertise in amalgamation with contemporary taste. Since the artisans' lacks education and awareness on design approaches for sustainability, the project aimed at ensuring the facts that sustainable design projects are truly sustainable in the long run in standings for effective design amalgamation to the existed products they work on and to inculcate and provide new ideation and technical support. The study is based on the available indigenous art practices across Barak Valley and pottery in prominence. The proposed study follows the descriptive analytical method. For the study, both the primary and secondary data were utilised. The sources of preliminary data are personal interviews and interaction with the potters engaged with the art practices across Barak Valley is considered. The secondary data includes, books, journals, magazines, and internet sources.

4. Identification of problem

The indigenous art and design practice is confined to a particular demographic area/community/locality causes low awareness among the practicing artisans and the young urban consumers. Preservation, transportation and seasonal market is always a big challenge for the indigenous crafts man. Customers prefer cheap factory-made alternatives. Another important problem is that the handmade items is time consuming resulting to less income. Several other problem ideated in due analysis is that the items were traditional in their appearance and stylization and did not suit modern tastes. And the prospect of selling the items is limited to the local area only due seasonal demand and lack of transportation. Flower vases, cups, and plates lacked modern utility and variety. Some prominent clay items of Barak Valley are: *Kalsi (Matka)*, an earthen pot used as an important daily household items in rural part of the valley. *Kalsi* is generally used in rituals along with the daily use. *Hadri* is one of the most familiar pottery items of Barak Valley. *Hadri* (Bowl for cooking) is also is used to store water as well as act as a rice maker. *Chaye Bhar* (Tea cup) made out of clay is usually consumed in tea stalls, but due to the adoption of paper cups, the skill remain almost outdated in use due to the brittleness, but in recent past it has a partial reach for the item and is also used as matter of

popularizing tea with the branding like *Kullar chai*. The market for clay flower pot is also seen shrinking owing to the adoption of plastic pots for its durability and price. *Fooldani* (Flower Vase) is a popular item for beautification. Another important item *Patil* (banga for bowl) used to culture and preserve curd is mostly preserved and widely used clay items hold a legacy of its own for not only daily use item but has cultural significance as well. *Tandoori* pot or tandoori stove is a clay pot that is traditionally used in fire, made of terracotta, this tandoori pot can be heated to the highest temperature. *Dhupdani*, (banga for incense burner pot) is an extraordinary coconut charcoal incense holder, a handmade item from natural red clay used extensively to get rid of mosquitos and also used in religious activity (Paul ,2022).

5. Sustainable approach and design integration

In context to the sustainable approach in integrating present-day design to the existed traditional art practices, a prospect space of the artisans had been identified across Barak Valley to recognize the need and revival of the traditional practices under community engaged design project which indicated a greater potentiality for design practicability and its sustainability in terms of product design, technical support, and innovative idea generation. One such identified community is from Bakerpar a small village in the Sonai area of Cachar district, Assam is locally knows for the traditional pots and clay utensils. More than eighty families of the Pal Community depends on this traditional practice for their livelihood. Shora, an earthen plate has been adopted and mostly practiced by the artisans of the same Community. The artisans draw images of god and goddesses on these clay plates which had become a traditional practice of visual narration. In due course of time it is found that this indigenous art practice is gradually disappearing due to the change in the household items in favour of more durable and cheap price. To address the issue where the need for urgent design intervention is formulated with a grant received as an award from Hyundai Motor India Foundation under “Art for Hope 2023”, REDESIGN, the design cell of the alumni of the Department of Visual Arts Assam University had led a design project to execute a space beautification project and product development project to promote the traditional art of Barak Valley which seems to be fruitful for the community to revive the

art practice with new idea generation approach and the present scenario is very promising with engagement of the artisans with new ideas based product practicability. Many such work also been carried out under the community engaged design project by the students of the Assam University Silchar, who made a thorough investigation on the current problem of sustainability of the artisans on such traditional skills to support a family from Allenpur, located in the Cachar district, where a local potter practices primarily involves producing bowls and pots used largely for ceremonial purposes using a traditional potter's wheel, following forms and techniques adopted for generations without any change. While his craftsmanship is consistent and rooted in tradition, the scope of products he creates remains limited, offering little opportunity for diversification or increased income. Unlike many narratives of disappearing crafts, this artisan did not have discontinued forms or forgotten products in his practice, that he thought might not be worth making, while also stating that he was content with making what he knew from the his childhood as mode of learning the craft from his ancestor. This presented a challenge, as the initial objective of reviving an abandoned craft that was not directly applicable. As a result, the project required an adaptive approach while still remaining grounded in the principles of community engagement, sustainability, and economic viability. A possible findings from the practicing community is also conducted in Dwarbond area, known for its traditional pottery practices where a local potter who still uses age-old techniques to produce handmade clay pots was identified who had previously crafted clay flower vases, cups, and plates, but discontinued them because of low demand and insufficient income. The purpose then was to come out for a design solution of these discontinued products so that they become more marketable, functional, and profitable for him. In continuation of such design integration with traditional norms, an idol maker family from Hailkandi district was also identified where traditional idol and clay dolls making process is still practice in a techniques which is in rudimentary form and locally sourced terracotta clay. During the interaction with the family it is revealed that they primarily produces idols as prime items and few utilitarian items to cater the religious practices-items such as pots, bowls, earthen lamp, and other similar utilitarian items were identified. Although these objects are well-crafted and functional, their demand has abridged over time,

owing to the increasing use of plastic, metal, and factory-made alternatives. Most of the items continue to follow repetitive forms with limited design innovation, making them less appealing to younger and urban consumers which had increased the tendency to shift their profession due to technological adaption and use of synthetic materials. This situation highlights the need for design intervention that respects traditional craftsmanship while introducing contemporary relevance. The outcome of the intervention had a possibility of revision of the existing pottery from functional and aesthetic modification to support sustainability and livelihood of the artisan.

6. Design concept and inspiration

To cater the need for sustainability of the livelihood of the artisan community who are engaged into these traditional art practice, the concept and inspiration for a sustainable design emerged from observing one of the most commonly used utility items that almost every house hold consider upon - a stationery item, a pen holder, organized in a multiple compartments to ease the workspaces with simple handmade product which has a prospect for students and office stationery items that is not only functional but also aesthetical and sustainable in practicability . With this approach, a clay desk organizer will replaces plastic ones with something more natural and personal. The stationery holder is meant to serve as an all-stationery product on a desk. Its usage involves potentially less use of the plastic factory- made stands that are available today, which also makes it environmentally friendly. Drawing inspiration to have more variants in applicability with new ideas, is a flower pot that was chosen due to its lack of daily usage as people are mostly driven by plastic pots, bowls and kitchen utensils for their needs. Although the artisan does not traditionally produce flower pots, the form itself is a widely recognizable decorative object with a simple structure and clear functional logic. The idea was then to explore how such a form could be adapted for contemporary needs while retaining recognisable elements of the original object. This approach allowed the design inspiration to remain respectful of the artisan's skills and tools, while opening possibilities for broader utility and appeal. The final design concept involved developing a stationery stand inspired by the basic form of a flower pot, adapted to suit the artisan's existing wheel-based techniques. The product

somewhat retains the key visual characteristics of the original design, like the tapered body - just slightly altered to make it look more interesting, while subtly modifying proportions and openings to accommodate stationery items like pens, brushes, and small tools. The inspiration for this project also came from observing contemporary ceramic products that need to be reinterpreting the traditional materials for modern lifestyles. Products such as perforated clay lamps creating shadow patterns and ceramic phone holders functioning as passive sound amplifiers, demonstrated how simple design changes can significantly enhance usability and value. These references showed that clay can move beyond conventional usage and become part of modern interior décor and everyday technology for sustainability and economic growth. This understanding encouraged a shift in perspective—from viewing the potter's work as purely traditional objects to recognizing them as adaptable forms with potential for modern application.

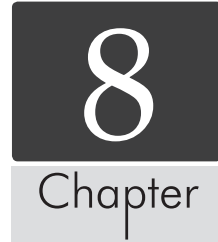
7. Conclusion

A community engagement design project is a collaborative process where designers work with a community to identify needs, co-create solutions (for spaces, policies, or services), and implement changes, ensuring projects are relevant, equitable, and foster ownership by involving locals in decisions from start to finish, using methods like workshops, interactive maps, and participatory budgeting. It's about building trust and shared leadership, moving beyond simple consultation to true partnership for positive, sustainable change. The story of the traditional artisans from *Panibhora*, *Allenpur*, *Bakerpar*, *Nayabil*, *Borjalenga*, *Katlicherra*, *Duarbond*, and *Hailkandi* as discussed, highlights a strong affiliation for traditional earthy culture that is currently under tremendous sustainable crisis. With thoughtful redesign of clay plates, flower vases, cups, and pots, the artisan can regain market relevance, attracting a wider customer to achieve sustainable income with sustainable product which is necessarily ecofriendly in nature. Such design interposition demonstrates the importance of combining traditional skill with contemporary design to uplift the artisans and preserve the craftsmanship and its culture. At its core, design for a change can acknowledge a simple yet profound truth : SUSTAINABILITY, which isn't just about materials and technology, but about people, creating sustainable design solutions that will genuinely meet the needs of those who will use and be affected by them. To

enrich the community with sustainable eco-friendly products, continuous design impetus is required to understand the needs and aspirations of the community for better economic stability, incorporating local knowledge and expertise from professionals in order to build trust and foster a sense of ownership of the legacy for a sustainable design approach to be effective in the long term. For an extensive design exercise to chance the sustainable design goal in relations of product development, branding, sustainable packaging design innovations in merchandising of the products etc., conducting regular workshops and training programs to help artisans learn new techniques, and co-create products that align with the current market demands can be commendable. Implementation of public awareness campaigns to nurture the cultural significance of local crafts and encourage community support for these artisans can be effective in dealing with the problems. Bringing community members together to brainstorm ideas, share knowledge, and develop design solutions to understand their needs and preferences followed by testing of those design ideas on a small scale to gather feedback from community can help and refine the approach of design to grow and sustain. Instead of merely commissioning work, designers can engage with artisans, respecting their traditional knowledge and allowing for shared creative input. Designers also can help reinterpret traditional techniques and motifs in contemporary contexts, ensuring the products that call to a wider consumption space and contemporary audience. The prospect for advocacy of sustainability can be improved by sourcing materials locally available in promoting handmade and durable products, aligned with a wider sustainability goals.

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An Analysis of Growth and Stability of Solar Energy and Small Hydro Power Installation Capacity in Northeast India

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Abstract

Non-renewable energy sources are depleting fast. These non-renewable sources are also contributing in global warming and climate change. Hence, it is necessary to use the sources of renewable clean and abundant energy sources. Among various types of renewable energy sources, solar power and small hydro power are the two most important energy sources available in northeast India. Arunachal Pradesh has one of the highest small hydro power potential. Among all the states of northeast India, only Manipur has a solar policy. Despite having very high potential of these two sources, all the states are exploiting very insignificant proportion of these two clean energy potentials. Moreover, high instability is also observed in the use of these two potentials. On the basis of the findings, the study suggests greater efforts on the part of state governments and more spending on R&D.

Keywords: *Renewable Energy, Solar Power, Small Hydro Power, North East India*

1. Introduction

Energy is the driving force of any economy. Unlike fossil fuels, renewable energy is a more sustainable energy source which can immensely contribute to economic growth (Hieu and Mai, 2023, Obani, et al., 2024). As a country experiences rapid economic development, its focus shifts from the use of non-renewable energy sources to renewable energy sources. Renewable energy consumption is high for countries with higher GDP compared to lower ones (Ntanos *et al.*, 2018). Empirical studies showed positive influence of economic growth and renewable energy and a bi-directional causal relationship between energy consumption and economic growth (Belke *et al.*, 2011; Zhang 2011; Das *et al.*, 2012; Dantama *et al.*, 2012; Asiudu *et al.*, 2021). GDP per capita influenced energy consumption in short run and decline in GDP due to energy consumption in long run south Asian nations during 1971-2006 (Noor and Siddiqui 2010). Long run positive relationship is found between economic growth and the use of renewable energy in several studies (Madson and Hansen 2019; Kasperowicz *et al.*, 2020; Li *et al.*, 2021; Topcu and Dogan 2022; Gupta and Guha 2024; Bhavsar *et al.*, 2025).

There are several sources of renewable energy, viz., small hydro power, biomass power, power generated from waste to energy, solar power and large hydro power. If we consider northeast India, this region has a lot of potential in terms of renewable energy especially solar and small hydro power. The topography has blessed this region a hydro power potential of 66000 MW, which is approximately 40% of the national potential (Saikia, *et al.*, 2023). Arunachal Pradesh has the 3rd highest estimated potential of small hydro power among all states of India (www.pib.gov.in). Assam is leading with rooftops and village level mini grids. Meghalaya and Tripura are experiencing urban rooftop boom. The community owned and operated solar micro grids are providing reliable power in Arunachal Pradesh and Nagaland. Mizoram and Manipur are using solar irrigation pumps to enhance crop yields without negative environmental effects. Moreover, Manipur used to face acute power shortage. By the introduction of solar heaters with a capacity of around 100 liters per day has helped to cope with power shortage. In 2012, Tripura has provided solar energy to almost 700 hamlets and 50 villages, thereby benefitting more than 30000 families.

The estimated potential of all the sources of renewable energy in northeast India is 128962.49 MW. Out of which, only 4834.58 MW has been installed (www.pib.gov.in). Despite having huge potential for renewable energy, all the states of northeast are power deficient states. Among all these sources, wind power has not been developed in the northeastern states of India at all despite having a potential of 300 to 500 MW at even the low hub heights of 50 and 80 meters respectively (cdn.cseindia.org). Small hydro power constitutes 98% of installed renewable energy in northeast region (cdn.cseindia.org). It does not have the problems like displacement of people, submergence of land in catchment area, ecosystem damage, risk of dam malfunction like large hydropower projects and exempted from forest, free from public sitting, economical, have low gestation period, and are idle for powering villages and isolated areas (Doso and Gao, 2020). The solar power potential of northeast India is almost 62300 MW. Only Manipur has a solar policy. Among the northeastern states, the electricity sector is dominated by renewable energy sources like small and large hydro power. Meghalaya is the only state which has 70% of its electricity generation from large hydro power with no deficit or surplus in terms of availability and requirement of electricity (cdn.cseindia.org). All other states are heavily dependent on small hydro power generation. Other forms of renewable energy sources like biomass power, waste to energy are not developed in this region.

2. Objectives of the study

The paper intends to study the variance and stability in installed capacity of renewable energy sources in the states of India. Moreover, average installed capacity of renewable energy sources and their consistency in these states are also investigated.

3. Data and Methodology

3.1 Data

This study is based on secondary data. The major data source is Renewable Energy Statistics, different years and Handbook of Statistics on Indian Economy, different years published by Ministry of New and Renewable Energy, Govt of India and Reserve Bank of India respectively. The data is collected for the 17 years' time period 2007-08 to 2023-24 on the renewable energy installed capacity of the states of India.

3.2 Methodology

This section discusses the methodologies of investigating the mentioned objectives.

3.2.1 Measurement of Instability

We have used Cuddy-Della Valle (1978) index to measure stability in installation of solar power and small hydro power. The Cuddy-Della Valle index is defined as

$$I_x = CV^2$$

Where CV is the coefficient of variation and r^2 is the corrected or the adjusted coefficient of multiple determination of the trend function that best fits the series of data. If F test is significant at 5% level, the index is calculated by selecting the trend function (linear or log linear) having the highest r^2 . If $r^2 < 0$, then unadjusted R^2 is chosen.

Low instability will be there if the value of the index lies between 0-15. Instability will be medium if it ranges between 15-30 and if the value of the index is more than 30, then it shows high instability. This index is better than coefficient of variation. A rising trend shows high CV despite having small fluctuations in different years. Cuddy Della Valle index corrects this by removing the trend effect.

4. Results and Discussion

In this section, the estimated results of the study are discussed.

Table: 1 Annual growth rates of installed capacity of small hydro power (SHP) and solar power (SP) in all the states of northeast India

Year	Arunachal Pradesh		Assam		Manipur		Meghalaya		Mizoram		Nagaland		Sikkim		Tripura	
	SHP	SP	SHP	SP	SHP	SP	SHP	SP	SHP	SP	SHP	SP	SHP	SP	SHP	SP
2007-08	0	0	0	-	0	-	0	-	0.4	-	0	-	0.2	-	0	-
2008-09	0.36	0.5	0	-	0	-	0	-	0.5	-	0	-	0	-	0	-
2009-10	0.2	0	0	-	0	-	0	-	0.01	-	0	-	0.11	-	0	-
2010-11	0.1	0	0.2	-	0	-	0	-	-0.01	-	0	-	0	-	0	-
2011-12	0.01	0	0	-	0	-	0	-	0	-	0	-	0	-	0	-
2012-13	0.3	0	0	-	0	-	0	-	0	-	0.03	-	0	-	0	-
2013-14	0	0	0.1	-	0	-	0	-	0	-	0	-	0	-	0	-
2014-15	0.01	0	0	-	0	-	0	-	0	-	0.03	-	0	-	0	-
2015-16	0	8	0	-	0	-	0	-	0.1	0	0	-	0	-	0	0
2016-17	0	0	0	0.1	0	71.3	0		-0.1	0	0	-	0	-	0	0.02
2017-18	0.02	18.9	0	-0.02	0	-0.9	0	5	0	1	0	1	0	-	0	0
2018-19	0	0	0	0.8	0	56.3	0	-0.7	0	0	0	0	0	-1	0	0
2019-20	0	0	0	0.8	0	0.5	0.1	5	0	1.5	0	0	0	-	0	0
2020-21	0.22	0.04	0	0.04	0	0.2	0	0	0	2.04	0	0	0	6	0	0.8
2021-22	0	0	0	2.4	0	0.9	0	0	0.2	0.01	0.1	0	0.06	0	0	0.6
2022-23	0.02	1.1	0	0.1	0	0.1	0.7	33.6	0	17.3	0	2.04	0	6	0	0.2
2023-24	0	0.01	0	0.1	0	71.3	0	0.02	0.4	0.1	0	0.04	0.2	0.5	0	0.05

*Adapted from secondary data

Table: 1 shows that both SHP Installation and SP installation growth rates were very negligible during the entire study period. Before 2015-16, almost all the northeastern states had no installation of solar power. Highest growth rate in SP installation was found in 2017-18 in Arunachal Pradesh, while the same year showed negative growth in SP installation in Assam. The SHP Installation remained same in Manipur during the study period. In 2018-19, SP installation had negative growth rate in Meghalaya but it showed sharp increase in 2022-23. In this year, Mizoram too had highest growth in SP installation. The SHP installation remained stagnant from 2007-08 to 2023-24. In Tripura. Sikkim too demonstrated same results from 2010-11 to 2020-21. Hence, it can be concluded from the table that the annual growth rate in the installation of SHP and SP were very much insignificant during this 17yres period.

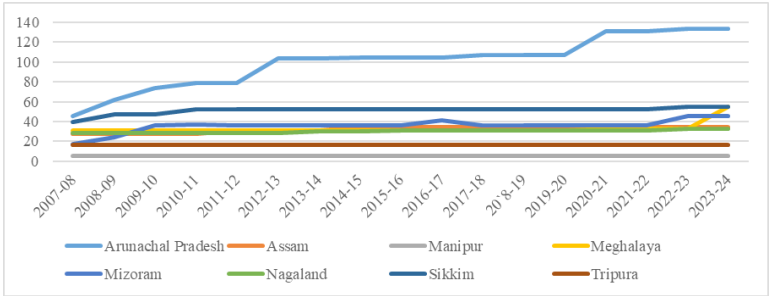


Figure:1 Trends in installation of SHP in all states of northeast India during 2007-08 to 2023-24

**Adapted from secondary data*

Figure:1 shows Arunachal Pradesh has seen a continuous growth but from 2011-12 to 2012-13, there was a sharp growth rate. From 2012-13 to 2019-20, small hydro power had a steady growth rate. Again, it showed a sharp rise. After that, it maintained a stable growth. Other states maintained a more or less stable growth during the study period. Tripura did not show any small fluctuation.

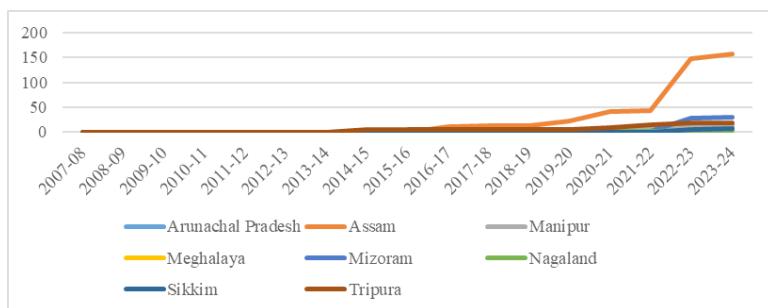


Figure:2 Trends in installation of SP in all states of northeast India during 2007-08 to 2023-24

**Adapted from secondary data*

Figure:2 shows Assam has experienced a continuous growth from 2016-17. From 2021-22 onwards, there was a sharp growth rate. Other states did not show much improvement. Only Mizoram showed small improvement from 2021-22.

Table: 2 Average installed capacity, estimated potential, coefficient of variation and stability (I_x) of SHP and SP in all northeastern states of India during 2007-08 to 2023-24

States	Small Hydro Power (SHP)					Solar Power (SP)				
	Mean	Estimated Potential*	CV	2	I_x	Mean	Estimated Potential*	CV	2	I_x
Arunachal Pradesh	100.6	2064.9	25.4	0.87	9.2	3.03	8650	134.9	0.72	71.4
Assam	31.9	201.9	9.3	0.73	4.8	26.3	13760	187.5	0.5	132.6
Manipur	5.45	99.9	0	0	0	2.5	10630	172.5	0.58	111.8
Meghalaya	32.7	230.1	17.6	0.16	16.1	0.5	5860	258.2	0.29	217.6
Mizoram	36	168.9	18.2	0.46	13.4	3.68	9090	261.1	0.3	218.6
Nagaland	30.1	182.2	4.4	0.84	1.8	0.7	7290	147.3	0.64	88.38
Sikkim	51.1	266.6	7.3	0.47	5.3	0.7	4940	284.3	0.26	244.6
Tripura	16.01	46.9	0	0	0	5.3	2080	117.6	0.78	55.2

*Researchers' own calculations based on secondary data

**Energy Statistics, different years, MoSPI, GOI

Table: 2 shows that the estimated potential of both SP and SHP are much higher than the average installed capacity of both the sources. Assam has the highest estimated SP potential among all states but only an average of 0.19 per cent has been installed. Manipur has the second highest estimated SP potential but only 0.02 per cent has been installed. The remaining states too have very low proportions of installed SP. Among all the states, average installed capacity of SP is highest in Assam and lowest in Meghalaya. The estimated potential of SHP in every state is quite high but only a small proportion has been utilized. Its potential is highest in Arunachal Pradesh followed by Sikkim. It is lowest in Manipur.

Among solar power and small hydro power, highest coefficient of variation is found in case of SP. Mizoram recorded highest coefficient of variation while Tripura registered lowest coefficient of variation in SP installation. In case of SHP installation, highest coefficient of variation is shown by Arunachal Pradesh and lowest variation is shown by Nagaland. Manipur and Tripura did not show any variation. This is because, throughout the study period, SHP installation remained almost stable in both the states.

The instability index for SHP is found to be lowest in case of Nagaland. Tripura and Manipur showed zero instability. On the contrary, the instability index for SP is found to be much higher than that of SHP. Among all the northeastern states, Sikkim has highest instability. None of the 8 states recorded low or medium instability in SP installation during the study period. The reason could be the less importance given to the installation of SP in all these states.

5. Conclusion and Policy Prescriptions

5.1 Conclusion

The paper looks into average installed capacity of the two most important sources of renewable power, viz., solar power and small hydro power and the variations in the installed capacity during the period from 2007-08 to 2023-24. Because of mountainous topography and perennial streams, northeast India has largest hydropower potential (Thakur, J. 2023). Arunachal Pradesh has adopted small hydro power policy to encourage private participation in small hydro power generation. Same

policy was adopted by Sikkim also. The central govt has granted Rs.22.5 million to all the states of northeast India for small hydro power projects (www.investindia.gov.in). Northeast India gets a healthy amount of 4-5 hours of daily peak sun for efficient and economical photovoltaic solar system. The use of urban rooftops in Guwahati, Shillong and Agartala, community micro-grids in Arunachal Pradesh, use of subsidized solar irrigation pumps in Mizoram, Manipur and Tripura are increasing (solarprabha.com). The Contribution of the present study is that it discusses whether the region is steadily increasing its installation capacity to meet its growing energy needs or not. Northeast India is facing certain challenges like heavy rainfall and humidity, weak transmission power lines, high initial costs, lack of awareness among local communities (solarprabha.com). In this study, most of the states showed high instability in the installation of solar power. On 31st March 2019, the Ministry of New and Renewable Energy has approved projects with capacities upwards of 55MWp in various northeastern states (www.investindia.gov.in).

The study helps to understand that over the years, a very insignificant proportion of both the energy sources have been utilized. For example, in 2009-10, per capita electricity consumption of Sikkim was 845.40 kWh (www.pib.gov.in). Again, the per capita electricity consumption in 2012-13 was 718.57 kWh in Arunachal Pradesh, 240.28 kWh in Assam, 352.86 kWh in Manipur, 690.20 kWh in Meghalaya, 469.38 kWh in Mizoram, 268.49 kWh in Nagaland, 296.05 kWh in Tripura. This was much lower than 914.41 kWh of India (Energy and energy access: northeast India, factsheet). But present analysis shows very insignificant contribution of both the clean energy sources to meet its energy needs. The empirical findings suggest that the estimated potential of both solar energy and small hydro power are much higher than the average installed capacity of solar energy and small hydro power. Both Assam and Manipur have highest estimated solar power potentials but none of the states of northeast India has installed its fullest potential. Similar results are also found in case of small hydro power installation also. Geographical disadvantage, tectonic problems, northeast being a part of Indo-Burma Hotspot with more than 1/3rd of country's total biodiversity, socio-economic challenges creating problems for the development of small hydro power in this

region (Saikia, *et al.*, 2023). In case of solar power, lower solar insulation, the output of solar power projects is less but the cost is high due to their remoteness, according to the Ministry of New and Renewable Energy.

Moreover, non-receipt of an adequate number of state govt proposals to set up grid connected solar projects (The Sentinel, 31st March, 2023, www.sentinelassam.com) shows lowest variation in installed capacity of solar energy is found in case of Tripura while it is highest in Mizoram. Assam showed high variation in installed capacity of solar energy. In case of small hydro power, Assam, Manipur and Tripura did not show any variation. The reason is all the three states recorded same amount of installed capacity of small hydro power installation. Highest instability in solar power installation capacity is registered by Meghalaya and Mizoram, while highest stability is found in case of Tripura and Assam. The instability index of small hydro power shows highest instability is found in Mizoram. If the CV and instability index of both the energy sources are compared, it is found that compared to solar power, the installation capacity of small hydro power showed greater stability with lesser variations.

5.2 Policy Prescriptions

The above analysis suggests that the state governments should increase their efforts to raise the installation capacity of these two largely untapped clean energy sources. The huge gap between the estimated potentials of solar energy and small hydro power and their installed capacity suggest more expenditures on R&D so that costs can be reduced and installation capacity can be increased.

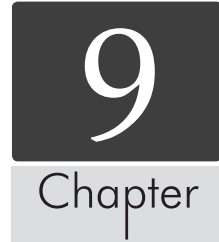
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Artificial Intelligence and Machine Learning

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Abstract

This chapter shows the evolving influence of Artificial Intelligence (AI) and Machine Learning (ML) on the digital economy, emphasizing their economic ramifications, adoption trends, and socio-economic effects. The digital economy has become a fundamental component of global economic operations, representing a substantial portion of world GDP. The swift advancement of AI and ML technologies has expedited this shift, augmented productivity, and stimulated innovation across several sectors. The implementation of these technologies is inconsistent, exhibiting significant discrepancies between the Global North and South. This chapter is to present the impact of AI and ML on economic performance, analyze the obstacles to their dissemination, and address the governance and ethical issues related to their application. The chapter used a mixed-method approach, integrating qualitative insights with quantitative data to show the adoption trends, economic implications, and societal challenges. The results indicate that although AI and ML possess the capacity to create trillions of dollars in value and enhance global GDP, their advantages are not uniformly allocated. Identified key hurdles are the governance-implementation gap, ethical

hazards including bias and privacy concerns, and environmental issues associated with energy usage in AI-driven data centers. The chapter enhances scholarly discourse regarding AI's economic implications and provides pragmatic guidance for politicians and industry professionals on promoting responsible AI use. The chapter highlights the necessity for comprehensive laws and regulatory frameworks to address the digital gap and guarantee fair access to AI technologies, in light of the swift advancement of AI. Future exploration must concentrate on formulating measures to mitigate AI's environmental impact, improve its inclusivity, and investigate its enduring implications on labor markets and global disparities.

Keywords: Artificial Intelligence, Digital Economy, Ethical Oversight, Generative AI, Global Adoption, Machine Learning, Policy Implications.

Introduction

The digital economy has undeniably emerged as a hallmark of contemporary marketplaces. Recent evaluations highlight that widespread digital connectivity is an essential catalyst for global growth, profoundly altering business structures and industries (Bai et al., 2024). In practice, digital goods and services support production, consumption, and trade on an unparalleled scale. A thorough assessment indicates that the ICT-driven digital economy has become a “significant contributor to economies worldwide,” highlighting its pivotal role in economic activity (Oloyede et al., 2023). The IDCA Global Digital Economy Report indicates that digital activities constitute approximately 15 percent of global GDP (IDCA, 2024). Between 2020 and 2024, the digital economy in the United States expanded to around 4.9 trillion U.S. dollars, accounting for over 18 percent of the U.S. GDP and sustaining around 28 million jobs (IAB, 2024). Academics caution that this expansion has exacerbated a “digital divide,” with affluent economies securing an inequitable percentage of digital market value, particularly in sectors such as e-commerce (Murthy et al., 2021). The global digital economy expanded almost 9 percent annually, surpassing the broader economy’s 7 percent growth (IAB, 2024). Asia’s digital economy, propelled by the swift adoption of mobile internet and e-commerce, grew by over 5 percent annually (IDCA, 2024). These statistics underscore the critical role of digital infrastructure and platforms in economic performance.

Artificial intelligence (AI) and machine learning (ML) have become important catalysts of digital transformation. Artificial Intelligence (AI) denotes systems capable of executing tasks that necessitate human-like cognitive abilities, whereas Machine Learning (ML) employs data to train models that discern patterns autonomously, without explicit programming (Wikipedia authors, 2024). Recent evaluations recognize AI as a crucial element of digital strategies, with firms throughout various sectors utilizing AI to innovate and secure competitive advantage (Kavak & Rusu, 2025). In the last ten years, AI and ML have transitioned from research settings to mainstream production situations. Industry estimates indicate that by 2024, almost 75% of surveyed firms globally will be utilizing AI in some form, highlighting its swift integration into contemporary business practices (Stanford Institute for Human-Centered AI, 2025). Forbes projects that the worldwide AI market would attain around 1.34 trillion U.S. dollars by 2030, with business adoption increasing at an annual pace of nearly 36 percent (Forbes, 2023). Businesses are utilizing AI in various applications, including intelligent recommendation systems, predictive maintenance, chatbots, and autonomous vehicles. This widespread use is evidenced by rigorous assessments indicating that AI has rapidly emerged as a primary technical focus for enterprises of all sizes, fundamentally transforming business processes (Ayinaddis, 2025). Approximately 72 percent of companies utilize AI in at least one capacity (Forbes, 2023), with adoption escalating to 84 percent inside the Gulf Cooperation Council (GCC) and roughly 88 percent worldwide, as per McKinsey's 2025 survey (BlueGrid, 2024; McKinsey & Company, 2025). These adoption figures demonstrate the rapid integration of AI across several industries. The potential of AI and ML resides in enhanced productivity and growth. Meta-analyses indicate that AI-driven automation and optimization might markedly enhance productivity; for instance, economic models forecast that AI could considerably elevate GDP growth, particularly if paired with extensive skill development (Cerutti et al., 2025). McKinsey & Company estimates that AI could produce an annual value ranging from 3.5 to 5.8 trillion U.S. dollars and elevate productivity growth to approximately 2 percent per year (McKinsey & Company, 2018). AI can automate routine tasks, optimize logistics, detect anomalies, personalize content and enhance decision making. Formal modeling suggests that AI will likely produce far

greater benefits in advanced economies: an IMF analysis reveals that anticipated GDP increases from AI are more than double in high-income countries compared to low-income nations (Cerutti et al., 2025; Rockall et al., 2025). AI is anticipated to enhance worldwide GDP by approximately 21 percent by 2030 (Forbes, 2023). However, the proliferation of AI is inconsistent. Adoption rates are highest in technology-intensive economies, such as the United Arab Emirates (UAE), Singapore, and Norway, where over 40 percent of the working-age population utilizes generative AI tools (Microsoft AI Economy Institute, 2026). Conversely, hardly 14 percent of the working-age population in the Global South utilizes such technologies (Microsoft AI Economy Institute, 2026). Experts assert that addressing these disparities necessitates inclusive policies; without deliberate action, AI may exacerbate current inequalities by consolidating its advantages in already privileged areas (Maghsoudi et al., 2025). The North–South divide suggests that technological progress may exacerbate existing inequities if not meticulously regulated.

This introduction prepares for a comprehensive investigation of AI and ML inside the digital economy. The remainder of the chapter will (i) examine the history and fundamental principles of AI and ML, (ii) analyze contemporary research on adoption trends, advantages, and hazards, (iii) provide a case study of practical AI deployment, and (iv) explore policy and managerial implications. The chapter emphasizes the need to balance enthusiasm about AI with critical observations on ethical, regulatory, and societal issues.

Background / Literature Overview

Historical Development and Conceptual Foundations

The term digital economy refers to economic activity that depends on digital technologies, platforms, and data. The interconnection of networks and data-driven services is widely acknowledged as a primary driver of global economic growth (Bai et al., 2024). With the ubiquity of digital instruments, digital goods and services increasingly constitute significant elements of production, consumption, and commerce. Systematic assessments indicate that ICT-driven digitalization substantially enhances GDP in numerous nations (Oloyede et al., 2023). The IDCA Global Digital Economy Report indicates that digital

activities constitute approximately 15 percent of global GDP (IDCA, 2024). Empirical research indicates that developed economies obtain an unequal percentage of digital market profits, illustrating a persisting “digital divide” (Murthy et al., 2021). Between 2020 and 2024, the digital economy in the United States expanded to over 4.9 trillion U.S. dollars, accounting for over 18 percent of U.S. GDP and sustaining around 28 million jobs (IAB, 2024). Trade evaluations indicate that even slight increases in internet access can significantly enhance exports and incomes for underprivileged economies (Herman & Oliver, 2022). The global digital economy expanded almost 9 percent annually, surpassing the broader economy’s 7 percent growth (IAB, 2024). The digital economy of Asia, propelled by the swift uptake of mobile internet and e-commerce, grew by over 5 percent annually (IDCA, 2024). Nevertheless, assessments of digitalization and sustainability caution that the swift growth of the ICT sector incurs environmental costs—such as electronic waste and substantial energy consumption—that require management (Raihan, 2024). These statistics underscore the critical role of digital infrastructure and platforms in economic performance. Prominent analysts assert that the digital economy may realize its potential as a catalyst for innovation and inclusive growth solely through flexible policy frameworks (OECD, 2024).

Artificial intelligence and machine learning have become the foremost catalysts of this digital transition. Artificial Intelligence (AI) pertains to the domain of developing systems capable of executing tasks that necessitate human-like cognitive functions, including perception, reasoning, and decision-making. In contrast, Machine Learning (ML) employs data to train models that autonomously discern patterns or functions without explicit programming (Wikipedia contributors, 2024). Recent evaluations recognize AI as a crucial element of digital transformation initiatives, with organizations in several sectors utilizing AI to foster innovation and enhance competitiveness (Kavak & Rusu, 2025). In the last ten years, AI and ML have transitioned from research laboratories to mainstream production settings. Forbes projects that the worldwide AI market will attain around 1.34 trillion U.S. dollars by 2030, with business adoption increasing at an annual pace of approximately 36 percent (Forbes, 2023). Analysis of corporate survey data indicates that by 2024, about 80% of organizations globally were utilizing AI, demonstrating

its swift integration into company operations (Stanford Institute for Human-Centered AI, 2025). Businesses are utilizing AI in various applications, including intelligent recommendation systems, predictive maintenance, chatbots, and autonomous vehicles. Approximately 72 percent of companies utilize AI in at least one capacity (Forbes, 2023), with adoption escalating to 84 percent inside the Gulf Cooperation Council (GCC) and approximately 88 percent globally, as reported by McKinsey's 2025 survey (BlueGrid, 2024; McKinsey & Company, 2025). Survey findings reveal that AI has emerged as a paramount technology goal for companies of all sizes, substantially transforming their operations and innovation strategies (Ayinaddis, 2025). These adoption figures demonstrate the rapid integration of AI across several industries.

The potential of AI and ML resides in enhancing productivity and fostering growth. Meta-analyses indicate that in economies with extensive AI use, annual productivity growth may increase by approximately 1 percentage point (OECD, 2025; Cerutti et al., 2025). McKinsey & Company estimates that AI could yield between 3.5 and 5.8 trillion U.S. dollars in yearly value and elevate productivity growth to approximately 2 percent per annum (McKinsey & Company, 2018). Artificial intelligence can automate repetitive operations, optimize logistics, identify anomalies, customize information, and improve decision-making. Recent modeling forecasts that AI-driven growth would result in substantial aggregate GDP increases, perhaps amounting to tens of trillions globally; nevertheless, the advantages will be inequitably allocated in the absence of governmental action (Cerutti et al., 2025; Rockall et al., 2025). AI is anticipated to enhance worldwide GDP by approximately 21 percent by 2030 (Forbes, 2023). The proliferation of AI is inconsistent. Adoption rates are highest in technology-intensive economies, such the United Arab Emirates (UAE), Singapore, and Norway, where over 40 percent of the working-age population utilizes generative AI tools (Microsoft AI Economy Institute, 2026). Conversely, hardly 14 percent of the working-age population in the Global South utilizes such technologies (Microsoft AI Economy Institute, 2026). Analysts caution that existing governance deficiencies may allow AI to intensify global disparities; for instance, uncoordinated digitalization typically advantages developed economies initially (Maghsoudi

et al., 2025). The North-South divide suggests that technological progress may exacerbate existing disparities if not meticulously regulated. Research on AI implementation emphasizes that comprehensive policy frameworks and investment in skills are crucial for the equitable distribution of AI advantages (Batool et al., 2025; Mokgata et al., 2026).

Case Study / Example

Netflix: Personalization at Scale

Netflix exemplifies how machine learning drives commercial success. The streaming service gathers extensive data on customers' viewing behaviors, search trends, ratings, and device utilization. Netflix employs supervised and unsupervised learning to generate personalized profiles and suggest films and series aligned with user tastes. In 2016, the business indicated that more than 75 percent of viewings were influenced by its recommendation engine, and by 2020, almost 80 percent of content consumed stemmed from personalized recommendations (Netflix, 2016–2020). This customization diminishes search friction, enhances engagement, and promotes binge-watching, all of which result in decreased churn and more revenue. The recommender system also impacts content acquisition and creation, as Netflix analyzes aggregated user data to discern genres and tales with a high probability of success. The efficacy of Netflix's AI strategy has motivated analogous solutions in the media and e-commerce industries.

GCC: High Adoption with Scaling Challenges

The Gulf Cooperation Council (GCC) nations—Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates—have initiated ambitious projects to establish themselves as leaders in artificial intelligence. In 2024, around 84 percent of surveyed GCC enterprises indicated the utilization of AI in at least one function, significantly exceeding the global average of around 72 percent; yet, only about 31 percent of GCC firms effectively expanded AI throughout their organization (BlueGrid, 2024). Governments have allocated resources to cloud infrastructure and artificial intelligence expertise, while legislative frameworks promote innovation. Notwithstanding this advancement, numerous companies exhibit insufficient internal alignment, encounter challenges in assimilating AI into legacy systems, and grapple with the recruitment of proficient professionals

(BlueGrid, 2024; McKinsey & Company, 2025). Companies that surmounted these obstacles frequently collaborated with technology providers, allocated resources for staff training, and implemented agile governance frameworks (BlueGrid, 2024). The GCC experience highlights that adoption is essential yet insufficient; scaling necessitates structural transformation, organizational learning, and ecosystem collaboration.

AI Diffusion and Global Inequality

Microsoft's paper on AI dissemination elucidates the correlation between national investment and individual adoption. Countries like the UAE, Singapore, and Norway exhibit working-age AI use rates over 40 percent, indicative of ongoing investment in digital infrastructure and skills (Microsoft AI Economy Institute, 2026). Conversely, adoption in the Global South is below 15 percent (Microsoft AI Economy Institute, 2026). In Africa, technological diffusion is facilitated by open-source platforms such as DeepSeek, which provides a complimentary chatbot, thereby lowering financial barriers; the report emphasizes the burgeoning AI rivalry between China and the United States to enhance adoption through proprietary versus open-source models (Microsoft AI Economy Institute, 2026). These geopolitical forces complicate global AI governance and highlight the necessity for international collaboration to prevent exacerbating divisions.

Ethical, Governance and Environmental Considerations

As AI deployment intensifies, an increasing array of evidence highlights the necessity of strong governance, ethical supervision, and environmental sustainability. Recent evaluations of multinational firms indicate a substantial gap between governance and implementation. Approximately 48 percent of organizations have released AI strategies or guidelines, with around 71 percent of these incorporating commitments to ethical, safe, or trustworthy principles; nevertheless, implementation frequently lacks efficacy (Thomson Reuters, 2026). Approximately 97 percent of companies do not explicitly evaluate environmental concerns when implementing AI, while around 68 percent neglect to address wider societal implications, including affects on vulnerable groups (Thomson Reuters, 2026). Although 76 percent of organizations indicate management-level supervision of AI projects, merely 41 percent provide accessible

policies to employees and mandate acknowledgment (Thomson Reuters, 2026). The discrepancies between policy and practice highlight the necessity for organizations to convert overarching values into practical procedures and clear responsibility.

Regional disparities in governance highlight regulatory constraints. In Europe, the Middle East, and Africa, organizations are more inclined to publish AI policies and disclose associated risks, whereas in the United States, only approximately 38 percent of firms have public AI policies (Thomson Reuters, 2026). Investor pressure is escalating: by 2025, over 72 percent of S&P 500 businesses will have reported at least one AI-related risk in their filings, an increase from approximately 12 percent in 2023 (Thomson Reuters, 2026). These disclosures indicate increasing expectations for ongoing AI audits, impact evaluations, and benchmarking (Thomson Reuters, 2026). Boards and CEOs are encouraged to progress from aspirational ethics pronouncements to demonstrable evidence of responsible AI implementation. National and international legislation, notably the EU AI Act and impending U.S. rules, will soon render such actions obligatory.

Governance initiatives encompass more than business policies. Over 72 countries worldwide have introduced more than 1,000 AI-related policy initiatives and regulatory frameworks to address public concerns over safety and accountability (Mind Foundry, 2026). Over 190 nations have embraced non-binding guidelines for the ethical utilization of AI, encompassing environmental provisions (UNEP, 2025). Notwithstanding this momentum, numerous national AI programs rarely incorporate environmental and sustainability factors (UNEP, 2025), underscoring a disparity between aspirational ethics and practical legislation. Gartner forecasts that expenditures on AI governance platforms would amount to around 492 million U.S. dollars in 2026, exceeding 1 billion U.S. dollars by 2030 (Backend News, 2026). Regulation is anticipated to increase fourfold and encompass around 75 percent of global economies by the decade's conclusion (Backend News, 2026). Organizations that use governance platforms are 3.4 times more likely to attain high performance in AI governance; nevertheless, merely increasing the number of tools cannot offset ambiguous strategies or insufficient executive backing (Backend News, 2026).

Ethical AI necessitates a focus on inclusivity. Demographic study indicates that women are around 20 percent less likely than men to utilize generative AI technologies; women constitute just about 42 percent of ChatGPT users, 31 percent of Claude users, and 27 percent of ChatGPT mobile app downloads (Haas News, 2025). These gender disparities may indicate variations in access, trust, and perceived utility. In the absence of targeted outreach and inclusive design, artificial intelligence may exacerbate existing inequities and hinder initiatives aimed at democratizing technology.

The environmental implications are a vital aspect of responsible AI. The International Energy Agency states that a single ChatGPT request can utilize up to 10 times the electricity of an average Google search (UNEP, 2025). Data centres, which facilitate the training and deployment of AI models, are seeing significant growth: the quantity of data centres increased from approximately 500,000 in 2012 to an estimated 8 million by 2025 (UNEP, 2025). Data centres in Ireland are anticipated to account for around 35 percent of national electricity consumption by 2026, an increase from 21 percent in 2023 (UNEP, 2025; Carbon Brief, 2025). In 2023, U.S. data centers consumed approximately 4 percent of the nation's electricity and may necessitate 7–12 percent by 2028 (Carbon Brief, 2025). Presently, AI constitutes 5–15 percent of global data center power consumption and may increase to 35–50 percent by 2030 (Carbon Brief, 2025). Fossil fuels currently provide approximately 60 percent of data center energy; renewables contribute 27 percent and nuclear energy 15 percent. However, this distribution is projected to change to around 60 percent clean energy by 2035 (Carbon Brief, 2025). These energy requirements provoke apprehensions over carbon emissions and grid stability.

Recent scientific research presents alarming forecasts: by 2030, ongoing AI expansion may generate 24–44 million metric tons of carbon dioxide emissions each year and deplete 731–1,125 million cubic meters of water—comparable to introducing 5–10 million vehicles to U.S. highways and exacerbating water shortages in already vulnerable areas (Cornell Chronicle, 2025). Optimal placement of data centers, grid decarbonization, and enhanced efficiency might diminish emissions by approximately 73 percent and water use by around 86 percent (Cornell Chronicle, 2025). Furthermore, estimations of AI energy consumption

differ: many specialists contend that each ChatGPT question utilizes only 0.3 Wh—similar to a Google search—contrary to previous assertions of 3 Wh (PC Gamer, 2025). These disparities underscore the necessity for transparent reporting and uniform measures.

Policymakers are implementing specific actions. The European Union and the United States have enacted legislation aimed at diminishing AI's environmental impact and fostering sustainable computing (UNEP, 2025). UNEP recommends five actionable measures: standardizing the assessment of AI's environmental impact, mandating the disclosure of energy and carbon emissions, enhancing algorithmic efficiency, constructing environmentally sustainable data centers (utilizing renewable energy and water recycling), and incorporating AI policies into comprehensive environmental regulations (UNEP, 2025). International collaboration is essential, as developed nations currently obtain almost one-fourth of the growth in electricity demand from data centers and artificial intelligence (Carbon Brief, 2025). Ultimately, successful governance must include ethical values, inclusivity, and sustainability, ensuring that AI developments correspond with overarching societal objectives.

Conclusion

This chapter presents the influence of Artificial Intelligence (AI) and Machine Learning (ML) on the digital economy, emphasizing their effects, adoption trends, and socio-economic consequences. The chapter aims to evaluate the impact of AI and ML on economic performance, presents the obstacles to their dissemination, and underscore the regulatory and ethical issues associated with these technologies. This chapter affirms that although AI and ML have considerable productivity and growth opportunities, their adoption is inconsistent, exhibiting greater prevalence in the Global North than in the Global South. Moreover, AI is anticipated to create trillions of dollars in value and substantially enhance global GDP by 2030. Nonetheless, the digital divide endures, and regulatory obstacles—such as the necessity for inclusive governance and ethical considerations—must be confronted to guarantee the sustainable and fair advancement of the digital economy. The primary findings indicate that the implementation of AI and ML is progressing

rapidly, yet is predominantly confined to established economies, while emerging countries are falling behind. The chapter revealed that although AI presents considerable economic advantages, the governance and implementation gap constitutes a major obstacle, since numerous companies have challenges in scaling AI applications throughout their organizations. Moreover, ethical issues, especially those related to bias, privacy, and environmental sustainability, necessitate immediate consideration to guarantee that AI implementation conforms to societal standards.

This chapter enhance academic knowledge and inform policy development by illuminating discrepancies in AI adoption and the necessity of developing strong governance frameworks. This chapter offers a thorough analysis of the developing interplay among AI, the digital economy, and socio-economic results. It underscores the necessity for ethical AI practices among industry professionals and provides insights on how companies might surmount adoption hurdles. Policymakers are encouraged to develop inclusive and sustainable AI plans that promote prosperity while alleviating the concerns linked to technology progress.

The theoretical implications for this chapter advocates for a more cohesive methodology in showing AI adoption, taking into account both technological and socio-political elements that affect its dissemination. The report underscores the necessity for ongoing investment in digital infrastructure, AI education, and open regulatory frameworks to address disparities in AI adoption and guarantee equitable distribution of its advantages. Future exploration should investigate the changing role of AI in low-income economies, assess the long-term impacts of AI on labor markets, and evaluate the efficacy of current regulatory frameworks in fostering responsible AI implementation.

In conclusion, although AI and ML possess transformative potential for the digital economy, their effective integration necessitates a balanced strategy that considers technological breakthroughs, ethical implications, and the requirement for comprehensive, inclusive policy. Additional study is necessary to investigate the legislative frameworks that will facilitate sustainable AI-driven growth and guarantee equitable distribution of AI advantages across all areas and demographics.

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10
Chapter

Governance and Sustainable Livelihoods among Tribal Communities in Northeast India

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Abstract

Sustainable development in indigenous regions requires more than policy declarations; it requires meaningful access, equity, participation and recognition of traditional knowledge systems. This study examines the lived realities of tribal youth in Northeast India in relation to access to basic services, socio-economic conditions, environmental awareness, governance participation, and engagement with the Sustainable Development Goals (SDGs). Based on a quantitative cross-sectional survey of 54 tribal respondents aged 18–35 years, the study identifies structural gaps in infrastructure, economic opportunity, youth empowerment, and institutional inclusion. While educational attainment among respondents is relatively high, the findings show that education does not consistently translate into income security, revealing a statistically significant negative correlation between education and income source ($r = -0.362$, $p = .007$). Although access to clean water and electricity is largely available, concerns remain regarding reliability and sanitation quality. Awareness of SDGs is limited, and community engagement in SDG-related activities remains low. Governance trust is moderate to weak, and traditional ecological knowledge is insufficiently integrated into formal planning systems.

Keywords: *Tribal Governance, Sustainable Livelihoods, Capability Approach, Youth Participation, Environmental Governance, Sustainable Development Goals (SDGs).*

Introduction

Rooted in place, Indigenous groups across Northeast India nurture enduring ties to soil, woods, and rivers. Because of long-term observation, customs around farming and shared living carry inherited insight about local ecosystems (Beckett & O'Loughlin, 2024; Priyadarshini & Abhilash, 2019). Even so, when it comes to planning by the state, tribal voices remain pushed aside - overlooked again and again (Bansal et al., 2024; Mulindwa, 2020).

Though launched worldwide in 2015, the practical impact of the Sustainable Development Goals varies sharply across communities. While designed to advance fairness, ecological balance, shared prosperity, along with transparent governance - per Arts (2017) - their real-world application often falters. Especially within indigenous territories do these objectives struggle to take root. Local traditions, belief structures, and community norms frequently sit at odds with standardized development models, as noted by Kiran and colleagues (2024) and also observed earlier by Das (2020).

Besides navigating modern life, tribal youth balance inherited customs. Though linked through technology, education shapes their choices. Mobility opens doors - still tradition holds ground. Opportunities appear alongside barriers they face daily. Their engagement with resources, work options, views on nature, plus how they join decision-making reveal inclusion gaps. When it comes to sustainability claims, such insights test real progress (Ali et al., 2021; Kenney & Phibbs, 2021).

Though earlier research highlights indigenous knowledge's role in ecological resilience (Kashif et al., 2023; Mallick et al., 2024), few data exist on how young tribal members perceive development. Instead of viewing them as recipients, this work looks at youth as participants shaping their own paths.

Theoretical Framework

Looking through multiple lenses sharpens understanding here. One approach alone would miss key details. Combining them

reveals patterns otherwise hidden. Each adds weight without repeating the others. Together, they form a more complete picture than any could alone.

Development matters less in terms of inputs, more in how freely people can live out their goals. Meaningful progress shows up not just in schools built or clinics opened, but in what lives people are able to lead because of them. When education levels rise yet financial stability lags, something breaks down in turning knowledge into secure livelihoods - this gap signals a shortfall in converting access into actual power to thrive (Vladimirova & Le Blanc, 2016; Das, 2024).

Though inclusive development emphasizes participatory governance, marginalization persists when institutions fail to respond. Representation gaps - especially among young people - reflect systemic barriers rather than lack of interest. Evidence from this analysis shows minimal youth involvement alongside weak connections to global goals. Such patterns point to entrenched exclusions within decision-making frameworks. When voices remain absent over time, sustainability efforts lose legitimacy. Structural conditions, not individual choices, shape these outcomes most significantly.

Starting differently each time, governance models show that merging local ecological insight improves climate responses alongside stewardship of resources (Beckett & O'Loughlin, 2024; Kramer et al., 2021; Timko et al., 2018). Without space for ancestral understanding, policy outcomes tend to split apart - losing strength.

Together, these frameworks guide the study's analysis of access, equity, livelihood sustainability and governance inclusion.

Literature Review

Recent scholars have emphasized the role of indigenous communities in advancing sustainability. Bansal et al. (2024) identify six thematic dimensions linking indigenous contributions to economic, ecological, and governance systems. Mallick et al. (2024) demonstrate how tribal home-gardens strengthen biodiversity and climate adaptation. Sahoo et al. (2022) advocate ecosystem-based development models for indigenous populations.

Singh et al. (2020) highlights the resilience embedded in traditional food systems among Adi women. Giribabu et al. (2019) connect social protection schemes like MGNREGA with SDG outcomes. Das (2024) stresses skill development as central to tribal youth livelihood security. Rasul et al. (2016) analyze regional development challenges in aligning policy with SDGs.

Governance-focused studies further strengthen the discourse. Scheyvens et al. (2021) examine indigenous tourism aligned with SDGs. Roy et al. (2023) identifies institutional inefficiencies affecting ethnic minorities. Ramli (2021) critiques fragmented SDG implementation. Ali et al. (2021), Bhushan et al. (2018), Kenney and Phibbs (2021), Kashif et al. (2023), and Madhanagopal and Jacob (2022) highlight indigenous climate adaptation strategies.

Despite this body of work, empirical studies focusing specifically on tribal youth in Northeast India remain limited.

Research Objectives

The study is guided by five interlinked objectives:

1. To assess access to and quality of basic services among tribal youth in relation to SDG targets.
2. To analyze socio-economic conditions, including income sources and the relationship between education and livelihood security.
3. To evaluate environmental awareness and perceptions of climate change.
4. To examine governance participation, youth empowerment, and gender inclusion.
5. To understand awareness and perceived relevance of the Sustainable Development Goals (SDGs).

Methodology

A quantitative cross-sectional survey design was employed. Data were collected from 54 tribal youth aged 18–35 years across six northeastern states. The sample was selected using stratified random and theoretical sampling to ensure diversity across gender, education and tribal affiliation.

The questionnaire covered demographic characteristics, access to infrastructure, economic status, environmental awareness, SDG familiarity and governance perceptions. Data were analyzed

using SPSS. Descriptive statistics, Pearson correlations, and cross-tabulations were generated. Statistical significance was evaluated at $p < .05$ and $p < .01$ levels.

Findings

Demographic Profile

The average age of respondents was 23.09 years ($SD = 3.16$). Females comprised 57.4% of the sample. Nearly 48.1% held postgraduate degrees, indicating strong educational capital.

Access to Basic Services

Clean water access was generally high ($M = 1.17$, $SD = 0.42$). Electricity access was nearly universal ($M = 1.06$, $SD = 0.23$), though reliability concerns persisted ($M = 1.91$, $SD = 0.56$). Sanitation quality was weaker ($M = 2.61$, $SD = 0.76$), reflecting infrastructure gaps (Shrestha, 2021; Mara & Evans, 2018). Housing quality was moderate ($M = 2.48$, $SD = 0.77$).

Healthcare and Education

Healthcare access was moderate (Median = 1.80, $SD = 0.53$). Educational attainment was high; however, economic returns were inconsistent (Vladimirova & Le Blanc, 2016).

Economic Conditions

Economic distress was evident (Median = 3.19, $SD = 2.07$). A statistically significant negative correlation between education and income ($r = -0.362$, $p = .007$) suggests that higher education does not guarantee improved earnings (Das, 2024). This indicates structural employment limitations.

From time to time, higher income links to better understanding of environmental goals ($r = 0.280$, $p = .041$), hinting that financial security may support learning about sustainable practices (Giribabu et al., 2019).

Environmental Awareness

Fear around climate shifts came through clearly in responses (Median = 3.30, $SD = 1.67$); still, knowledge of precise ecological effects stayed somewhat limited. That gap suggests recognition exists - just not embedded into systems.

Governance and Inclusion

Leadership trust stayed weak - median at 1.69, standard deviation 0.64. A deeper issue emerged with youth influence: median just

1.18, spread narrow at 0.39. Despite time passing, gender gaps remain unchanged, earlier studies confirm (Kiran et al., 2024; Mulindwa, 2020). Scoring near the bottom, environmental rules faced strong doubt - rating of 1.37, variation small (SD = 0.49), past work echoes this (Kashif et al., 2023; Timko et al., 2018).

A link emerges - clearer when SDGs take root locally - showing how environmental worry tends to dip; this pattern holds at a noticeable level ($r = -0.461$, $p < .01$), based on findings by Kenney and Phibbs in 2021. Though not perfect, the trend leans downward: more SDG integration ties to less concern about ecological decline.

Discussion

Despite available education, turning knowledge into economic growth remains rare. Capability gaps show up even where training is offered. Access to infrastructure does not always mean reliable service. Even when people care about environmental issues, systems fail to include those concerns. Quality varies widely across regions. Policy often misses the connection between ecological needs and planning.

Though young people rarely join decision-making bodies, Inclusive Development thinking offers a clear explanation. Recognition matters when it comes to traditional wisdom - Environmental Governance studies stress that institutions must acknowledge local ways of knowing.

A shift toward lasting progress begins not just with policy but through reshaping how schools connect to jobs. Governance gains strength when people actively shape decisions that affect them. Planning processes gain depth once environmental insight becomes part of their foundation.

Final Thoughts and What They Mean for Policy

Despite showing high levels of school success and deep cultural strength, young people from tribal communities in northeast India face systemic hurdles. Job markets remain difficult to enter due to entrenched limitations. Poor transport, energy, and communication networks limit opportunity. Involvement in decision-making processes is often minimal or symbolic at best. Efforts to align development goals with local realities struggle to take root. These factors together constrain growth beyond current conditions.

Policy must prioritize

Youth-centred governance participation, Skills shaped by market demands appear closely tied to employment outcomes (Das, 2024), Infrastructure quality improvement, Integration of indigenous ecological knowledge (Beckett & O'Loughlin, 2024), Gender-sensitive development frameworks. A system of governance that includes participation alongside accountability - this idea comes from Kramer and colleagues in 2021

Beginning with people's real skills shapes lasting progress in tribal areas. When institutions open doors widely, inclusion grows quietly over time. Culture matters deeply - ignoring it weakens outcomes slowly. Where changes skip these elements, results stay incomplete by design. Fairness limps along uneven ground. Lives hang exposed when systems fail to adapt fully.

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Timing Abilities of Mutual Fund Managers in India- A Case Study of SBI Mutual Funds

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Abstract

Mutual funds play as a key investment method for investors. It provides safe and systematic avenues by which investors can reduce their risk through risk diversification features. In today's volatile market scenario, the mutual fund is a suitable sector for investors as compared to other investment options. In India, the MF industry has been functioning for more than five decades (Sehgal & Babbar, 2017). Since the emergence of the Indian Capital Market and the deregulation of the economy in 1992, it has undergone significant transformations with many fluctuations. There have been fundamental changes in both the primary and secondary markets since that year. The study has empirically analyzed Indian fund managers' market timing and selectivity skills abilities of public sector bank-sponsored schemes by utilizing two popular models. The two models analyze the return-based timing abilities of fund managers. The fund managers' market timing abilities are crucial in bringing equity mutual funds' superior financial performance. A manager can show up timing skills if they predict the stock market's direction using suitable techniques and select the portfolio to add value to the mutual fund. The results from

both models suggested that fund managers cannot time the market correctly; instead, they go in the wrong direction.

Keywords: *Mutual Funds, Timing and Selectivity Skill, SBI Mutual Fund, Fund Manager*

1. Introduction

Mutual funds play as a key investment method for investors. It provides safe and systematic avenues by which investors can reduce their risk through risk diversification features. In today's volatile market scenario, the mutual fund is a suitable sector for investors as compared to other investment options. In India, the MF industry has been functioning for more than five decades (Sehgal & Babbar, 2017). Since the emergence of the Indian Capital Market and the deregulation of the economy in 1992, it has undergone significant transformations with many fluctuations. There have been fundamental changes in both the primary and secondary markets since that year. Mutual Funds are vital contributors to the globalization of financial markets and serve as one of the primary sources for capital inflows into developing economies (Klapper et al., 2004). As implied by its name, Mutual Funds consist of many investors who pool their resources to invest in various fund schemes. Mutual Funds are essential to an economy as they aggregate savings and deploy them in the capital market, thereby creating a connection between savings and the capital market (Y. C. Chen et al., 2011). Stock selection involves making informed predictions about market price movements based on expertise and experience.

Mutual funds operate based on two principles: maximizing returns and diversifying risk, both of which necessitate sound operational practices and effective investment management. Systematic investment management entails various activities, including selecting stocks, allocating assets, managing investment styles, and timing the market (R. Deb & Panja, 2022).

The MF industry has the most upward trend in recent times for the development of new and existing mutual fund companies. The development also takes place by way of increasing foreign-owned mutual fund companies. The nationalized banks which have started operation in mutual funds in the early nineties become successful for the stock market boom afterward. Due to its growing demand, it becomes pertinent to judge mutual funds' performance before making any investments.

Performance measurement of mutual funds has been creating an interest among the academic and professional for the last few decades. It is happening as the mutual fund industry boosts its expansion and its association with the efficient market hypothesis. Investors get an advantage out of the repeated evaluation of fund performance, and they can know the ability of fund managers in terms of value addition or reduction in their portfolio management by the managers (Zabiulla, 2014).

In today's world, effectively timing the market plays a crucial role in making investment decisions. Fund managers can achieve better returns by accurately timing the market, alongside their stock selection strategies. Therefore, though not just micro-level forecasting but also broader market timing approaches, a skilled fund manager can yield exceptional returns amidst fluctuating stock markets. As a result, examining the presence and level of these two skills in Indian mutual fund managers is crucial to deliver superior performance.

It is a well-known fact that, like developed countries, the mutual fund industry is also one of the fast-growing sectors in India since the injection of economic reforms in 1991. The development of the sectors also creates difficulties for the number of investors in selecting suitable schemes as there are more than 2,500 schemes as of March 2019. Another risk associated with the fund managers whose single wrong decision may also put the investors in a financial crisis. The present study shows an insight into fund managers' timing abilities by considering SBI mutual Fund schemes. The study has empirically tested Indian fund managers' market timing abilities by utilizing two popular models, Treynor & Mazuy Model, Henriksson & Merton Model, and other indices. The two models analyze the return-based timing capabilities of managers. The fund managers' market timing abilities are crucial in bringing equity mutual funds' superior financial performance.

1.1 Backgrounds

The history and development of mutual funds can be divided into discrete phases, each of which can be identified by significant advancements, modifications to regulations, and changes in investor opinion (Roy & Ghosh, 2013). These stages show how the business has grown and how mutual funds have evolved from specialized to popular investment solutions. Below is a breakdown of the stages of mutual fund development in India:

Phase 1: The Initial Years – Pre-1987

UTI Monopoly's Early Years, Before 1987:

The concept of mutual funds originated in India in 1963 when the Unit Trust of India (UTI) was established by a parliamentary legislation.

Before the Industrial Development Bank of India (IDBI) took over in 1978, the Reserve Bank of India (RBI) was in charge of UTI's founding and management. During this period, UTI was the only player in the Indian mutual fund industry, creating a monopoly that lasted for nearly two decades. Unit Plans: The first mutual fund scheme ever created by UTI, Unit Scheme 1964 (US-64), was a flagship product that offered the benefits of mutual fund investing to the Indian people. It was designed to provide both income and capital growth, and it became very popular.

Assured Dividends and High profits: US-64, which emphasized fixed-income securities, drew investors with the promise of assured dividends and high profits. The plan established the standard for mutual fund products in the future, but UTI eventually encountered difficulties in handling the guaranteed return.

Limited Access and knowledge: Mutual fund knowledge was low, and UTI's reach was restricted. The mutual fund industry remained little and mostly unknown to most Indians outside of major cities due to the lack of competition.

Phase 2: Entry of Public Sector Funds – 1987–1993

Breaking of Monopoly and Increase in Competition:

UTI's dominance in the Indian mutual fund industry came to an end during the second phase. The government allowed public sector banks and insurance companies to create mutual funds in 1987, which improved competition and expanded the selection of products offered.

Public Sector Funds: A number of public sector entities, including the State Bank of India, Life Insurance Corporation (LIC), and General Insurance Corporation (GIC), launched their own mutual fund programs.

As a result, individual investors across the country now have easier access to mutual funds. Diverse Fund Offerings: The

newcomers provided a number of previously restricted equity and balanced fund designs. This helped investors diversify their investments and introduced them to a variety of mutual fund types.

Growth in Market Penetration: As the number of companies and product options increased, investors started to take greater interest in mutual funds. The industry was growing even if there was still a lack of awareness.

But as the market grew and changed, the mutual fund business still lacked a thorough regulatory structure, which would become essential.

Phase 3: The Birth of a Regulatory Framework – 1993–1996

SEBI's Arrival and Private Sector Involvement:

SEBI Regulation: With the release of the Mutual Fund Regulations in 1993, the Securities and Exchange Board of India (SEBI) created a formal regulatory framework for mutual funds. The primary goals of the regulations were to safeguard investor interests, improve corporate governance in mutual funds, and increase transparency.

Private Sector Fund Entry: Major financial institutions and investment firms entered the market because of SEBI's laws encouraging private sector corporations to set up mutual funds. Examples were ICICI Prudential, HDFC, and Kothari Pioneer Mutual Fund, the first private fund to register with SEBI.

Product Innovation: As private companies entered the market, they brought new fund categories, aggressive marketing strategies, and a competitive approach to portfolio management. Funds provided a wider range of investment options, such as debt funds, sectoral funds, and balanced funds, allowing investors to select funds that matched their financial objectives and risk tolerance.

As competition grew, mutual fund companies enhanced their performance, transparency, and customer services, which in turn increased investor confidence.

Phase 4: Market Expansion and Growth – 1997–2003

Development and Challenges:

Mutual fund assets and investor interest increased significantly in the late 1990s. However, because of internal issues and macroeconomic reasons, the market experienced both highs and lows throughout this time.

Growing Interest in Equity Funds: Equity-oriented mutual funds became more well-liked by investors looking for larger returns after the private sector entered the market. The potential advantages of equity investments became more widely known to investors. **Growth in Assets Under Management (AUM):** Despite difficulties, the AUM of mutual funds continued to grow, reflecting rising investor interest. New investors entered the market, driven by innovative schemes and aggressive marketing campaigns by both public and private players.

The US-64 Crisis: In 2001, UTI faced a significant crisis with its flagship scheme, US-64, because of years of offering assured returns without aligning the scheme's investment strategies. This led to significant losses, forcing UTI to halt redemptions and restructure the scheme, which affected investor sentiment.

AMFI Formation: A major step towards industry self-regulation was taken in 1995 with the founding of the Association of Mutual Funds in India (AMFI). AMFI sought to improve investor education, encourage best practices, and raise ethical standards.

The US-64 crisis served as a wake-up call, emphasizing the necessity of stricter regulatory compliance and risk management. The industry's growth trajectory was unaffected by the crisis, nevertheless, as investors continued to be drawn to mutual funds because of their prospective rewards.

Phase 5: Consolidation and Reform – 2003–2008

Strengthening of Regulations and Rapid Expansion:

This phase was characterized by important reforms that helped consolidate the mutual fund business, establish investor confidence, and stimulate higher participation

UTI's Restructuring: In 2003, UTI was split up into two distinct companies: UTI Mutual Fund, which was regulated by SEBI, and the Specified Undertaking of UTI (SUUTI), which handled non-performing assets. The goal of this reorganization was to boost investor trust following the US-64 crisis.

New Schemes and Financial Innovations: Systematic Investment Plans (SIPs), which allowed investors to make recurring investments with lesser sums, were developed by mutual fund providers. This made mutual funds more accessible to individual investors. SIPs transformed the market by lowering the cost and increasing the convenience of equity market investing.

Phase 6: Global Financial Crisis and Resilience – 2008–2014

Adapting to Economic Turbulence and Investor Protection Measures:

The 2008 global financial crisis had a significant effect on global financial markets, particularly the mutual fund sector in India. Indian mutual funds' durability was put to the test during the crisis, and regulatory measures were taken to safeguard investors.

The 2008 Crisis's Effect: As global stock markets crashed during the crisis, the NAVs of equities mutual funds fell precipitously. Although there was volatility in debt funds as well, the mutual fund sector showed resiliency, as evidenced by the ensuing years' AUM recovery. **Direct Plan Introduction:** In 2013, SEBI required mutual funds to implement direct plans, which let investors make direct investments in mutual funds without having to pay distributor charges. This enhanced openness, reduced expenses for investors, and promoted the development of long-term wealth. **Emphasis on Transparency and Investor Education:** In order to promote informed decision-making, SEBI and AMFI stepped up their efforts to educate investors about mutual funds.

The sector became more transparent as a result of stronger rules on fund performance reporting and improved disclosure standards.

By reviving investor trust, these regulatory changes aided mutual funds in their recovery from the financial crisis. The crisis marked a sea change, and the sector came out stronger and more open.

Phase 7: Digital Transformation and Retail Boom – 2015–Present

Tech-Driven Growth and Financial Inclusion:

The most recent phase of mutual fund evolution in India has been marked by rapid digital transformation and a considerable increase in retail investor engagement, driven by technical breakthroughs and regulatory changes.

Digital Platforms and Easy Investing: The rise of robo-advisors, smartphone apps, and digital investment platforms has made mutual funds more accessible than before. The simplicity with which individuals can now invest, monitor, and remove their mutual fund assets is encouraging a new generation of retail investors to enter the industry.

Growth of SIPs and Retail Participation: SIPs are a disciplined and reasonably priced way to invest in the equity markets, and they have grown incredibly popular, particularly among young and novice investors. SIP accounts have increased dramatically, making a substantial contribution to the industry's AUM.

Investor Protection Measures: SEBI has persisted in enacting changes that are focused on investors, such as capping expense ratios, curbing mis selling, and strengthening rules pertaining to fund advertising and product labelling. The credibility of the sector has been further enhanced by such actions.

Growth in Mutual Fund Offerings: Funds are becoming more specialized to satisfy investor objectives, and retirement funds, sector funds, and thematic funds are becoming more prevalent. Additionally popular are index funds and exchange-traded funds (ETFs), which provide cost-effect.

1.2 A brief background of the selected AMC

SBI Mutual Fund is one of India's largest and most trusted asset management companies. It was established in June 1987 as a joint venture between: State Bank of India (SBI) – India's largest and oldest public-sector bank and AMUNDI Asset Management – a leading European asset management company

The fund house operates under SBI Funds Management Ltd. (SBIFML), with SBI holding a majority stake (Gupta et al., 2008).

Key Highlights

- First public sector mutual fund in India, launched under SBI's sponsorship.
- Offers a diverse portfolio of schemes including equity, debt, hybrid, index funds, ETFs, and offshore funds.
- Manages assets for retail investors, HNIs, corporates, and institutions.
- Known for its strong research base, risk management framework, and long-term investment philosophy.
- Has a pan-India network leveraging SBI's banking presence and wide distribution channels.
- Continuously introduces investor-awareness initiatives to promote financial literacy.

1.3 Rational of the Study

The reason behind for assessing the timing and selection skills of mutual fund managers in India is, with the growing significance of mutual funds in the Indian financial landscape, it is essential to comprehend the factors influencing fund performance for both investors and regulators. In particular, separating the effects of market timing and security selection skills enables a more detailed assessment of manager competence and guides investment choices. The distinct features of the Indian market, such as its regulatory environment, investor behavior, and market fluctuations, require a customized approach for evaluating these capabilities.

2. Review of Literature

The empirical literature has witnessed several indices and studies relating to mutual fund development. The pioneering approach Sharpe index (1966), Treynor index (1965) & Jensen measure (1968) are the most important. These indices are all based on the CAPM model. There has been growing curiosity or urge among the investors and in the financial literature about skills among the mutual fund managers. The earlier literature (Treynor & Mazuy, 1966);(Henriksson & Merton, 1981);(Jensen, 1968);(Grinblatt & Titman, 1992); (Chang & Lewellen, 1984) witnessed fund manager's insignificant timing skills. The pioneering studies include (Chang & Lewellen, 1984) on mutual fund investment performance and market timing. The authors used a parametric approach to test the market timing and selection skills in a sample of mutual funds during the 1970s. The study found no skillful market timing and apparent security selection abilities. market timing and selection performance using the Treynor-Mazuy model. Their study revealed a positive and significant timing ability for 633 funds during the 1984-94 periods. The study also found a positive and negative relationship between turnover and market, turnover and selectivity respectively.

Indian literature also witnessed studies related to the fund manager's abilities. (N. P. Tripathy, 2006) had one study where fund managers' market timing abilities belonged to India's thirty-one tax planning schemes were evaluated. The study found that managers did not reap market returns; instead, they mistimed the market. To research the timing and selectivity

abilities of Indian mutual fund managers, (S. G. Deb & Banerjee, 2007) used conditional and unconditional approaches. They had confirmed that in the case of unconditional models out of 768 possible cases, at a 10 percent level of significance, there were only four instances of substantial positive market timing. However, for unfavorable market timing, the results remain high, as only 133 in a total of 768 cases have significant market timing at a 5 percent significance level. Bantwa & Bhuva (2012) studied some selected equity diversified schemes and found the outperformance of all schemes except one scheme from the sample in terms of the risk- adjusted measure. Adequate diversification was found among the schemes with a negative correlation between diversification levels, measured by R². Prasad & Srinivas (2012) also studied Indian fund managers' timing abilities related to seventeen equity schemes using the T&M and H&M model. The study found a successful timing performance of managers to get returns over the market.

A similar study (Bodla, 2012) & (Chen et al., 2013) analyzed timing and selectivity skills using the H & M model and the conditional approach of the T&M and H&M models. The latter study found a positive side of the mutual fund, which shows Indian mutual funds can compensate the investors for taking additional risks by investing in mutual funds. Most of the selected managers do not implicate market timing ability in Indian and Taiwanese cases;

instead, they rely a little on stock selection. Again, another study was done by (Skrinjaric, 2013), who is a Croatian author on the market timing ability resulted in no timing ability of Croatian fund managers like earlier studies. The author also used Treynor-Mazuy and Henriksson-Merton's framework for the analysis.

The study (Kumar, 2016) confirmed that the Indian mutual fund industry could beat the benchmark market's return performance. However, although it is to be suggested for the investors, about 8 percent of such schemes failed to beat the market performance. Hence, the fund scheme selection deserves to be given the utmost consideration. They also stated that Indian mutual funds do have the ability of stock selection. But they are devoid of market timing ability.

3. Objectives of the study

1. To know the ability of the fund managers to beat the market by their stock selection skills.
2. To know if the fund manager able to time the market well.

4. Research Methodology

The current study uses secondary data that have been collected for public sector bank- sponsored schemes. Daily Net Assets Value (NAV) has been used as raw data for analyses purpose. The required NAV for the work period has been collected from the individual company's websites and other websites like Morningstar India, Amfi India, and BlueChip India. The benchmark data collected from the NSE website. For the risk-free rate of interest, RBI 91 days Treasury Bills has been used (Bodla, 2012); (N. P. Tripathy, 2006); (N. Tripathy, 2017); (Goel & Mani, 2018).

The current work has been covered the study period of three years from 1st April 2020 to 31st March 2023. The study will be carried out using the timing and selectivity measures which are mentioned below.

The study considers open-ended equity public sector funds in India. The sample has been obtained from SBI Funds Management Pvt. Ltd. The following criteria have been used for sampling, like data availability for the whole period, open-ended schemes, high resources mobilization, bank-sponsored mutual funds. Based on sampling criteria, 13 (thirteen) mutual funds have been collected. The summary of the sample schemes is provided in Table 1.

Table 1: Summary of Sample Schemes

SF 01	SBI Blue Chip Fund (G)	23-Dec-05
SF 02	SBI Contra Fund (G)	14-Jul-99
SF 03	SBI Focused Equity Fund (G)	23-Aug-04
SF 04	SBI Healthcare Opportunities Fund(G)	16-Dec-04
SF 05	SBI Infrastructure Fund(G)	06-Jul-07
SF 06	SBI Large and Midcap Fund(G)	27-Apr-05
SF 07	SBI Magnum Comma Fund (G)	30-Jun-05
SF 08	SBI ESG Exclusionary Strategy Fund (G)	29-Oct-93

SF 09	SBI Mag. Global Fund(G)	06-Jun-05
SF 10	SBI Mag. Midcap Fund(G)	21-Feb-05
SF 11	SBI Flexicap Fund (G)	22-Aug-05
SF 12	SBI PSU Fund(G)	17-May-10
SF 13	SBI Small Cap Fund(G)	27-Jul-09

In the context of methodology, various techniques are employed to evaluate the risk- adjusted performance as well as the timing and selectivity skills of Indian fund managers.

Metrics such as average return, standard deviation, portfolio beta, has been determined to assess their real return, risk, and level of diversification. Following the needs of the above objectives, the following tools are used for the analysis purpose:

NAV Returns (Daily basis)

It is the present market value of holding a fund, minus the fund's obligations. The following formula has been used to find the average NAV returns.

$$R_p = \left[\frac{NAV_t - NAV_{t-1}}{NAV_{t-1}} \times 100 \right]$$

Where, R_p = Portfolio returns in period 't'

NAV_t = Net Asset Value in period 't'

NAV_{t-1} = Net Asset Value in period '(t-1)'

Market Return

The difference between the two consecutive periods' market indices is divided by the market index for the beginning period. In this study, the S&P BSE SENSEX index has been used as a benchmark as it is India's most tracked index.

The market return has calculated as follows;

$$R_m = \left[\frac{Mi_t - Mi_{t-1}}{Mi_{t-1}} \times 100 \right]$$

R_m = Market return

Mi_t = Market index at the end

Mi_{t-1} = Market index at the beginning

Risk-free Rate

The rate is generated on risk-free instruments like bank deposits, government bonds, and treasury bills.

Treynor & Mazuy Model

Treynor & Mazuy(1966) developed the following model. They clarified that if a manager can forecast market returns, he will clutch more of the market portfolio when the market return is high and a smaller fraction when the returns on the market are low. The output of the portfolio will, therefore, be a nonlinear market return function. A positive gamma value indicates superior market timing skills.

$$(R_p - R_f) = \alpha + \beta(R_m - R_f) + \gamma(R_m - R_f)^2 + \varepsilon_t$$

Where;

R_p = Return on funds

R_f = Risk-free returns

R_m = Returns on the market portfolio

ε_t = Random or error term

α, β, γ are the parameters of the model

Henriksson & Merton Model

A similar but simplified model was introduced by (Henriksson & Merton, 1981) to test the fund manager's market timing skills. They presumed those market timers are needed to predict whether market returns are greater than or equal to risk-free rate (down markets) and if the market is expected to do well, pick a fund beta as a large value. A fund manager, a good market timer, was therefore expected to choose a high up-market beta and a low down market beta as per this model. Mathematically, they describe such a relationship via regression equations involving a dummy variable.

$$(R_p - R_f) = \alpha + \beta(R_m - R_f) + \gamma(D(R_m - R_f)) + \varepsilon_t$$

Where,

R_p = Return on funds

R_f = Risk-free returns

R_m = Returns on the market portfolio

ε_t = Random or error term D =Dummy variable

$D=0$, if $(R_m > R_f)$ and $D=-1$

otherwise. α, β, γ are parameters of the model.

5. Results and Discussion

The below section provides a detailed analysis of the results that have been generated from the two-timing models.

Table 2: Summary of TMs Model

Fund's Name	β	Std. Error	t Stat	γ	Std. Error	t Stat	R ²
SBI Blue Chip Fund (G)	0.784	0.012	63.997	-0.030	0.007	-4.501*	0.710
SBI Contra Fund (G)	0.757	0.014	54.877	-0.035	0.008	-4.628*	0.644
SBI Focused Equity Fund(G)	0.559	0.016	34.827	-0.062	0.009	-7.036*	0.435
SBI Healthcare Oppo. Fund(G)	0.569	0.024	23.272	-0.071	0.013	-5.345*	0.259
SBI Infrastructure Fund (G)	0.866	0.021	41.633	-0.031	0.011	-2.699	0.5089
SBI Large and Midcap Fund (G)	0.796	0.014	55.122	-0.045	0.008	-5.723*	0.648
SBI Magnum Comma Fund (G)	0.842	0.021	41.061	-0.059	0.011	-5.222*	0.508
SBI Magnum Equity ESG Fund (G)	0.842	0.012	67.618	-0.015	0.007	-2.167*	0.730
SBI Magnum Global Fund (G)	0.506	0.015	34.003	-0.058	0.008	-7.156	0.425
SBI Magnum Midcap Fund (G)	0.617	0.018	35.271	-0.072	0.010	-7.554	0.443
SBI Magnum Multicap Fund (G)	0.797	0.014	58.820	-0.043	0.007	-5.827*	0.677
SBI PSU Fund (G)	0.874	0.022	40.357	-0.043	0.012	-3.621	0.495
SBI Small Cap Fund (G)	0.666	0.021	32.225	-0.069	0.011	-6.143*	0.396

Source: Authors' compilation

*significant at 5% level

Table 2 presents the empirical results for the Treynor and Mazuy model. The table shows that none of the schemes show market timing indications out of the total mutual fund schemes. Most of the scheme's t-values are significant at the five percent level but

are negative. So based on the output of the Treynor and Mazuy model, we can say that for the sampled schemes, fund managers do not seem to be engaged in market timing activities; instead, fund managers time the market in the wrong direction.

Table 3: Summary of HMs Model

Fund's Name	β	Std. Error	t Stat	γ	Std. Error	t Stat	R ²
SBI Blue Chip Fund (G)	0.862	0.022	39.758	-0.148	0.037	-4.044*	0.710
SBI Contra Fund (G)	0.850	0.024	34.839	-0.177	0.041	-4.309*	0.644
SBI Focused Equity Fund(G)	0.732	0.028	25.803	-0.331	0.048	-6.922*	0.435
SBI Healthcare Oppo. Fund(G)	0.747	0.043	17.254	-0.337	0.073	-4.624	0.256
SBI Infrastructure Fund (G)	0.962	0.037	26.172	-0.184	0.062	-2.973*	0.509
SBI Large and Midcap Fund (G)	0.911	0.026	35.639	-0.219	0.043	-5.081*	0.647
SBI Magnum Comma Fund (G)	0.989	0.036	27.232	-0.278	0.061	-4.546*	0.506
SBI Magnum Equity ESG Fund (G)	0.875	0.022	39.720	-0.061	0.037	-1.652*	0.730
SBI Magnum Global Fund (G)	0.664	0.026	25.179	-0.299	0.044	-6.750*	0.423
SBI Magnum Midcap Fund (G)	0.815	0.031	26.309	-0.376	0.052	-7.218*	0.441
SBI Magnum Multicap Fund (G)	0.914	0.024	38.165	-0.224	0.040	-5.559*	0.676
SBI PSU Fund (G)	0.972	0.038	25.362	-0.184	0.065	-2.858*	0.494
SBI Small Cap Fund (G)	0.883	0.036	24.203	-0.415	0.061	-6.764	0.399

Source: Authors' compilation

*significant at 5% level

Table 3 depicted the Henriksson and Merton model results, where none of the sample schemes showed market timing skills. All the schemes under observation exhibited the wrong market timing abilities of fund managers. Based on both models, it is pretty clear that none of the schemes has shown market timing abilities. The empirical results do not support the hypothesis that the selected AMC's fund managers can time the market. These results are similar to studies (Rijwani, 2014);(Alam et al., 2014); (N. P. Tripathy, 2006);(S & Padmasani, 2013);(Ramesh & Dhume, 2014). Researchers have utilized other categories of Indian mutual funds data from time to time. So, it is to be said that none of the schemes has rewarded the investors and the main reason is the incapability of portfolio managers who couldn't book the profits at the boom phase of the market.

6. Conclusion

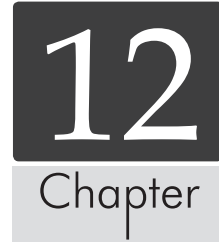
The study has empirically analyzed Indian fund managers' market timing abilities of public sector bank-sponsored schemes by utilizing two popular models. The two models analyze the return-based timing abilities of fund managers. The fund managers' market timing abilities are crucial in bringing equity mutual funds' superior financial performance. A manager can show up timing skills if they predict the stock market's direction using suitable techniques and select the portfolio to add value to the mutual fund. The results from both models suggested that fund managers cannot time the market correctly; instead, they go in the wrong direction. Other than the timing abilities of managers, a few mutual fund issues may also consider in future studies, like mutual fund abuses, poor trade execution, etc.

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Examining the Status of Women Empowerment in India: A Rural – Urban Analysis

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Abstract

This paper tries to examine the status of women empowerment in rural and urban India, based on secondary data gathered from the National Family Health Survey-5 state fact sheets. Based on rankings of states and union territories, women's empowerment is highest in Puducherry and lowest in West Bengal in rural India. In urban India, Sikkim, Arunachal Pradesh, and Manipur have the highest empowerment levels, while Tripura has the lowest empowerment level. The finding indicates that the status of women empowerment is moderate in both rural and urban India. The women empowerment index is also significantly lower in rural India than in urban India. Interstate disparity in terms of women empowerment is also found to be relatively higher in rural India. Based on the findings of the study, we recommend that the Government of India should implement more gender-based programmes to enhance women empowerment, particularly in rural areas.

Keywords: Women empowerment, Rural-Urban Disparities, Regional Disparities, NFHS - 5

1.1 Background of the Study

Gender equality and women's empowerment are not only fundamental human rights but also essential drivers of sustainable economic growth and social development. As enshrined in the 'United Nations' Sustainable Development Goal 5, achieving gender equality and empowering women is a global priority for 2030. In India, a country characterised by rapid economic transition and socio-cultural diversity, the trajectory of women's empowerment remains a complex and multidimensional phenomenon. At the same time, India has witnessed significant legislative and policy interventions to bridge the gender gap through gender-based programmes. However, the outcomes are still spatially and sectorally uneven. The rural-urban divide, in particular, continues to be a defining feature of India's development landscape. Rural women often face barriers such as limited access to formal education, traditional patriarchal norms, and a lack of digital infrastructure. Conversely, while urban women may have better access to information and healthcare, they often struggle with lower labour force participation in rapidly urbanising environments.

Women's empowerment has emerged as a central theme, particularly in developing nations like India. It encompasses the expansion of women's capabilities, access to resources, labour market participation, and active participation in household decision-making. Empowering women means growing them as more aware individuals in society. According to Kabeer (1999), empowerment involves the ability to make strategic life choices, especially in contexts where such choices were previously constrained. In the Indian context, empowerment is closely associated with socio-economic transformation, gender equality and inclusive development. The literature conceptualised women's empowerment as a multidimensional phenomenon consisting of resources, agency and achievements (Kabeer, 1999). Resources include material, human and social assets; agency refers to the decision-making powers, and achievement represents the outcomes. Numerous studies have examined the status of women empowerment in India. Studies have found that Indian women are relatively less empowered and have enjoyed a lower level of privilege than men (Nayak & Mahanta, 2012). The study conducted by Waghamode and Kalyan (2014) highlights

the existence significant gender gap in access to education, employment status, and political participation. Moreover, they also pointed out that rural women are more vulnerable to domestic violence. In examining the status of women's empowerment in India, Vignitha et al. (2024) found that India's mean empowerment index was 21.3. The study also highlights that Goa, Sikkim, and Himachal Pradesh have the highest levels of empowerment. In contrast, West Bengal, Andhra Pradesh, and Telangana have the lowest levels of empowerment. The study conducted by Choudhury and Kumar (2021) found that Northeastern women are in relatively better conditions than women in the rest of India with respect to mobility, space in their lives, life choices, and related dimensions. Similarly, Das (2013) found that women's status in the NE region is relatively better than in the rest of the country on some dimensions. Studies also highlight that the NE region is also better off than the rest of India in terms of gender quality (Mahanta & Nayak, 2013). The literature on women's empowerment in India suggests that Indian women are relatively less empowered and have enjoyed a lower status than their male counterparts.

So far as the existing literature is concerned, we have found a very limited number of works devoted to the Indian context that examine the status of women's empowerment using a standardised composite index. Against this backdrop, the present paper seeks to address this gap by examining the status of women's empowerment in India, in relation to rural and urban India, by constructing a composite women empowerment index based on secondary data collected from the National Family Health Survey – 5.

1.2 Objectives of the Study

The broad objective of the study is to examine the status of women's empowerment in India across rural and urban contexts. However, this paper has the following specific objectives:

- a. To examine the status of women empowerment in rural India.
- b. To look into the status of women empowerment in urban India.
- c. To make a rural-urban comparison in the level of women's empowerment in India.

2. Data Source and Methodology

This study is based on secondary data gathered from the National Family Health Survey-5 (NFHS, 2019-21). The NFHS-5 provides a comprehensive snapshot of health, female empowerment, and household characteristics across 36 States/UTs and 707 districts. The survey covered 636,699 households and 724,115 women (aged 15–49). Due to the COVID-19 pandemic, NFHS conducted its 5th round in two phases. In the first phase, the reference period was 2019-20; in the second phase, 2020-21.

2.1 Analytical Framework

To examine the status of women empowerment in India, we have constructed a composite women empowerment index (WEI) by following the max-min approach. It is to be noted that the maximum value is 100 and the minimum is 0. The value of the WEI ranges from 0 to 1. A similar kind of approach is also followed by Choudhury and Roy (2025) while constructing the WEI. A value closer to 1 indicates higher empowerment, whereas a value closer to 0 indicates less empowerment. The study used Student's t-test, Spearman's rank correlation coefficient, and one-way ANOVA to analyse the study objectives.

2.2 Construction of Women Empowerment Index (WEI)

The construction of WEI involves two steps. The construction of the WE index is shown below. In step I, we have constructed the dimensional indices, and in step II, we have constructed the composite WEI.

Step I: Construction of Dimensional Index:

$$DMEI_i = \frac{X_a - X_{\min}}{X_{\max} - X_{\min}}; 0 \leq DMEI_i \leq 1; i = 1, 2, 3, \dots, n$$

Where, $DMEI_i$ = Decision-making empowerment index of women of the i th state.

X_a = Actual percentage of women having decision-making empowerment in the i th state.¹

$X_{\max}$ = Maximum percentage of women having decision-making empowerment in the i th state

1 Women who usually participate in three household decisions, i.e., decisions about health care for herself, making major household purchases, and visits to her family or relatives (NFHS, 2019-21).

$X_{\min}$ = Minimum percentage of women having decision-making empowerment in the i th state

$$EMPI_i = \frac{X_a - X_{\min}}{X_{\max} - X_{\min}}; 0 \leq EMPI_i \leq 1; i = 1, 2, 3, \dots, n$$

Where $EMPI_i$ = Economic empowerment index of women of the i th state.

X_a = Actual percentage of women having economic empowerment in the i th state.²

$X_{\max}$ = Maximum percentage of women having economic empowerment in the i th state

$X_{\min}$ = Minimum percentage of women having economic empowerment in the i th state

$$HI_i = \frac{X_a - X_{\min}}{X_{\max} - X_{\min}}; 0 \leq PI_i \leq 1; i = 1, 2, 3, \dots, n$$

Where, HI_i = Housing index of women of the i th state.

X_a = Actual percentage of women having a house in the i th state.³

$X_{\max}$ = Maximum percentage of women having a house in the i th state

$X_{\min}$ = Minimum percentage of women having a house in the i th state

$$FEI_i = \frac{X_a - X_{\min}}{X_{\max} - X_{\min}}; 0 \leq FEI_i \leq 1; i = 1, 2, 3, \dots, n$$

Where, FEI_i = Financial empowerment index of women of the i th state.

X_a = Actual percentage of women having financial empowerment in the i th state.⁴

$X_{\max}$ = Maximum percentage of women having financial empowerment in the i th state

$X_{\min}$ = Minimum percentage of women having financial empowerment in the i th state

2 Women who worked in the last 12 months and were paid in cash (NFHS, 2019-21).

3 Women owning a house and/or land (alone or jointly with others) (NFHS, 2019-21).

4 Women having a bank or savings account that they themselves use (NFHS, 2019-21).

$$INFI_i = \frac{Xa - X_{\min}}{X_{\max} - X_{\min}}; 0 \leq INFI_i \leq 1; i = 1, 2, 3, \dots, n$$

$$INFI_i; 0 \leq INFI_i \leq 1; i = 1, 2, 3, \dots, n$$

Where, $INFI_i$ = Information index of women of the i th state.

Xa = Actual percentage of women having information facilities in the i th state.⁵

$X_{\max}$ = Maximum percentage of women having information facilities in the i th state

$X_{\min}$ = Minimum percentage of women having information facilities in the i th state

Step II: Construction of Women Empowerment Index (WEI):

$$WEI_i = \frac{1}{5} (DMEI_i + EMPI_i + HI_i + FEI_i + INFI_i); 0 \leq WEI_i \leq 1; i = 1, 2, 3, \dots, n$$

Where WEI_i = Women Empowerment Index of the i th state.

$DMEI_i$ = Decision-making empowerment index of women of the i th state.

$EMPI_i$ = Economic empowerment index of women in the i th state

HI_i = Housing index of women in the i th state

FEI_i = Financial empowerment index of women of the i th state

$INFI_i$ = Information index of women of the i th state.

Table 1. Distribution of States and UTs with regard to the level of WEI.

Women Empowerment Index (WEI_i)	Women's Empowerment Levels
$0 \leq WEI_i \leq 0.25$	Very low
$0.26 \leq WEI_i \leq 0.50$	Low
$0.51 \leq WEI_i \leq 0.75$	Moderate
$0.76 \leq WEI_i \leq 1.00$	High

Source: Developed by the Authors

5 Women having a mobile phone that they themselves use (NFHS, 2019-21).

3. The State of Women's Empowerment in India

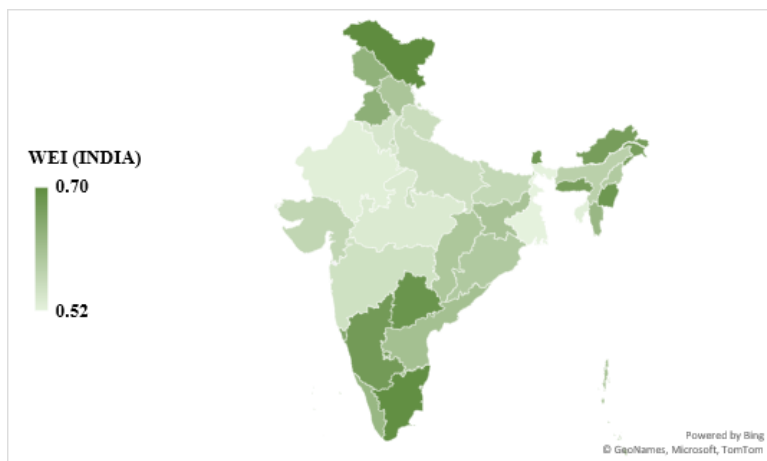


Fig 1: State of Women Empowerment in India

Source: Drawn by the Authors

The status of women empowerment in India is depicted in Fig 1. Tamil Nadu, Puducherry, and Ladakh have the highest women's empowerment level in India as a whole, followed by Manipur and Telangana. West Bengal, Tripura, and Rajasthan have the lowest empowerment levels, followed by Madhya Pradesh and Haryana.

4. Result and Discussion

The result and discussion section is divided into three sub-sections. 4.1 discusses the state of women empowerment in rural India. 4.2 depicts the status of women empowerment in urban India, whereas 4.3 depicts the rural-urban comparison of women empowerment in India.

4.1 The State of Women Empowerment in Rural India

Table 2. Ranking of States and UTs in terms of Women Empowerment in Rural India

States and UTs	WEI	Rank	States and UTs	WEI	Rank
Andaman & Nicobar Islands	0.61	8	Maharashtra	0.53	15
Andra Pradesh	0.60	9	Manipur	0.67	4
Arunachal Pradesh	0.67	4	Meghalaya	0.69	3
Assam	0.57	11	Mizoram	0.60	9
Bihar	0.56	12	Nagaland	0.56	12
Chhattisgarh	0.59	10	NCT Delhi	0.61	8
Daman and Diu	0.64	6	Odisha	0.59	10
Goa	0.66	5	Puducherry	0.71	1
Gujarat	0.54	14	Punjab	0.63	7
Haryana	0.52	16	Rajasthan	0.51	17
Himachal Pradesh	0.59	10	Sikkim	0.67	4
Jammu and Kashmir	0.64	6	Tamil Nadu	0.70	2
Jharkhand	0.60	9	Telangana	0.70	2
Karnataka	0.67	4	Tripura	0.52	16
Kerala	0.63	7	Uttar Pradesh	0.54	14
Ladakh	0.70	2	Uttarakhand	0.55	13
Madhya Pradesh	0.52	16	West Bengal	0.48	18

Source: Calculated by the Authors

Table 2 provides the rankings of the states and union territories (UTs) in terms of women’s empowerment in rural India. The ranking shows that Puducherry has the highest level of women’s empowerment, followed by Ladakh, Tamil Nadu, and Telangana. Furthermore, West Bengal has the lowest level of women’s empowerment, followed by Rajasthan and Madhya Pradesh. Moreover, West Bengal is the only state that falls under a low level of women’s empowerment. The study’s findings are consistent with the studies of Vignitha et al. (2024).

Table 3. Descriptive Statistics of Women Empowerment Index in Rural India

Variable	Maximum	Minimum	Mean	SD
WEI	0.71	0.48	0.60	0.06

Source: Calculated by the Authors

Table 3 shows that the mean WEI in rural India is 0.60, indicating a moderate level of women's empowerment. Compared with Table 2, 15 states in rural India have achieved higher empowerment levels than the national average. The maximum women empowerment level is 0.71, and the minimum is 0.48 in rural India. The standard deviation also indicates the existence of interstate disparities in WE in rural India.

Table 4. Status of the Dimensional Indices of Women's Empowerment in Rural India

Dimensional Indices	Mean	SD	F- value
DMEI	0.901	0.051	F (4,165) df =124.05** P > F=0.00
EMPI	0.287	0.117	
HI	0.450	0.179	
FEI	0.796	0.084	
INFI	0.591	0.173	

Source: Calculated by the Authors, **, meaning significant at 1% level of significance

Table 4 presents the status of the dimensional indices of women's empowerment in rural India. The findings of the study show a substantial variation across the different dimensions of women's empowerment in rural India. Decision-Making Empowerment (DMEI) is highest in rural India, with a low standard deviation (0.051), indicating that women in rural India exhibit relatively higher participation in the decision-making process with minimal disparity. The Financial Empowerment Index (FEI) is also found to be comparatively higher in rural India, indicating relatively better financial inclusion. In contrast, Informational Index (INFI) is found to be moderate in rural India, and the value of standard deviation shows a higher level of disparities in access to information. The Housing Index (HI) is relatively low in rural India, with greater interstate disparity. Moreover, the Employment Index (EMPI) is lowest in rural India, indicating low levels of employment opportunities and labour market

participation among women in rural India. The F-statistic is statistically significant at the 1 per cent level, indicating a significant difference in the dimensions of WE in rural India.

Table 5. Regional disparities in the level of Women Empowerment in rural India

Region	Mean	Standard Deviation	F- value
North India	0.59	0.07	F (5,28) df =2.43*
Central India	0.55	0.04	
East India	0.56	0.05	
Northeast India	0.62	0.06	
West India	0.60	0.07	
South India	0.66	0.05	

Source: Calculated by the Authors, *, meaning significant at 10% level of significance.

Regional disparity in terms of the level of women's empowerment in rural India is reflected in Table 5. It is observed that women in the Southern region of rural India have the highest level of empowerment, followed by those in the Northeastern region. Women's empowerment is lowest in Central India, followed by the Eastern region of the country. The standard deviation also indicates the presence of disparities in WE level. The F-value is statistically significant at the 10% level, indicating a difference in women's empowerment across regions of rural India.

4.2 The State of Women's Empowerment in Urban India

Table 6. Ranking of States and UTs in terms of Women Empowerment in urban India

States and UTs	WEI	Rank	States and UTs	WEI	Rank
Andaman & Nicobar Island	0.62	8	Madhya Pradesh	0.58	12
Andhra Pradesh	0.63	7	Maharashtra	0.57	13
Arunachal Pradesh	0.70	1	Manipur	0.70	1
Assam	0.61	9	Meghalaya	0.68	3
Bihar	0.58	12	Mizoram	0.64	6
Chandigarh	0.61	9	Nagaland	0.64	6
Chhattisgarh	0.62	8	NCT Delhi	0.57	13

Daman and Diu	0.65	5	Odisha	0.59	11
Goa	0.65	5	Puducherry	0.69	2
Gujarat	0.60	10	Punjab	0.66	4
Haryana	0.58	12	Rajasthan	0.56	14
Himachal Pradesh	0.66	4	Sikkim	0.70	1
Jammu and Kashmir	0.63	7	Tamil Nadu	0.69	2
Jharkhand	0.63	7	Telangana	0.66	6
Karnataka	0.69	2	Tripura	0.54	14
Kerala	0.62	8	Uttar Pradesh	0.59	11
Ladakh	0.69	2	Uttarakhand	0.58	12
Lakshadweep	0.57	13	West Bengal	0.59	11

Source: Calculated by the Authors

Table 6 presents the rankings of the states and UTs with respect to women's empowerment in Urban India. Based on the rankings, it is observed that the level of women empowerment is highest in Sikkim, Arunachal Pradesh, and Manipur, followed by Tamil Nadu, Ladakh, Puducherry, and Karnataka. While it is found to be lowest in Tripura and Rajasthan, followed by NCT Delhi and Lakshadweep.

Table 7. Descriptive Statistics of Women Empowerment Index in Urban India

Variable	Maximum	Minimum	Mean	SD
WEI	0.70	0.54	0.63	0.05

Source: Calculated by the Authors

The mean value of WEI in Table 7 shows that the average women empowerment level in urban India is 0.63. This indicates that the status of women empowerment in urban India is mostly moderate. The women empowerment index is also found to be moderate in urban India. In comparison with Table 6, it is found that 15 states in urban India have achieved higher empowerment levels than the national average. The maximum empowerment level is found to be 0.70. while the minimum is 0.54. The interstate disparity in terms of women's empowerment is found to be relatively low in urban India in relation to rural India.

Table 8. Status of the Dimensional Indices of Women's Empowerment in Urban India

Dimensions Indices	Mean	SD	F- value
DMEI	0.917	0.045	F (4,165) df =285.15** P > F=0.00
EMPI	0.265	0.082	
HI	0.383	0.156	
FEI	0.811	0.058	
INFI	0.752	0.109	

Source: Calculated by the Authors, ** meaning significant at 1 % level of significance

Table 8 provides the status of various dimensional indices of women empowerment in urban India. The finding shows substantial variations in dimensional indices. The Decision-Making Empowerment Index (DMEI) has the highest mean value in urban India, indicating that the women of urban India have relatively higher household decision-making empowerment. The Financial Empowerment Index and Informational Index are also found to be higher, indicating that urban women have relatively better access to financial services and information. However, the Housing Index and Employment are relatively low in urban India. This indicates that women in urban India have limited employment opportunities and lower rates of housing ownership. The F-statistic is statistically significant, indicating a difference in the dimensional indices of women's empowerment in urban India. Interstate disparities are also relatively higher in the Housing Index, whereas lowest in household decision-making empowerment.

Table 9. Regional disparities in the level of Women Empowerment in urban India

Region	Mean	Standard Deviation	F- value
North India	0.62	0.05	F (5,30) df =1.48
Central India	0.59	0.02	
East India	0.60	0.02	
Northeast India	0.65	0.06	
West India	0.62	0.04	
South India	0.65	0.04	

Source: Calculated by the Authors

Table 9 reflects the regional disparities in WEI level in urban India. The WEI is found to be highest in the Southern and Northeastern regions of the country and lowest in the Central region of India. Intra-regional disparity also exists in urban India. The F-value is not statistically significant, indicating no difference across regions of India in WE. Table 9 also shows that the northeastern and southern regions perform exceptionally well in terms of WE in India, compared with the other regions in urban India.

4.3 Rural-Urban Comparison in the Level of Women Empowerment in India

Table 10. Rural-Urban Comparison in the Level of Women Empowerment in India

States and UTs	Level of Women Empowerment				
	Rural	Rank	Urban	Rank	Rank Difference
Andaman & Nicobar Islands	0.61	8	0.62	8	0
Andra Pradesh	0.60	9	0.63	7	2
Arunachal Pradesh	0.67	4	0.70	1	3
Assam	0.57	11	0.61	9	2
Bihar	0.56	12	0.58	12	0
Chhattisgarh	0.59	10	0.62	8	2
Daman and Diu	0.64	6	0.65	5	1
Goa	0.66	5	0.65	5	0
Gujarat	0.54	14	0.60	10	4
Haryana	0.52	16	0.58	12	4
Himachal Pradesh	0.59	10	0.66	4	6
Jammu and Kashmir	0.64	6	0.63	7	-1
Jharkhand	0.60	9	0.63	7	2
Karnataka	0.67	4	0.69	2	2
Kerala	0.63	7	0.62	8	-1
Ladakh	0.70	2	0.69	2	0
Madhya Pradesh	0.52	16	0.58	12	4
Maharashtra	0.53	15	0.57	13	2
Manipur	0.67	4	0.70	1	3
Meghalaya	0.69	3	0.68	3	0
Mizoram	0.60	9	0.64	6	3

Nagaland	0.56	12	0.64	6	6
NCT Delhi	0.61	8	0.57	13	-5
Odisha	0.59	10	0.59	11	-1
Puducherry	0.71	1	0.69	2	-1
Punjab	0.63	7	0.66	4	3
Rajasthan	0.51	17	0.56	14	3
Sikkim	0.67	4	0.70	1	3
Tamil Nadu	0.70	2	0.69	2	0
Telangana	0.70	2	0.66	6	-4
Tripura	0.52	16	0.54	14	2
Uttar Pradesh	0.54	14	0.59	11	3
Uttarakhand	0.55	13	0.58	12	1
West Bengal	0.48	18	0.59	11	7
Student's T-test = - 1.77*		Spearman rank correlation coefficient = 0.84**			

Source: Calculated by the Authors, **, * meaning significant at 1&10 % level significance.

The rural-urban comparison in terms of women empowerment is portrayed in Table 10. The T-test is statistically significant at 10 % level, indicating that the women's empowerment index is significantly lower in rural India compared to urban India. The findings of the present work are in tune with existing studies (Waghmode & Kalyan, 2014). The Spearman rank correlation coefficient is statistically significant at 1% level, indicating a significant difference in the rankings of states and UTs in WE across rural and urban India. Due to data unavailability, two states have been excluded from the analysis.

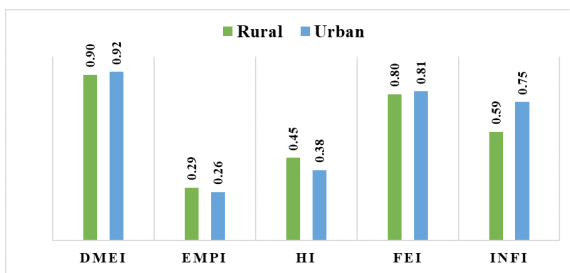


Fig 2: Rural-Urban Differences in the Different Dimensions of Women Empowerment

Source: Drawn by the Authors

Fig. 2 presents a rural-urban comparison across dimensions of women's empowerment in India. Both women in rural and urban India exhibit relatively higher levels of Decision-making Empowerment and Financial Empowerment. This suggests that both rural and urban women in India have greater autonomy in household decision-making and greater financial empowerment. The Decision-making Empowerment (DMEI), Financial Empowerment, and Information Index (INFI) are found to be relatively higher in urban India than rural India. This suggests that women in urban India have greater household decision-making power, greater access to and use of financial services, and better access to information than their rural counterparts. In contrast, women in rural areas have higher Economic Empowerment Index (EMPI) and Housing Index (HI) scores than their urban counterparts. This suggests that women in rural India have relatively higher employment and economic opportunities than their urban counterparts.

5. Conclusion and Policy Recommendations

To conclude, this paper examines the status of women's empowerment in both rural and urban India. Based on the rankings of the states and union territories. Puducherry has the highest level of women's empowerment in rural India, followed by Ladakh, Tamil Nadu, and Telangana. West Bengal has the lowest empowerment level, followed by Rajasthan and Madhya Pradesh. Moreover, in urban India, Sikkim, Arunachal Pradesh, and Manipur have the highest levels of women's empowerment, followed by Tamil Nadu, Ladakh, Puducherry, and Karnataka. Tripura and Rajasthan have the lowest empowerment level, followed by NCT Delhi and Lakshadweep. The findings indicate that the level of women's empowerment in both rural and urban India is moderate, and rural women are significantly less empowered than their urban counterparts. Interstate disparity in terms of women empowerment is also found to be relatively higher in rural India as compared to urban India. Additionally, the study reveals that urban India has relatively higher Decision-making Empowerment Index (DMEI), Financial Economic Empowerment Index, and Information Index (INFi) than rural India. However, the Housing Index (HI) and the Economic Empowerment Index (EMPI) are relatively higher in rural

India than their urban counterparts. Based on the findings of the study, we recommend that the Government of India should implement more gender-based programmes to enhance women empowerment, particularly in rural areas.

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Environmental Degradation and Sustainable Development: A Case Study of Brick Kilns in Palasbari Revenue Circle, Assam

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Abstract

Environmental pollution poses a serious threat to human development by adversely affecting both the physical and mental well-being of people. Changes in the physical, chemical, and biological components of the environment have made human survival increasingly challenging. A clean and pollution-free environment is therefore essential for human existence, as a healthy environment alone can ensure a better quality of life. Among small-scale industries, brick kilns play a significant role in meeting construction demands. However The Central Pollution Control Board (CPCB), Delhi, has recognized the brick production industry as highly resource and energy intensive as well as polluting industry, primarily due to obsolete and traditional production techniques used in India. The brick kilns are source of local air pollution, land degradation and water pollution which ultimately affect the local population, agriculture and vegetation and also contribute to climate change at global level. This paper examines the environmental impacts of brick kilns in the Palasbari Revenue Circle, Assam, focusing on air, soil, and water degradation and their implications for sustainable development.

The study is based on primary data collected through field surveys, interviews and observations, supported by secondary data from government reports and published literature. The study highlights the need for adopting cleaner technologies, enforcing environmental regulations, and promoting sustainable alternatives in the brick-making sector.

Keywords: *Environmental Degradation, Sustainable Development, Brick Kilns, Air, Water and Soil Pollution.*

1. Introduction

Over the past few decades, environmental pollution has increased significantly due to the pollutants released into the air, water and soil. This rise in pollution is largely linked to rapid population growth, expanding industries, urban development, mechanisation, excessive use of chemical fertilisers and pesticides in agriculture, and improper disposal of human waste. Continuous environmental degradation has become a major obstacle to achieving sustainable development, as it negatively affects agriculture, industry, and livestock production. In India, the brick industry is one of the largest producers of clay fired bricks in the world, ranking second after China and contributing more than ten percent of global production. However, brick manufacturing is considered a highly resource-intensive and polluting industry by the Central Pollution Control Board. (CPCB). In the Palasbari Revenue Circle, brick kilns are among the main sources of environmental pollution. Emissions from these kilns deteriorate air quality, excessive removal of clay reduces soil fertility, and poor waste management contaminates nearby water bodies, posing risks to ecosystems as well as human health. Although brick kilns create employment opportunities and contribute to local economic growth, many of them have yet to adopt sustainable practices. In this context, examining the environmental impacts of brick kilns becomes essential for developing balanced development strategies. This paper aims to analyze the extent of environmental degradation caused by brick kilns in the Palasbari Revenue Circle and to assess their implications for sustainable development. The study highlights the need for cleaner technologies, effective environmental regulations, and sustainable alternatives to ensure environmental protection while maintaining economic benefits.

1.1 Meaning of Sustainable Development

In 1987 the “brundland commission” set up by the United Nations (UN) published their report as “our common future” and defined “sustainable development” for the first time as “development that meets the need of the present without compromising the ability of the future generation to meet their needs” It aims to secure the needs of society, its welfare, security, safety and prosperity, without compromising the ability of future generations to achieve this in the future.

1.2 Brick Industry of Palasbari Revenue Circle

A considerable number of brick kilns have been established in various parts of the Palasbari Revenue Circle in recent years. According to data obtained from the Palasbari Revenue Circle office, a total of 13 brick kilns exist within the circle, out of which 12 are currently operational. These functioning units are distributed across three development blocks: 4 kilns in Rampur Development Block, 7 kilns in Chhayani Development Block, and 1 kiln in Rani Development Block. Together, these kilns produce approximately 45–50 million bricks during a single production season to meet the construction needs of the circle and nearby areas. The industry also provides seasonal employment to nearly 2,000 workers. Brick manufacturing in this region is largely seasonal and usually takes place during the winter months, beginning in October and continuing until the middle of April.

Brick kiln labourers in the study area largely consist of migrant families, many of whom bring their children along during the working season. Each year, a significant number of workers migrate from states such as Uttar Pradesh, Bihar, and Jharkhand, as well as from backward districts of Assam including Dhubri district and Barpeta district. These migrant labourers usually reside within the kiln premises in temporary shelters made of brick or bamboo walls and roofs covered with galvanized tin sheets. Most of the migrants are landless labourers or marginal farmers who arrive before November to work in the brick kilns of the Palasbari Revenue Circle. Recruitment is generally carried out through labour contractors, locally known as “sardars,” who provide advance payments to workers. In return, the labourers are expected to report for work at the beginning of the following brick-making season to repay the advance. Field survey findings indicate that all 12 operating brick kilns in the area (100%) use

the Fixed Chimney Bull's Trench Kiln (BTK) technology. No evidence was found of other kiln types such as moving chimney BTK, Vertical Shaft Brick Kiln (VSBK), High Draught Kiln, or Habla Kiln in the Palasbari Revenue Circle.

Table 1.2: Brick Kilns in Palasbari Revenue Circle with their Labour Employment and Productivities

Sl No.	Name of the Brick Kilns	Year of Establishment	Ownership	No. of Workers Employed		Production Level Per Season (in lakhs)
				Permanent	Temporary	
1	CBI	1995	Proprietorship	6	175	50
2	JRK	2005	Proprietorship	6	200	70
3	MAA	2005	Proprietorship	6	180	40
4	MDB	2005	Proprietorship	5	160	50
5	HSI	2012	Partnership	5	80	20
6	BPR	2010	Partnership	7	120	30
7	HMB	2010	Proprietorship	5	40	10
8	GBI	2005	Proprietorship	6	144	50
9	NBI	1992	Proprietorship	5	125	40
10	TBI	2010	Partnership	5	125	30
11	PLB	1996	Proprietorship	4	100	25
12	SBI	2013	Proprietorship	5	150	40

Source: Compiled from field survey, Records of Sub- Divisional Circle Office, Palasbari.

1.3 Review of literature

Environmental protection plays a crucial role in the development process, as it supports the sustainable use of resources and improves overall human well-being. According to UNESCO, safeguarding the environment is essential for achieving sustainable development goals (<http://www.unesco.org>). A significant milestone in this regard was the United Nations Conference on the Human Environment held in Stockholm in 1972, which brought together representatives from 113 countries along with participants from 19 international organizations. This was the first global conference dedicated entirely to environmental concerns. During the conference, a panel of 27 experts highlighted the strong interdependence between

environmental protection and economic development, pointing out that although conflicts may arise in specific situations, both are fundamentally interconnected and should be understood as complementary aspects of progress (**Vogler, 2007**).

Rapid industrial growth in developing nations such as India has significantly increased environmental stress, particularly from small-scale industries like brick kilns. These kilns are considered major contributors to air pollution in South Asia. Conventional technologies, including Fixed Chimney Bull's Trench Kilns (FCBTK), release substantial amounts of pollutants such as particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and black carbon (**CPCB, 2017; World Bank, 2020**). Additionally, the United States Environmental Protection Agency (EPA) has noted that brick manufacturing contributes to climate change through the release of carbon dioxide and black carbon. In India, the industrial sector is responsible for around 15% of total black carbon emissions, with approximately two thirds of those emissions i.e. 9% attributable to brick kilns.

A study by **Joshi and Dudani (2008)** examining the environmental health impacts of brick kilns in the Kathmandu Valley revealed that children studying in schools located near brick kilns experienced poorer health compared to those attending schools situated farther away. The research also identified a higher occurrence of respiratory illnesses, including tonsillitis and acute pharyngitis, among students living and studying in areas close to these kilns.

Skinder et al. (2014) investigated air pollution generated by brick kilns in Panzan village, Budgam district of Jammu and Kashmir. To assess the levels of gaseous pollutants, emissions were monitored at eight-hour intervals during both operational and non-operational periods of the kilns. The findings indicated that concentrations of pollutants such as sulphur oxides (SO_x), nitrogen oxides (NO_x), respirable particulate matter (RSPM), non-respirable suspended particulate matter (NRSPM), and total suspended particulate matter (SPM) exceeded the limits set by the National Ambient Air Quality Standards (NAAQS) when the kilns were in operation. Based on these observations, the study recommended adopting cleaner production methods, including the use of vertical shaft brick kilns (VSBK) as an alternative to traditional Bull Trench Kilns (BTK).

Beyond their role in air pollution, research also points to the harmful impact of brick kilns on soil and water resources. The extraction of topsoil for brick production and associated excavation activities lead to a decline in soil organic matter, nutrient levels, and moisture content, while increasing electrical conductivity—signs of declining soil health. This degradation reduces land productivity and poses a serious risk to long-term agricultural sustainability, particularly in areas where brick kilns operate close to farmland (**Jeet et al., 2021**).

Singh and Asgher (2005) analyzed changes in land use and land cover in areas surrounding brick kilns near Aligarh city, India. Their findings showed that brick production leads to the degradation of fertile agricultural land and disrupts established land use patterns in villages where these kilns operate.

Khan and Vyas (2008) investigated the impact of the brick industry on the water quality of the Kshipra River and observed that these activities have detrimental effects on soil, water, air, vegetation, and human health in the surrounding region. The study noted that brick kilns consume large quantities of fuel and rely on inefficient production methods, which contribute to significant air pollution and harm both plant life and human well-being. Furthermore, it was found that waste materials from the kilns are discharged into the river, leading to increased levels of total solids, suspended solids, reduced dissolved oxygen, and higher calcium hardness in the water.

In addition to environmental concerns, existing studies highlight the wider socio-economic implications of brick kiln operations. A bibliometric and thematic analysis by **Parvez et al. (2023)** indicated that the adverse effects of this industry also impact human health, sustainable livelihoods, and social well-being. The review further pointed out serious challenges in poorly regulated settings, including exploitative labour practices and conditions resembling modern slavery.

1.4 Objectives

- To identify the different environmental pollutions created by the brick kilns of Palasbari Revenue Circle.
- To assess the impact of environmental pollutions on human health and vegetation caused by brick kilns of Palasbari Revenue Circle.

- To examine whether existing environmental regulations and practices are properly implemented to control pollution and protect the environment.
- To recommend sustainable strategies and policy measures for promoting sustainable development in brick kiln industries of Palasbari Revenue Circle.

1.5 Research Methodology

- a. Nature of Study:** The present study is descriptive as well as Analytical in nature.
- b. Area of study:** The area of the study is Palasbari Revenue Circle. It comprises of approx. 374.57 sq. km. geographical area and is one of the twelve revenue circles comprising the district of Kamrup in Assam. The circle is situated in the south bank of river Brahmaputra and situated almost 30 km away from Guwahati city. The circle has 190 revenue villages and 20 forest villages. It has one Municipal Board (Palasbari Municipal Board) with 10 wards. As of the 2011 Census, the Palasbari Revenue Circle has a total population of 239,026, comprising 121,926 males and 117,100 females, with a sex ratio of 960. The average literacy rate is 79.95% with 76.19% male and 65.98% female literacy rate.
- c. Research Design:** In Palasbari Revenue Circle twelve brick kilns are in operation and all of these brick kilns are taken for the study. First data and information have been collected from each of the twelve (12) owners of brick kilns. Secondly, a few focused people have been consulted in the areas close to the brick kilns for collecting information regarding the impact of brick kilns on human health, crop productivity, livestock etc. For this purpose three focused group discussions have been arranged in different areas. Such a focused group comprises of heads of the village (Gaonburha), a few teachers of nearby schools, a few social workers of the locality, a few members of Mahila Samities, Panchayat Secretaries, NGO People and a few progressive farmers.

Table 1.5: Members of Focused Group Discussion

Sl No	Focused people	Numbers	Remark
1	heads of the villages (Gaonburha)	05	One from each cluster of villages where kilns are concentrated.
2	Teachers	03	One from each development block.
3	Social Workers	03	One from each development block.
4	Mahila Samity Members	03	One from each development block.
5	Panchayat Secretary	03	One from each development block.
6	NGO People	03	One from each development block.
7	Progressive farmers	05	One from each cluster of villages where kilns are concentrated.
Total		25	

d. Data Collection: Both primary and secondary data have been collected for the study. The primary data are collected by the technique of field survey, interviewing all categories of respondents administering questionnaires among them. Secondary data are collected from various offices and libraries viz. Sub Divisional Office, Palasbari, District Industrial Centre, Ghy, Pollution Control Board, Ghy, Office of Chief Inspector of Factories, IIE (Guwahati), OKDISCD (Guwahati). Moreover different books, newspapers, official reports, journals and websites are also consulted for the present study.

2. Air Pollution Created by Brick Kilns of Palasbari Revenue Circle and its Effect

Air pollution is an atmospheric condition in which certain substances like gases, particles and biological molecules are present in concentration high enough above their normal ambient levels which can cause measurable effects on man, animals, vegetation or materials (Kaushik & Kaushik, 2012).

Brick kiln emissions consist of a variety of pollutants generated during both complete and incomplete combustion processes

involved in firing raw (kutcha) bricks. These emissions originate not only from the fuels used but also from the raw materials themselves (RERIC, 2003; Zhang, 1997). Pollutants are released through chimney (stack) emissions as well as fugitive sources, and typically include fine coal particles, dust, organic matter, and various gases. Once emitted, these pollutants are dispersed by wind into surrounding areas, leading to a decline in local air quality. In addition, several stages of brick kiln operations—such as clay excavation, fuel feeding, coal crushing, ash handling and spreading, and the loading and unloading of bricks—contribute significantly to dust generation and overall air pollution.

2.1 Air Pollution Due to Use of Coal in the Brick Kilns

The combustion of large quantities of coal and wood in brick kilns leads to significant air pollution, which negatively affects the health of nearby residents as well as kiln workers. It also poses serious risks to local vegetation and agricultural productivity. The extensive use of coal in these kilns results in the release of pollutants such as carbon dioxide (CO₂), carbon monoxide (CO), sulphur dioxide (SO₂), nitrogen oxides (NO_x), and particulate matter (PM), including black carbon (BC). These pollutants are emitted in the form of smoke, fumes, dust, soot, and ash, contributing to environmental degradation.

In the Palasbari Revenue Circle, brick kilns primarily rely on coal as the main fuel for firing bricks. During the initial stages of the process, firewood is also used to remove excess moisture from the raw bricks. On average, about 25–30 tonnes of coal are consumed for producing one lakh bricks, with supplies sourced from Assam and Meghalaya. The level of air pollutant emissions varies considerably among kilns during a typical firing cycle of about seven days. According to Le and Oanh (2010), the average emissions per 1,000 bricks are estimated at 6.35–12.3 kg of carbon monoxide (CO), 0.52–5.9 kg of sulphur dioxide (SO₂), and 0.64–1.4 kg of particulate matter (PM). On an average the brick kilns of Palasbari Revenue Circle produce three to four million pieces of bricks in a season. This large-scale production results in the release of substantial amounts of CO, SO₂, and particulate pollutants into the atmosphere, contributing to air pollution. The quantities of these emissions from different kilns in the study area are presented in Table 2.1

Table 2.1: Annual Coal Consumption and Emissions of Pollutants from the Brick Kilns of Palasbari Revenue Circle

Brick Kilns's Name	Brick Production (in lakhs)	Consumption of Coal (in tons)	Carbon Monoxide (CO) Emission (in kg)*	Sulphur Dioxide (SO₂) Emission (in kg)*	Particulate Matter (PM) Emission (in kg)*
CBI	50 lakhs	1500	31,750-61,500	2,600-29,500	3,200-7,000
JRK	70 lakhs	2000	44,450-86,100	3,640-41,300	4,480-9,800
MAA	40 lakhs	1100	25,400-49,200	2,080-23,600	2,560-5,600
MDB	50 lakhs	1200	31,750-61,500	2,600-29,500	3,200-7,000
HSI	20 lakhs	620	12,700-24,600	1,040-11,800	1,280-2,800
BPR	30 lakhs	840	19,050-36,900	1,560-17,700	1,920-4,200
HMB	10 lakhs	300	6,350-12,300	520- 5,900	640-1,400
GBI	50 lakhs	1350	31,750-61,500	2,600-29,500	3,200-7,000
NBI	40 lakhs	1200	25,400-49,200	2,080-23,600	2,560-5,600
TBI	30 lakhs	840	19,050-36,900	1,560-17,700	1,920-4,200
PLB	25 lakhs	750	15,875-30,750	1,300-14,750	1,600-3,500
SBI	40 lakhs	1200	25,400-49,200	2,080-23,600	2,560-5,600
Total	455 lakhs	12, 900	2,88,925-5,59,650	23,660-2,68,450	29,120-63,700

**Calculation is done on the basis of estimation given by Le and Oanh (2010).*

The data presented in the table indicate that, in the surveyed brick kilns, annual carbon monoxide emissions range from 2,88,925 to 5,59,650 kg, while sulphur dioxide (SO₂) emissions vary between 23,660 and 268,450 kg. Particulate matter (PM) emissions are estimated to lie between 29,120 and 63,700 kg. The total coal consumption across these kilns is approximately 12,900 tonnes. These figures suggest that the high level of coal usage in the area contributes significantly to elevated concentrations of air pollutants within the circle.

Most brick kilns in the Palasbari Revenue Circle depend on coal sourced from Assam and Meghalaya for firing green bricks. The coal from these regions is known for its relatively high sulphur content. While sulphur levels in Indian coal generally range between 0.1% and 0.8%, coal from Assam contains significantly higher levels, reaching up to 3.9% (Coal Atlas of India, 1993). Studies by Barooah and Baruah (1996) further indicate that coal from northeastern India typically contains between 2.7% and 7.8% sulphur, with a significant share (approximately 75% to 90%) present in organic form. The use of such high-sulphur coal is environmentally harmful, as its combustion releases sulphur dioxide (SO₂), a toxic and corrosive gas that contributes to acid rain and poses serious health risks.

2.2 Solid Waste Generation

Coal ash is the main form of solid waste produced in brick kilns, and its quantity depends on the volume of coal used and its ash content. In addition, a significant amount of waste is generated in the form of over-burnt, under-burnt, and broken bricks, which are usually accumulated near the stockyard. To provide thermal insulation, much of the ash is reapplied to the top layer of the kiln and, at times, along its walls. The process of unloading fired bricks, along with the removal of ash from the kiln surface, also creates substantial dust. As ash and dust remain deposited on the kiln top and walls, even light winds can easily disperse these particles into nearby areas. If not regularly cleared or properly managed, this accumulation can make the kiln environment extremely dusty.

2.3 Air Pollution Due to Use of Traditional Technology

The continued use of outdated and inefficient firing technologies, along with the absence of proper emission control systems, leads to the release of large amounts of air pollutants. A notable example of such inefficient technology is the Fixed Chimney Bull's Trench Kiln (FCBTK). This type of kiln operates as a continuous, moving-fire system that relies on natural draught created by a fixed chimney and is comparatively more resource- and energy-intensive than modern alternatives. According to the World Bank (2007), Moving Chimney Bull's Trench Kilns emit about 8.06 kg of suspended particulate matter (SPM) per 1,000 bricks, whereas Fixed Chimney kilns release around 1.71 kg, and Vertical Shaft Brick Kilns (VSBK) emit only 0.55 kg for

the same output. This indicates that fixed chimney kilns are nearly five times cleaner and VSBK over fourteen times cleaner than traditional kiln types. In the Palasbari Revenue Circle, brick production is largely carried out using FCBTK technology, which is associated with incomplete fuel combustion, black smoke emissions, and the accumulation of unburnt coal residues within the kiln. Such incomplete combustion results in high emissions of suspended particulate matter (SPM) and black carbon (BC), with SPM concentrations typically ranging between 150 and 1250 mg/Nm³ (GKSPL, 2011).

The brick kilns surveyed do not have adequate arrangements for handling or storing toxic by-products generated during combustion. From October to April, the surrounding areas are heavily affected by the persistent smell of burning coal and other materials. With the beginning of the monsoon season in May/June, the brick kilns stops it's functioning. During this inactive period, residual pollutants gradually settle and disperse into the surrounding soil and vegetation.

2.4 Effects of Air Pollution:

Deterioration of air quality poses serious risks to both human health and the environment. According to estimates by the World Health Organization, air pollution is responsible for around three million deaths annually, with nearly eight lakh premature deaths attributed to conditions such as respiratory diseases, lung cancer, and cardiovascular disorders. A significant share of these health impacts is linked to exposure to outdoor air pollution (WHO, 2000). Exposure to polluted air can affect multiple body systems, including the respiratory, cardiovascular, urinary, digestive, and nervous systems (Nilsson, 2015). High concentrations of coal dust and particulate matter can also reduce visibility and lead to skin irritation. Beyond its impact on human health, air pollution adversely affects ecosystems by contributing to problems such as acid rain, ozone layer depletion, and damage to crops, trees, and wildlife. It can also disrupt aquatic ecosystems by harming fish and other organisms. Acid rain can alter the chemical composition of soil, making it less suitable for organisms that rely on it for habitat and essential nutrients.

Brick kiln dust contains various elements such as calcium (Ca), sodium (Na), cadmium (Cd), zinc (Zn), magnesium (Mg), chloride (Cl), sulphur (S), molybdenum (Mo), along with

elevated levels of phosphorus (P) and potassium (K), making it as harmful as smoke emissions. This dust is alkaline in nature, with a pH range of 8.2 to 10.5. Such characteristics can adversely affect plant growth, particularly by interfering with their maturation process (Upadhyay, 2004).

Air pollution from brick kilns also has a significant impact on workers' health. Long working hours expose them to high levels of dust, increasing their risk of health problems. In the Palasbari Revenue Circle, workers face multiple health hazards as they both work and reside within the kiln premises, often just a few meters away from the emission sources. Many workers live on-site with their families, including women and children, which further exposes them to health risks from pollution. Labourers are involved in activities such as moulding raw bricks, crushing coal, feeding fuel, and loading and unloading bricks, all of which contribute to dust exposure. Workers in the brick kilns of the Palasbari Revenue Circle face various health issues, largely due to the highly unhygienic conditions present at the kiln sites. Field observations indicate that kiln owners have largely failed to implement adequate safety measures to protect workers from the harmful effects of air pollutants.

During focus group discussions, most participants identified brick kilns as the primary source of air pollution in the area. They reported that emissions from these kilns are linked to several health issues among local residents, including breathing difficulties, eye irritation, nasal problems, and skin diseases. Beyond health impacts, the community also reported concerns such as declining groundwater availability and reduced agricultural yields. Vegetation near the kilns appeared weakened and degraded. Some villagers mentioned that dust from the kilns settles on clothes during sun-drying, leaving dark stains. Additionally, the frequent movement of heavy trucks carrying coal, bricks, and soil has led to significant damage to village roads.

3. Land Degradation from the Manufacturing Activities of Brick Kilns and its Effect

In addition to air pollution, the brick industry causes significant harm to agricultural land. Brick kilns require extensive open areas for their operations, and in the Palasbari Revenue Circle, many of them are located within traditional paddy fields.

Continuous firing of bricks leads to the burning of soil layers several feet deep and alters its natural composition. The intense heat also destroys microorganisms in the surrounding soil, accelerating land degradation. As a result the local farmers or the owners of adjacent land are compelled to either sell or lease their land to brick kiln owners. Brick production relies on high-quality loamy soil, which is equally important for agriculture. The climate and soil conditions of the Palasbari area are well-suited for rice cultivation; however, since agriculture is largely rain-fed, fields are mostly left uncultivated during the dry season, with only limited rabi crops and vegetables grown.

Apart from air pollution the brick industry also causes serious damage to agricultural land. Brick kilns require a large amount of open fields for its allied activities. In Palasbari Revenue Circle all brick kilns are situated at the centre of the traditional paddy field. Due to continuous burning of bricks the soil of the kiln burn down up to few feet deep from the top and also changes the soil composition. Moreover the extreme heat burn the micro organism of the land up to few meters from the kiln and the land started to degrade. As a result the local farmers or the owners of adjacent land are compelled to either sell or lease their land to brick kiln owners. The traditional method of making bricks requires good quality loamy soil. Such good quality soil is also used for agricultural purpose. The climatic condition and the soil of Palasbari Revenue Circle are suitable for rice production. Moreover as the agriculture in the study area is only rain-fed, paddy fields are not cultivated during dry season and only a few fields are planted with rabi-crops whereas some fields are also used for vegetables. In the Palasbari Revenue Circle, brick kilns collect soil both from nearby riverine wastelands and by excavating land from adjacent agricultural fields. Focus group discussions revealed that many younger landowners are reluctant to continue farming and instead prefer to lease their land for soil extraction for periods of four to five years, as it provides quicker and higher financial returns compared to agriculture. This practice involves removing the top 4–5 feet of fertile soil, which eventually renders large areas of farmland unproductive and fallow after a few years. Additionally, during the off-season, brick manufacturers often procure soil from distant locations at lower costs and store it for use in the next production cycle.

During field survey it is observed that due to excessive digging of soil the land becomes infertile for which the vegetations has been cut at these sites. The soil quarrying activities also lowered the level of agricultural land by about 2–4 feet compared to surrounding areas and alter the natural composition of the soil. Furthermore, once the soil has been removed, the excavated pits are typically left unattended, rendering the land unsuitable for grazing and other uses.

According to guidelines issued by the Pollution Control Board, the topsoil or humus layer removed during earth extraction and kiln operations should be carefully preserved within the brick field for future land reclamation of exhausted or abandoned kiln sites. However, field observations reveal that, in practice, none of the brick units follow this requirement.

3.1 Quantitative Measurement of Degraded Land in the Study Area

According to the Central Building Research Institute, Roorkee (CBRI, 2001), approximately 0.003 cubic meters of soil is required to produce a single brick. In the Palasbari Revenue Circle, the average production of bricks per kiln are around 4 million in one season. Based on this estimate, each kiln removes nearly 12,000 cubic meters of topsoil annually for brick production. Table 3.1 presents the extent of land degradation (measured in bighas) and the yearly loss of topsoil (in cubic meters) caused by brick kilns in the study area.

Table-3.1: Land Degradation (in bighas) and Annual Loss of Topsoil (in cu. m) Through Brick Kilns of Study Area

Sl No.	Name of the Brick Kilns	Present Land Under brick kilns (in Bigha)	Production of bricks (in Lakhs)	Loss of Top Soil per Season (in cu.m)
1	CBI	48	50	15,000
2	JRK	23	70	21,000
3	MAA	19	40	12,000
4	MDB	17	50	15,000
5	HSI	19	20	6,000
6	BPR	5	30	9,000
7	HMB	26	10	3,000
8	GBI	13	50	15,000

9	NBI	24	40	12,000
10	TBI	17	30	9,000
11	PLB	19	25	7,500
12	SBI	8	40	12,000
Total	-	238	455	1,36,500

The data in the table indicate that brick kilns in the Palasbari Revenue Circle occupy about 238 bighas of land, much of which can be regarded as completely degraded. Additionally, the surveyed kilns collectively use approximately 136,500 cubic meters of fertile topsoil each year for brick production.

3.2 Loss of Soil Fertility

A major consequence of mining and quarrying activities is the decline in soil fertility. These processes bring about significant changes in the physical, chemical, and biological properties of soil, making quarried land less productive. There is a loss of $\frac{3}{4}$ th of soil nutrients was reported due to brick production in different regions of Bangladesh (Khan et al. 2007). Moreover, the continuous heat generated by kilns reduces the moisture content of nearby soil, while unregulated excavation disrupts the natural drainage patterns of the area.

3.3 Erosion Caused by Adjacent Quarried Lands

One of the significant negative impacts of soil quarrying on agricultural land is increased soil erosion. The removal of topsoil makes the land more vulnerable to being washed away by water, especially along sloping areas. Focus group discussions with villagers indicated that a substantial amount of fertile topsoil is also extracted from nearby agricultural fields. Due to this inconvenience, many landowners of the adjacent land are often compelled to lease or sell their land to brick kiln operators.

4. Water Logging

Waterlogging is another major issue associated with quarried land, where the accumulation of rainwater results in flooding. This problem is not confined to the rainy season and may also occur at other times of the year. Extensive soil excavation from agricultural fields can result in both temporary and long-term waterlogging in the study area. In the Palasbari Revenue Circle, temporary waterlogging has been observed in areas surrounding brick kilns, making it difficult for local farmers to cultivate crops in affected fields.

Field observations revealed that quarried lands often turn into deep pits due to the absence of proper leveling. During the rainy season, these ditches are filled with water, creating suitable breeding grounds for mosquitoes and other pests. In some cases, nearby villagers and workers use this stagnant water for activities such as washing and bathing, which can lead to serious health risks. Additionally, these abandoned excavation sites are sometimes used as dumping grounds for waste.

4.1 Water Pollution and its Effect

Dey and Dey (2015) reported that brick kiln activities significantly influence the physical, chemical, and biological characteristics of nearby aquatic systems. Heat released from kiln operations contributes to a rise in water temperature in surrounding water bodies. The study also found increased turbidity in these areas, mainly due to land excavation, sand extraction, and the disposal of ash, which raises the silt content in the water. This elevated turbidity may further contribute to higher water temperatures, as suspended particles absorb and retain heat from sunlight, thereby warming the aquatic environment.

In the Palasbari Revenue Circle, three brick kilns are located within approximately 200–300 meters of the Brahmaputra River. Wastewater generated from these kiln sites contains a high concentration of suspended solids. Additionally, nearby open areas along the riverbank are often used by workers for sanitation purposes, leading to unpleasant odors and unsanitary conditions in the surrounding environment.

Various diseases are transmitted through contaminated water, including typhoid, cholera, infectious hepatitis, and bacillary dysentery. The World Health Organization reports that around 1.1 billion people worldwide lack access to safe drinking water, while approximately 2.4 billion people do not have adequate sanitation facilities. This situation contributes significantly to the spread of both acute and chronic water-related illnesses. It is further estimated that preventable water-borne diseases cause about 3.4 million deaths annually, including a large number of children.

5. Legislative Development Relating to Environment in India as well as in Assam

India has developed an extensive framework of environmental laws to address pollution and conservation issues. Key legislations

enacted after independence include the Air (Prevention and Control of Pollution) Act, 1981; the Environment (Protection) Act, 1986; the Forest (Conservation) Act, 1980; the National Environment Tribunal Act, 1995; the National Environmental Appellate Authority Act, 1997; and the Biological Diversity Act, 2002. In addition, several older laws—such as the Factories Act, 1948; the Mines Act, 1952; the Atomic Energy Act, 1962; the Wildlife (Protection) Act, 1972; the Industrial (Development and Regulation) Act, 1957; and the Indian Forest Act, 1927—have been amended over time to better address emerging environmental challenges.

In Assam, environmental governance is primarily handled by the Department of Environment and Forests and the Assam Pollution Control Board. These bodies function under the guidance of the Regional Office of the Ministry of Environment, Forest and Climate Change located in Shillong, to which matters related to approvals and policy direction are referred. This regional office operates through two main divisions—environment and forestry—while monitoring and regulatory responsibilities are carried out in coordination with the State Pollution Control Board.

The Assam Brick Kilns Establishment and Regulation Rules, 2013 were introduced to control the establishment and functioning of brick kilns with the aim of minimizing environmental impacts. These rules place several restrictions on setting up kilns in the state. Brick kilns are permitted only on land that has been officially classified as non-agricultural by the concerned Circle Officer of the Revenue Department. Additionally, the establishment of a new kiln requires a public hearing in the respective Gaon Panchayat to assess local acceptance, and a No Objection Certificate from the Panchayat is mandatory. The area selected for soil excavation must also comply with the limits specified under Rule 7 of the Assam Minor Mineral Concession Rules, 2013. Furthermore, kiln operators are required to ensure a legitimate and sustainable source of raw materials. Some additional measures for controlling pollution from brick manufacturing units in Assam under these rules include:

- i. The approach road within the site of brick kiln area should be pucca / stabilized with brick bats etc.
- ii. Brick kilns should use crushed coal for better burning efficiency.

- iii. Bricks should be laid in such a staggered manner for firing to entrap maximum particulate matter (PM) at the starting place itself.
- iv. Adequate pollution control measures like gravity chamber, water sprayers etc should be installed and operated at strategic locations of the brick unit.
- v. Permanent or fixed stack (chimney) should be installed at the brick kiln and the minimum the height of chimney /stack should be 30 meters.
- vi. For controlling dust, smoking and pollution the every brick unit should install water sprayers.
- vii. The approach road to site of brick kiln (including the storage site if it is at different place) from the nearest public road which is generally used for the transportation of raw materials and final products must be paved or hard surfaced.
- viii. Active haul roads inside the brick unit should be adequately wetted with water (preferably recycled and treated waste water) to reduce dust.
- ix. Exhausts of trucks for transportation of materials within the site should be directed upward.
- x. Brick kilns should provide wheel cleaning facilities for delivery trucks for the removal of mud.

6. Implementation of Various Measures for Controlling of Pollution in the Brick Kilns of Palasbari Revenue Circle:

Brick kilns of Palasbari Revenue Circle require substantial amounts of water for their production processes, which are typically sourced within the kiln premises to ensure uninterrupted operations throughout the season. Most units rely on water pump systems to meet their needs. So, there is no scarcity of water in the brick units in this area. The use of water is not subject to regulation or monitoring by local government authorities. Notably, three brick kilns in the area are located within 500 meters of the Brahmaputra River. The discharge of wastewater from these kilns, which contains high levels of suspended solids, contributes to river pollution and poses potential health risks to nearby communities.

The study found that brick kilns in the Palasbari Revenue Circle were established on land officially certified by the Circle

Officer of the Revenue Department, and the required “No Objection Certificates” were obtained from the respective Gaon Panchayats. However, field observations revealed that internal access roads within most kiln premises are neither paved nor stabilized with brick bats. Although all units use crushed coal as fuel and have installed fixed chimneys ranging from 80 to 100 feet in height in accordance with Pollution Control Board guidelines. Only one kiln has adopted measures such as water sprayer to control dust and emissions. Furthermore, approach roads of five brick kilns for transportation raw materials and final product are not hard surfaced. The frequent movement of heavy trucks carrying coal, soil, and bricks has also led to the deterioration of village roads. Additionally, there is a noticeable lack of greenery and tree plantation around the kiln sites.

The Assam Pollution Control Board, Guwahati has laid down specific guidelines regarding the location of brick kilns in the state. According to these norms, kilns should be established at a minimum distance of 500 meters from residential areas with a population exceeding 150 people or more than 20 houses, whether kutchra or pucca. They must also maintain at least a 500-meter aerial distance from public facilities such as schools, hospitals, and other institutions. However, In Palasbari Revenue Circle, it is observed that three brick kilns are situated hardly 400 m away from a Government LP School and five brick kilns are located directly in one village.

7. Sustainable Strategies and Policy Measures for Promoting Sustainable Development in Brick Kiln Industries

- All brick kilns in the Palasbari Revenue Circle continue to depend on conventional production techniques that require high fuel consumption and generate considerable air pollution, thereby contributing to environmental degradation. The adoption of more environmentally friendly technologies can significantly reduce these impacts. It is therefore important for the government to mandate the use of improved methods such as Vertical Shaft Brick Kilns (VSBK) and zig-zag kilns instead of traditional Bull Trench Kilns. These modern technologies are more fuel-efficient, ensure better combustion, and reduce heat loss during the firing process. Their adoption would not only lower pollution levels but also improve the quality of bricks produced.

- Adopting cleaner and alternative fuels, along with better insulation and efficient heat recovery systems, can significantly reduce energy use in brick production. Sustainable approaches also involve utilizing alternative raw materials such as fly ash, stone dust, rice husk, and other industrial by-products, which help limit the excessive removal of fertile soil.
- The government should enforce strict regulations to prevent the conversion of fertile agricultural land into brick kiln sites and ensure that such activities are limited only to areas unsuitable for cultivation.
- Brick production requires considerable amounts of water during molding processes. Implementing water recycling systems, rainwater harvesting, and proper wastewater management can help minimize water wastage and prevent contamination of local water resources
- To promote awareness about environmental impacts and sustainable production techniques Government should arrange different orientation and training programme from time to time.
- Financial incentives, subsidies, and tax benefits can encourage kiln owners to adopt cleaner technologies. These incentives help small-scale operators transition to sustainable production systems.
- There is a need for strict enforcement of environmental policies governing brick kilns, including clearly defined emission limits, effective pollution control strategies, and compulsory environmental clearance before their establishment or operation.

8. Conclusion

The study highlights that brick kiln industries contribute significantly to local economic development and help meet the increasing demand for construction materials. However, their reliance on traditional production techniques leads to considerable environmental damage, including air pollution, high coal consumption, and the depletion of fertile topsoil. These impacts not only degrade environmental quality but also pose serious threats to public health and agricultural productivity in nearby areas. Top of FormBottom of FormThe findings of the

study indicate that the lack of modern technology, inadequate regulatory enforcement, and limited awareness among kiln owners are major factors contributing to unsustainable production practices. Therefore, adopting cleaner and energy-efficient technologies, improving fuel efficiency, and promoting the use of alternative materials like fly ash bricks are essential steps toward reducing environmental impacts. In addition, strengthening environmental regulations, ensuring regular monitoring, and providing training and financial incentives to kiln owners can help encourage the adoption of sustainable practices. Through coordinated efforts from government agencies, kiln owners, and local communities, it is possible to minimize environmental degradation while maintaining the economic benefits generated by the brick kiln industry.

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14
Chapter

Assam: Nature's Canvas and Cultural Mosaic – A Tourism Perspective

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Abstract

Tourism has emerged as a dynamic sector with significant potential to drive economic growth, generate employment, and promote cultural exchange. This study explores the multifaceted role of tourism in Assam, a state rich in natural beauty, cultural heritage, and biodiversity. It examines the global and national context of tourism, highlighting its contribution to GDP and employment, and narrows the focus to Assam's unique offerings—ranging from wildlife sanctuaries and tea gardens to spiritual and adventure tourism. The research identifies key tourist destinations, evaluates the sector's economic impact, and analyzes government initiatives aimed at sustainable development. Despite its promise, Assam's tourism industry faces persistent challenges, including inadequate infrastructure, policy gaps, and security concerns. Using secondary data and descriptive analysis, the study underscores the need for coordinated efforts, policy reforms, and strategic investments to unlock Assam's tourism potential and position it as a premier destination in India and beyond.

Keywords: Tourism, Assam, Employment, Infrastructure, Sustainability.

Introduction

The growing influence of the tourism sector as an economic powerhouse and its potential as a tool for development are irrefutable. Not only does the tourism sector spearhead growth, it also improves the quality of people's lives with its capacity to create large scale employment of diverse kind. It supports environmental protection, champions diverse cultural heritage and strengthens peace in the world.

The word tourism has originated from the French word "tourner", which means "to turn" and the Latin word "tornare" meaning "to fashion" this term, began to be used in English in the 17th century to describe a journey particularly indicating towards the Grand tour which was a traditional trip across Europe, undertaken by wealthy young man for leisure.

In modern language, the word tourism can be described as the temporary movement of people. From the very beginning, the thirst of fascination, exploration of new places and unheard adventures has led the people to move across the globe. It can be described as an outcome of man's craze about adventures and exploration. "Tourism is the sum of the phenomenon and relationship arising from the travel and stay of non residents, in so far as they don't lead to permanent residence and are not connected with any earning activity" (Hunkizen & Krapt, 1942)

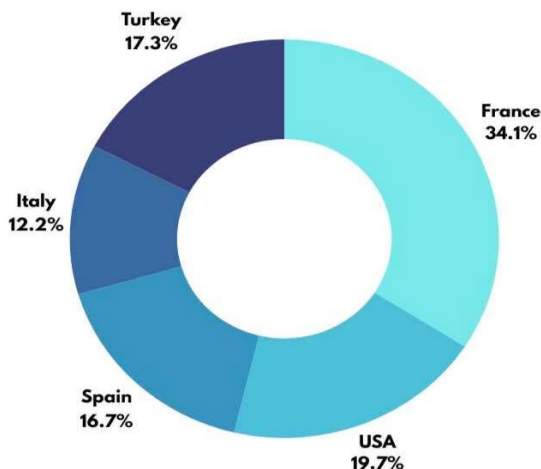
Tourism is not merely a social activity. It has high economic significance, especially in the current world scenario. It is one of the fastest growing sectors of the world economy. This is mainly due to rapid development of tourism infrastructure, high count of tourist inflow and outflows across the globe. World wide "It is a harbinger of economic progress and inclusive development". (Assam gazette. 2022).

Global Scenario of Tourism

Being a labour intensive sector. It is one of the largest job creating industries in the world. In terms of GDP contribution tourism accounts for almost 10% of the Global GDP which is almost equal to 9 Trillion USD in 2019. (Annual Economic Impact Report, WTTC). This data shows the potential of the tourism sector. It is crucial not only for developed nations but also for developing Nations. Tourism has been a driving force in protecting natural and cultural heritage. People specifically visit those historical places for different purposes, including

research, exploration, adventures. Thereby, we can safely say that tourism is an ever expanding industry, having tremendous growth potential and future prospects. The steady rise in the count of domestic and foreign tourist support this statement, In the recent year specifically after the COVID-19 pandemic countries across the globe have been experiencing rapid rise in the average number of foot falls annually, because of all such reasons , countries are currently focusing on strengthening this sector in an integrated manner, so as to maintain the sustainable development and contribute to the economic growth of the nation at the same time.

The following figure shows the top 5 visited countries by tourists in 2023—



The tourism sector employs over 300 million people worldwide, making it a critical driver of employment, among the major destinations including Europe ,China , Thailand, the US remains the top destination by generating over 1.3 trillion USD revenue in 2023. Specifically nations like Maldives , and other Caribbean Nations derive over 30 to 40% of their total GDP out of tourism , making the sector crucial for their economic development. The COVID-19 pandemic led to the 70% dip in international arrival in the year 2020, causing an estimated loss of 4.5 trillion dollars in tourism revenue according to United Nation World Tourism Organisation.(UNWTO) .Although recovery is going on with 2024 projections indicating the return to pre-pandemic level.

Tourism in India

Population wise it's the largest country in the world as a result naturally it has a large market for travel and tourism. India has been recognized as a destination for spiritual tourism for domestic and international tourists as well.

Tourism sector is one of the fastest growing economic sectors with a significant impact on employment and accelerates regional development with a multiplying effect on the activity of related sectors. Among economically advanced states, domestic tourism has become a springboard to the development of tourism. It can generate resources for conservation of cultural and natural heritage and has huge potential to make positive contribution to sustainable development goals. As per the 3rd Tourism Satellite Account (TSA), the study conducted by Ministry of Tourism, estimated share of tourism jobs in India during 2022-23 is 12.57%. The tourism sector contributes 5% to India's GDP, further highlighting its crucial role in the country's economic growth.

In pursuance to the appeal made by the Honourable Prime Minister during Independence Day speech asking every citizen to visit at least 15 destinations by the year 2022, to promote domestic tourism in India, the Ministry had launched the Dekho Apna Desh initiative in January 2020. Dekho Apna Desh is promoted extensively on social media accounts and website of the Ministry and by Domestic India Tourism offices. Under this initiative Ministry has been organizing webinars, quiz, pledge, discussions to keep connected with the stake-holders and to encourage citizens to travel within the country.

Domestic tourism together with Inbound tourism has emerged as a key driver of economic growth. In year 2024, India recorded Foreign Tourist Arrivals (FTAs) of 9.66 million (Provisional) which account for Foreign Exchange Earnings (FEEs) of `2,77,842 crores (Provisional estimates) with a growth of 19.8%. Besides as per the data furnished by State/UT Governments and other information available with the Ministry of Tourism, there were 2509.13 million Domestic Tourist Visits (DTV) all over the country during the year 2023.

Tourism significantly contributes to India's economy, with its share in the Gross Domestic Product (GDP) varying over recent years. According to the most recent reports published

by (Ministry of Tourism and Press Information Bureau) in December 2024 itself , India recorded 10.29 lakh foreign tourists arrival, generating a huge revenue of 32,788 crore INR. It shows the growing potential of this sector

Tourism in Assam

North-East India is a paradise for tourists. Its enchanting hills, dancing rivers, roaring waterfalls, thick and dark forests, heavy rains during monsoon, innumerable varieties of flora and fauna, countless species of wild animals and plants, mysterious clouds, melodious folk music, thrilling dances and festivals, variety of many delicious dishes, handlooms and handicrafts, and above all its green landscape used to attract people from different parts of the world since time immemorial. Assam, one of the constituent states of the region, an embodiment of the natural beauty and grace, a true representative of the region, has been at the centrestage of tourist attraction.

The recorded history tells that since the days of Hieu-en Tsang, the great Chinese traveller, who came to Assam during the reign of Kumar Bhaskar Burman (594-650 AD), Assam has been fascinating millions of people by its aura of myths, mystery, music, mountains, nay, all the gifts of nature. The ungrudging blessings of nature have made tourism in Assam essentially nature-centric, despite the fact there are historical and religious places of tourist attraction.

Tourism has generated employment in different parts of the country. Besides creating opportunities for tourist guides, conducted tours, establishment of hotels, and so many other avenues in the tertiary sector, tourism can be a major source of employment in Assam. It is argued that every domestic tourist can generate direct and indirect employment of three persons, and this can be higher (seven) in the case of inflow of every foreign tourist. It is also projected that every one million rupees invested in tourism, 47.9 direct jobs can be created, besides, of course, creating more avenues for indirect employment.

Tourism Potential in Assam

Existing places of tourist attraction

Tourism in Assam is essentially nature based, therefore, natural parks and sanctuaries, rivers, lakes, warm water springs, forests, wild life, are the principal components of tourist attraction.

These places can be grouped together under four categories: (a) nature related, (b) historical, (c) religious and (d) others.

It is noteworthy that the tourists visit Assam throughout the year. But the peak period starts from October when the rainy season comes to an end, the climate becomes more pleasant and the national parks like Kaziranga are opened for the visitors. The peak period continues till April when the national parks are closed due to rain and other accompanying problems. The rising number of tourists footfalls within the period from 2018-2023 is shown with the help of line diagram.



Source: Assam Tourism Development Corporation, 2023-24

Tourism continues to be a significant driver of employment and economic growth in Assam. Recent data from the Assam Tourism Development Corporation indicates that in the fiscal year 2023-24, the state welcomed 7,041,206 domestic tourists and 26,129 international tourists. This influx of visitors has directly boosted up employment in sectors such as hospitality, transportation, and tour services. The establishment and expansion of hotels, resorts, have created numerous jobs for administrative staff, culinary professionals etc.

Additionally, the increased tourist movement has raised the demand for local transport operators, including taxi services, bus operators, and rental agencies, thereby generating employment for drivers and support staff.

Development Initiatives

Apart from famous locations like Kaziranga National Park , Manas National Park etc , there are other places where the tourism Industry in spite of having huge potential, is still under developed. For the development of such areas huge emphasis has been given on the advancement of circuits, destination wayside amenities etc. Moreover, various other tourism policies have also been adopted by the government of Assam over the years. It includes National Tourism policy of 2002, 2008 and 2017. All these policies mainly focused on making Assam a global tourist destination by achieving sustainable development, promoting public private partnership, and developing infrastructure. And finally by preserving the rich cultural heritage of Assam, although both the tourism policies promised a lot but, in reality. These promises are far away from being implemented properly, this policy basically included objectives like enhancing the contribution of tourism in Assam's economy, maximizing the number of footfalls of tourists and enhancing the infrastructure at par with international standards with potential sectors like river tourism, tea tourism etc. And most importantly to ensure sustainable, responsible and inclusive development of tourism in the state.

The state's commitment to Eco tourism is exemplified by different initiatives. Like the Gethsemane Man-Made Forest in Bhairav Kunda, this massive community led project transformed 5500 bighas of barren land into a lush forest such endeavours , attracting nature enthusiasts and establishing a fundamental relationship between tourism and environmental conservation.

Objectives of the Study

The main objectives of the study are as following:

1. To focus on the prospect of Tourism industry in Assam.
2. To analyze the challenges faced by tourism sector in Assam.
3. To find out the contribution in income and employment generation.

Methodology

This study is based On descriptive research method and undertakes secondary data into account. Here data are presented using tabulation method and the comparisons are

done using various statistical diagrams. To get an overview of the Indian tourism industry, various research papers, reports, government websites, articles are explored in detail. Following are the source of information of the study-

1. Reports of various government departments.
2. Special supplements published by news papers / magazines etc.
3. Other relevant online publications etc.

Analysis

Tourism Potential

Existing places of tourist attraction

Tourism in Assam is essentially nature based, therefore, natural parks and sanctuaries, rivers, lakes, warm water springs, forests, wild life, are the principal components of tourist attraction. These places can be grouped together under four categories:

- a. Nature related,
- b. Historical,
- c. Religious and
- d. Others.

a. Nature related

Sl. No.	Places in alphabetic order	Distance from Guwahati in km	Speciality
1	Bhairabkunda	137	A beautiful place at the border of Arunachal Pradesh
2	Bhalukpong	205	A beautiful place by the side of river Jia Bhoroli, famous for angling and water sports
3	Chandubi	64	A natural lagoon, beautiful picnic spot
4	Dibru-Chaikhowa	490	70 km from Dibrugarh, national park, the habitat of elephants, buffaloes, famous for wild horses
5	Haflong	355	One of the hill stations in Assam with unsurpassed sylvan beauty

6	Jatinga	364	Near Haflong, North Cachar district, a beautiful hilly place, where birds behave in a mysterious way, the local people call that the birds commit suicide here on certain specific days
7	Kaziranga	217	Internationally famous national park, the home of great Indian one-horn rhinoceros, tigers, elephants, buffaloes, deer, wild ducks and geese, breeding place of pelicans, habitat of reptiles and monkeys more particularly golden langurs and host of other species
8	Manas	176	Situated in the foothills of the Himalayas, one of the magnificent national parks in the country, the Manas river flows through it, famous for the tiger project, a habitat for various wild animals
9	Orang	150	A wild life sanctuary, known as a miniature Kaziranga
10	Pabitara	65	A wild life sanctuary
11	Potasoli	173	38 km from historic town of Tezpur, near the picturesque river Jia Bhoroli, famous for eco-camp set up jointly by the Department of Forest and Assam Anglers Association.
12	Son Beel	331	Famous for its fishery and it is one of the main producers of fish for the entire district in southern Assam. Son Beel is best visited during rainy season that is March onwards till the beginning of winters. Till then the lake is full of water and offers a view that is hard to find elsewhere.

Source: Directorate of Tourism, Guwahati

b. Religious Related

Sl. No.	Places in alphabetic order	Distance from Guwahati in km	Speciality
1	Barpeta	137	Famous for a Vaishnava monastery
2	Batadrawa	134	Birth place of Shri Sankardeva, the Vaishnava reformer, saint and a great literary figure
3	Hajo	35	Sacred place for Hindus, Muslims and Buddhists
4	Kamakhya		An important religious place of the Hindus within the city of Guwahati, on the top of Nilachal hill, attracts thousands of devotees and other tourists every day by its natural grandeur
5	Madan Kamdev	35	Vast archeological ruins of fine erotic sculpture
6	Majuli	326	The largest river island in the world, centre of Vaishnava culture, seat of many satras which are known as the centres of Assamese art, dance, drama, music, a safe heaven for various migratory birds
7.	.Surya Pahar	162	Situated on a hill surrounded by innumerable statues of Durga Devi, Ganesha, Surya, Chandra, Buddha

Source: Directorate of Tourism, Guwahati

c. Historical

Sl. No.	Places in alphabetic order	Distance from Guwahati in km	Speciality
1	Digboi	523	Famous for the first oil refinery in Asia, war cemetery of World War II
2	Sibsagar	369	Seat of the Ahom rule, famous for royal palaces, monuments, temples and massive ponds
3	Tezpur	137	Ruins of an ancient capital of the Mahabharata time, famous for the love story of Usha-Anirudha

Source: Directorate of Tourism, Guwahati

d. Others

- i. Guwahati : The places of worth visiting are: the famous Shakti 205 temple of mother Goddess Kamakhya on the Nilachal hills, the ancient Siva temple Umananda situated on the Peacock island in the middle of the river Brahmaputra, the Navagraha temple, Srimanta Sankardeva Kalakshetra, Balaji temple, Science Museum, Vaisisthashram (founded by famous sage Vaisistha amidst grand natural beauty), the State Museum, the State Zoo-cum-Botanical garden, the Saraighat Bridge, the Lachit Barphukan Park etc.
- ii. Sualkushi : 32 km from Guwahati, known as the silk town of Assam, it is famous for Assamese silk, muga (golden thread) and other varieties of silk.

Potential to Attract Tourists of Diverse Interests

There is an ample scope for tourism to grow as an industry in with it diverse endowments of tourist interests. The following are the existing and potential variety of tourism:

a. Nature Tourism

Assam and its seven neighbouring states of the North-East are known for their bio-geographic richness (Coopers and Lybrand Report, 1996, p. 49). With its dense forests, uneven topography,

flora and fauna, the majestic Brahmaputra and its tributaries, wild life sanctuaries like Kaziranga, Manas, Pabitora, Dibru-Saikhowa, Bhalukpong, Pabitora and similar others, and many rare species of animals, Assam offers basically nature-centric tourism. From one end to the other, the state offers to the tourists so many places of natural beauty with wide variety of wildlife that very few places in the world can compete with it. Nature tourism understood in terms of wildlife sanctuaries constitutes the core of tourism in Assam. The tourists, both domestic and foreign, are likely to find these places attracting, nay alluring, provided a well-definite programme of action is evolved.

b. Tea Tourism

Tea was first discovered in Assam in 1823 by two intrepid British adventurers, Robert and Charles Bruce and since then tea has become an integral part of Assam's economy. Each of these lush green tea gardens in Assam (about 1000 in number) is a treasure house of exotic beauty of nature with colourful people and their enchanting songs and dances, sprawling bungalows, and residential facilities. Many of these tea gardens have polo fields and golf courses. There are as many as 30 air strips and helipads maintained by the tea garden management. These facilities can form into an attractive package for tourism. The road communication to most of the tea gardens is fairly well maintained, and the rest houses and bungalows with modern facilities located there are generally kept ready for visitors and guests. Therefore, coordination with the management of the tea gardens can effectively do a lot in promoting tea tourism in the state. It may be noted that tea tourism is a recent concept, its potentiality, remains unexplored.

c. Eco-tourism

Eco-tourism is also a new concept, developed around the idea of travelling to places of natural beauty, moving around and staying with the places of nature for a couple of days. It has the twin objectives of conserving environment and improving the welfare of the local people. Countries like Kenya, Costa Rica, South Africa have already successfully promoted eco-tourism. Kerala presents a unique success story of eco-tourism in our country. On this similar line, Assam has immense scope for eco-tourism, as its natural scenario and climatic condition resemble those in Kerala. The state is virtually free from industrial pollution. Its green forests, blue hills, enchanting rivers are the

basis on which an eco-friendly tourism can be developed. For that a host of matters to be properly addressed, including:

- i. development of good approach road to the spots of tourist attraction,
- ii. creation of infra-structural facilities like good quality tents with provisions for food and other logistics,
- iii. river cruising and water sports, bird watching towers etc. These facilities are likely to attract eco-tourists. It may be noted that eco-tourism is yet to come to the take-off stage.

d. Cultural Tourism

Assam is a conglomeration of various ethnic tribes and groups each having a distinct language, culture, way-of-life, festivals, songs and dances. Most of these people have their spring festivals. Songs and dances, display of colourful dresses, tasting of innumerable varieties of both vegetarian and non-vegetarian dishes mark these festivals. Sankardev Kalakhetra, Guwahati, has been organising, in recent years, spring festivals, on the line of the desert festival of Rajasthan, the Rangali Utsav in the month of April in which the various colourful shades of Assam are presented. This could be as big an attraction as the Pushkar Mela in Rajasthan.

e. Pilgrim Tourism

Assam has many ancient temples and shrines, some of which like Kamakhya date back to pre-historic time. As stated already Kamakhya is one of the most revered religious places in the country. An average of 1000 visitors visit the Kamakhya temple every day throughout the year. It becomes a centre of attraction in the month of June when it celebrates the Ambubachi mela. At that time more than hundred thousand pilgrims come for pilgrimage from different places of India. Situated on a hill top Kamakhya is also a very beautiful place that attracts many tourists. There are other religious places where visitors often come from different parts of the country. But most of the places do not provide adequate facilities to the tourists and pilgrims, for which these places of religious importance fail to attract a large number of tourists.

f. Adventure Tourism

The enchanting blue hills and speedy rivers of Assam provide an enormous scope for the development of adventure tourism.

Recently, some of the adventure sports activities like rock-climbing, trekking, para-sailing, water sports, river rafting and angling are promoted by the Department of Tourism. There is an annual angling competition held at Bhalukpung Potasali side every year in November in which Indian and foreign tourists participate. But other areas of adventure tourism like hang gliding are yet to grow. Assam has a number of ideal places like Nilachal hills (where the Kamakhya temple situated) in the city of Guwahati and the hills around Kaziranga. Since most of the tourists come to the state through Guwahati and visit Kaziranga, there is an enormous scope for hang gliding.

g. Golf Tourism

There are about 10 golf courses located mostly within the compact areas of tea gardens. The Oil India maintains a very good golf course in the industrial town of Duliajan. These offer a unique opportunity to develop golf tourism in the state. Most of the courses are located near to air-strips and helipads maintained by the tea garden management. In recent years, domestic and foreign tourists are coming to play golf in different golf courses, and a good number of them use these air-strips and helipads. Golf tourism can be integrated with eco and tea tourism. One has to recognize that some tourists may more than one interest and may like to combine various aspects of tourism described above.

Challenges of Tourism sector in Assam

However Assam has a significant prospective for producing income and employment opportunities, but even then, no appreciable change has been seen due to some complications in this sector.

- a. Deficiency of well-developed Tourism Policy:** A policy on tourism has prepared in Assam in November 1987. Unfortunately, this policy is not available in any of the offices related to tourism. But these steps did not bring ahead any definite result. The State still has no any satisfactory tourism policy.
- b. Restricted Area Permit:** The RA to the North-Eastern region was enforced in 1955, under which, a foreigner intending to visit North-East including Assam had to undergo a long arduous procedure of obtaining permission from the Home Ministry. RAP was in force till May 18, 1999, and the presence

of RAP still continues to loom large and create false anxiety in the mind of the foreign tourists.

- c. **Insurgency:** The problem of insurgency hampered all the development work and has become the drawback in every development strategy of the state. Bandh, strikes, curfews, kidnapping, killing and extortion converted as the structure of a day. The foreign and domestic tourists consider it risky to visit this part of the country, in view of prevailing law and order situation.
- d. **Lack of Basic Infrastructure:** To attract tourists and promote tourism infrastructural facilities, well-founded communications, circulation of information, availability of equipment for different sports activities etc. are needed. Most of the places of tourist attraction are not by the side of the nationals' highways, and approach roads are in bad condition. This is a strong discouraging factor, which works against a good inflow of the tourists.
- e. **Lack of coordinated Efforts:** For development of tourism industry properly, there should be proper coordination among all the agencies related to the industry. Special focus should be given on partnership of public and private to tap the undeveloped potential opportunities. But the coordination among the agencies that are associated with tourism is not effective and appreciable enough in Assam.
- f. **Need of Trained tourist Guides:** Practically Assam does not have trained guides in important places of tourist attraction. As a result, there is barely someone to satisfy the curiosity of the tourist, as the tourists arrive at such a place. The Department of Tourism initiated a program to train tour, but the effort does not yield good result.
- g. **Problem related to finance:** The local entrepreneurs are not getting proper financial assistance from government, bank and other financial institutions. The financial institutions are interested to provide financial assistance mainly to industrial undertaking. These institutions have common notion that state tourism sector is not in a viable position to earn profit.
- h. **Lack of basic facilities at tourist destination:** Facilities which are basic to attract tourist are still very much lacking almost all tourist spots of this study. These include basic

services such as pure drinking water, cafeteria, 24 x 7 hours electricity supply, well maintained and clean waiting rooms and toilets, first aid and wayside facilities such as lounge, and parking facilities etc.

- i. **Cluster proposal towards tourism:** The perception of tourist places in Assam is not set up even among the people of the state. There are hardly any proper organizations working towards the goal of commercializing and bringing pride to Assam's tourism.
- j. **Catering to the needs of local masses:** Problems like traffic, crowd, poor infrastructure, pollution, littering, underdevelopment, crime etc. are not just the problems of the tourists but also affect the local population residing in and around of the destination.

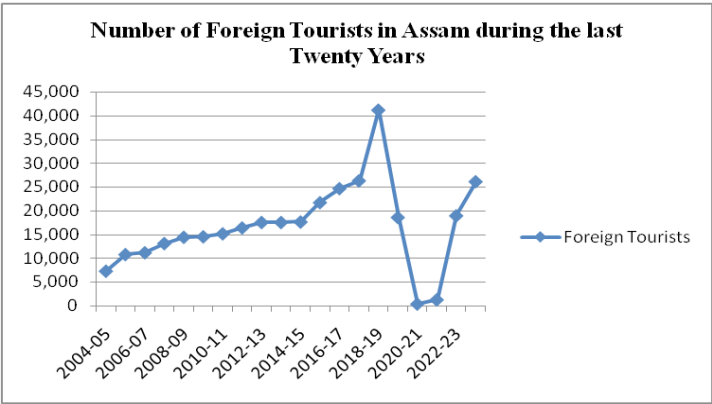
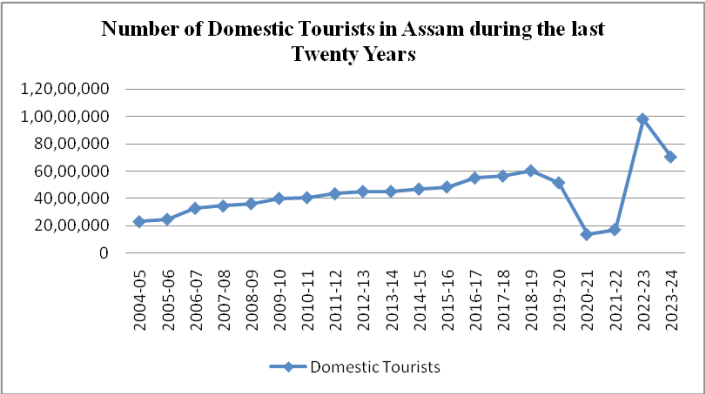
Tourism and Its Contribution to Economic Development

The importance of tourism industry in economic field grows rapidly each and every passing year. Assam is well blessed by nature, and it lays at the center of one of the world's richest biography areas. Sources revealed that revenue collected from tourism increase year by year, and it directly helps in economic development of Assam. Assam is well known for its cordial behavior for all visitors, whether they come from any place across the world. The development of the tourism sector can increase economic growth directly and also increases domestic incomes and effective demand by stimulates the growth of other related sectors through backward and forward linkages. This sector can contribute to economic development of the State positively. The following table shows the inflow of both domestic and foreign tourists to the state. The table reveals an increasing trend of both Indian and foreign tourist inflow

Table 5.1: Number of Domestic and Foreign Tourists to Assam.

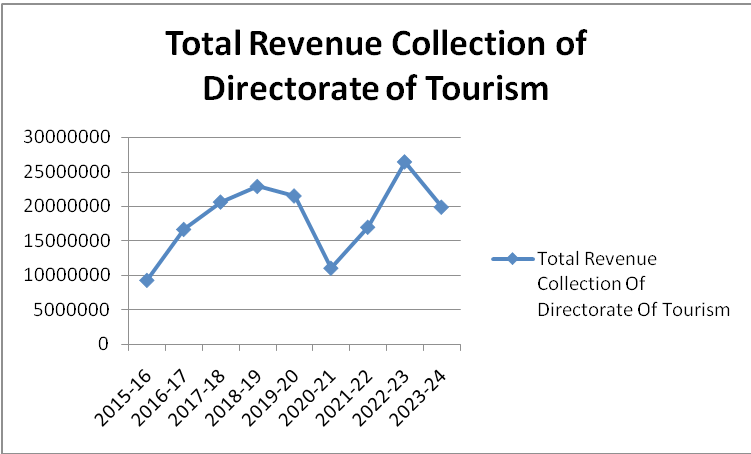
Year	Domestic Tourists	Foreign Tourists
2004-05	22,86,630	7,285
2005-06	24,67,656	10,782
2006-07	32,68,657	11,151
2007-08	34,36,484	13,105
2008-09	36,17,306	14,426
2009-10	39,98,706	14,533
2010-11	40,50,924	15,157

2011-12	43,39,485	16,400
2012-13	45,11,407	17,542
2013-14	45,11,407	17,542
2014-15	46,84,527	17,638
2015-16	48,35,492	21,725
2016-17	54,91,507	24,673
2017-18	56,42,950	26,320
2018-19	60,27,002	41,209
2019-20	51,46,307	18,594
2020-21	13,51,690	347
2021-22	17,01,701	1,231
2022-23	98,12,195	18,946
2023-24	70,41,206	26,129
2024-25		



Revenue Collection of Directorate of Tourism in Assam

Year	Total Revenue Collection of Directorate of Tourism
2015-16	9213492.00
2016-17	16606650.00
2017-18	20576627.00
2018-19	22843279.00
2019-20	21461173.00
2020-21	10971743.00
2021-22	16918063.00
2022-23	26409895.00
2023-24	19838168.00



From table 2 and figure we can see the growing trend of tourist inflow in the state as well as the revenue collection also in an increasing trend. It also depicts a picture of huge inflow of tourist in future and great earning source of the state. This sector has a great potentiality of employment in the state.

Share of tourism in GDP and Employment Generation

The tourism industry is a wind farm, generating several employment opportunities that positively smash global economies and societies. In India employment generation through tourism is a determining factor of economic growth. The industry creates multiple job opportunities across distinct skill levels, availing both urban and rural areas. These functions range from hotel staff and tour guide to crafts person and

entrepreneurs. In the financial year 2020 Travel and tourism sector in India come up with employment to nearly 80 million people and Making up of five percent of the country's GDP. In 2021, around 5.8% contributed to the total GDP of the country which amounted to over 13 billion Indian rupees. As per the report of WTTC (World Travel and Tourism Council) in 2022 travel and tourism industry contributes worth Rs 15.7 trillion to India's economy and 37.2 million people was employed in this sector. As per the 3rd Tourism Satellite Account (TSA), 2015-16, the percentage contribution of tourism sector to the country's Gross Domestic Product (GDP) for 2015-16 to 2022-23 is given below:

Tourism GDP	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22	2022-23
Total Share in GDP (in %)	5.09	5.04	5.02	5.01	5.18	1.50	1.75	5.00
Direct (in %)	2.65	2.62	2.61	2.61	2.69	0.78	0.91	2.60
Indirect (in %)	2.44	2.42	2.41	2.40	2.49	0.72	0.84	2.40

Assam is the most vibrant of eight states comprising the Northeast; the state is a treasure trove of natural beauty and diverse history. Assam in particular has vast tourism potentials, which are to be explored yet. It is necessary to get adequate investment and attached and correlated efforts from the entire concern department to explore tourism potentials. With the great potentialities of tourism sector in Assam it contributes various economic benefits to the economy of the State. Assam's tourism sector contributes to state GDP around 5.5%, and it also has been providing approximately 10.5% of the total employment of the state. For the development of the tourism sector in Assam, the challenges should be removed. Tourism infrastructure is inadequate in the state, so by providing good transport and communication and making sufficient provision for accommodation of the tourists at and near the tourist spots with all types of civic facilities the states can earn massive amount of income from tourist sector.

Conclusion

Today, the tourism business is one that is both leading and emerging globally, and some people even rank it as the top industry. Traveller demands have always changed as a result of demographic, sociostructural, and sociocultural trends, and service providers in the tourism industry must make significant adjustments. The latent vulnerability of tourism as a boom sector has been well illustrated by war and tourism, bad weather, the ongoing globalisation of tourism, and the ageing of society (which is becoming more and more visible in the public consciousness). The current report offers a thorough examination of the advantages, disadvantages, possibilities, and risks facing Assam's tourist industry. This provides a comprehensive picture of the current situation regarding performance and its many stages. Right now, a well-thought-out design and plan for every traveller is important. Therefore, a successful and efficient marketing plan would have a profoundly revolutionary effect on Assamese tourism.

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Chapter

Impact of Cyber Security in the Digital Economy

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Abstract

As the whole world turns into digital, so the technological devices have impacted nearly every part of our lives. The uses of these devices are growing very rapidly to simplify our day to day lives that directly proportional to the growth of Digital Economy. Resultant, exponential growth of the international economy and interconnections of global landscape. However, others side of the coin, is also being misused for these technological devices that give birth to cybercrime. Since digital technology align with business strategy so cyber security is not only the responsibility of IT department only, it also the responsibility of each individual employee to maintain the growth of Digital Economy. To resolve the issues of cybercrime Cyber forensic plays vital role in this society. This paper provides the awareness knowledge of dynamic development of digital economy and, how cybercrime effect the growth of digital economy. Moreover, this paper also discusses about the overview of different forensic investigation methodology in perspective of cyber forensic investigator which allows law enforcement, private detectives, and cyber security experts to reveal digital action after a cyber event.

Keywords: *Digital Economy, Cybercrime, Cyber Security, Cyber Awareness, Forensic Investigation Tools.*

1. Introduction

The rapid growth of digital technologies is impact on the global world, giving birth to a interlinked digital economy. So Journey from online banking to cloud computing via e-commerce using of different smart devices, change our life to modern life, Upgrading efficiency, accessibility, and economic growth. Therefore, we have been very familiar on digital systems, and resultant significant challenges in the form of cyber threats, data breaches, and privacy concerns. Consequently, cyber security and data protection have become essential priorities for individuals, organizations, and governments across the globe.

The various form of cyber crime has been rapidly growing and targeting different individual, Government and non government organization officials. Due to this crime, not only cause financial loss but also rescinded the trust on technology which directly impact on our digital economy. To resolve these issues, it is considerable to understand the different types of cyber crime, risk associated with this crime and the challenges for securing digital environment.

In this regards, cyber forensics plays a vital role such as providing the tools and methodologies required to investigate cyber incidents and uncover digital evidence. The main steps for Cyber forensic are detecting, analyzing, and responding to cybercrimes. It also supporting legal proceedings.. For this proceeding one forensic investigation team will be allotted to investigate team that is very much familiar with FSL and CFSL. Their systematic investigative procedure ensure that digital evidence is handled with integrity and can be used effectively in legal and regulatory contexts.

This paper focuses on main impacts of cybersecurity in the domain of digital economy with special focus on cybercrime and its types, challenges faced in data protection, risk assessment strategies, and the role and investigation team of cyber forensic investigators. In this research, it has been providing a brief overview of the domain, the paper aims to highlight the importance of cybersecurity awareness and forensic readiness n to ensure secure and sustainable growth of the digital economy.

A. Motivation

The reason behind this research is to analysis the dynamic relationship between cybercrime and digital economy, while special focus on the crucial role of cyber forensic investigation team to ensure the maintain of CIA (Confidentiality, Integrity and Accessability) so that trust in the digital ecosystem consistent. This paper aims to raise awareness and provides awareness of the continuous growth of the digital economy through robust forensic and cybersecurity practices.

B. Issues and Challenges

The rapid growth of the digital economy has introduced numerous cybersecurity and data protection challenges that influence individuals, governments and non government organizations. These challenges grows geometrical progress due to technological advancements and digital dependency.

1. Increasing Advancement of Cyber Attacks

Cyber threats are becoming more technicality, including ransomware attack, phishing, vishing, Advanced Persistent Threats (APTs), and zero-day attacks. Attackers are utilizing automation such as AI and social engineering techniques to bypass established security mechanisms.

2. Data Privacy and Authentication

The classification of private and sensitive data raises significant challenges. Unauthorized access, data breaches, and misuse of personal information can lead to identity theft, financial fraud, and reputational damage.

3. Lack of Digital Literacy

Human emotions is one of the weakest links in cybersecurity. Unawareness about password setting, phishing attacks, vishing attacks, digital arrests and negligence about classification of data such as handling data increase the risk of security breaches.

4. Rapid Growth of Internet of Things(IoT) and Connected Devices

The expansion of Internet of Things (IoT) devices has increases the probable of attack. Different cheap IoT devices has lack of security features, resulting vulnerable to exploitation and large-scale attacks such as botnets.

5. Deficiency of Cybersecurity Infrastructure

Many organizations, especially small and medium enterprises (SMEs) used old version of software and hardware devices, not used proper antivirus, firewall. Due to resources constraints, skilled staffs, and advanced tools to implement effective cybersecurity measures.

6. Inequality of laws and Compliance Challenges

Different countries have their different data protection laws and regulations, making complex compliance for global organizations. The digital agreement among all the countries are not same.

7. Insider Threats dishonesty and fraud

Employees within the organizations may access intentionally or unintentionally compromise data security. To detect and prevent insider threats is very challenging due to trust and access advantages.

8) Risks for Cloud Data

Now all the data we store in the cloud, cloud is very concern about data storage, access control, multi-tenancy, and third-party dependency. So there is chances of misleading data if high security is not implemented.

9. Lack of a standard policy for cyberforensic practices.

The cyberforensic investigation tool often faces challenges such as lack of standardized procedures, jurisdictional issues, and difficulties in collecting and preserving digital evidence.

10. Cross-Border Cybercrime and Jurisdiction Issues

Cybercrimes often cross national boundaries, and make investigation and prosecution challenging due to differences in legal frameworks and lack of international cooperation.

11. Emerging Technologies and Unknown Threats

Latest technology, such as artificial intelligence, blockchain, and quantum computing, introduces new vulnerabilities and unknown risks that require continuous adaptation of security strategies.

12. Cost and Resource Constraints

Implementing robust cybersecurity measures requires significant investment in technology, training, and infrastructure, which may not be feasible for all organizations.

2. Cybercrime and its Type

Cybercrime defined as a crime related to illegal activities that are carried out using computers, digital devices, or networks as a weapon or target or both. In today's digital economy, where most of the transaction happen in online with the help of technology such as banking, communication, education, and business operations are conducted online, cybercrime has emerged as a serious global concern. It not only causes financial losses but also threatens privacy, data security, and national security.

The increasing dependence on digital platforms has made individuals and organizations more vulnerable to cyber threats. One major category of cybercrime is crimes against individuals, which primarily target personal information and privacy.

These include identity theft, where attackers steal sensitive personal data for fraudulent purposes, and phishing attacks, where users are tricked into revealing confidential information through fake emails or websites. Cyberstalking and online harassment are also common, causing psychological distress to victims. Such crimes exploit human vulnerabilities and lack of awareness.

Another important category is crimes against property, which involve unauthorized access, damage, or theft of digital assets. Hacking is one of the most common forms, where attackers gain unauthorized entry into systems or networks. Malware attacks, including viruses, worms, and Trojans, are used to disrupt or damage systems. Ransomware is a growing threat that encrypts user data and demands payment for its release. Intellectual property theft, such as software piracy and illegal distribution of digital content, also falls under this category.

Cybercrimes against organizations target businesses, institutions, and government bodies, often with the aim of financial gain or operational disruption. Data breaches are a major concern, where confidential information of customers or employees is exposed. Denial of Service (DoS) and Distributed Denial of Service (DDoS) attacks disrupt services by overwhelming systems with traffic. Insider threats, where employees misuse their access privileges, and corporate espionage, involving theft of sensitive business information, also pose significant risks.

Crimes against society represent a broader category that affects public order and national security. Cyber terrorism involves attacks on critical infrastructure to create fear and instability. The spread of fake news and misinformation through digital platforms can influence public opinion and create social unrest. Illegal online activities such as gambling, trafficking, and distribution of harmful content also fall under this category.

Financial cybercrimes are specifically aimed at monetary gain and have increased significantly with the rise of digital transactions. These include online banking fraud, credit and debit card fraud, e-commerce scams, and cryptocurrency-related frauds. Attackers use sophisticated techniques to exploit vulnerabilities in financial systems and deceive users into transferring money or revealing sensitive financial information.

With the advancement of technology, new and emerging forms of cybercrime are continuously evolving. These include AI-based attacks such as deepfakes and automated phishing, IoT-based attacks targeting connected devices, and cloud security breaches. Social engineering attacks, which manipulate human behavior to gain unauthorized access, are also becoming more prevalent.

In conclusion, cybercrime is a complex and rapidly growing threat in the digital age. Its diverse types affect individuals, organizations, and society at large. Understanding these categories is essential for developing effective cybersecurity measures and implementing cyber forensic techniques to detect, prevent, and investigate cyber incidents.

3. Risk Assessments in Cyber Security for Digital Growth

Risk assessment in cybersecurity is a systematic process of identifying, analyzing, and evaluating potential threats and vulnerabilities that can affect digital systems, data, and infrastructure. In the context of digital growth, where organizations increasingly rely on technology for operations, services, and innovation, risk assessment plays a crucial role in ensuring secure and sustainable development. It helps organizations understand their risk posture and implement appropriate safeguards to protect digital assets.

The first step in cybersecurity risk assessment is the identification of assets and potential threats. Assets may include sensitive data, software systems, hardware infrastructure, and network

resources. Threats can arise from various sources such as cybercriminals, insider attacks, malware, phishing, and natural disasters. Identifying these elements is essential to understand what needs protection and from whom.

The next stage involves identifying vulnerabilities within the system. Vulnerabilities are weaknesses that can be exploited by attackers, such as outdated software, weak passwords, misconfigured systems, or lack of proper security controls. Regular vulnerability assessments and penetration testing are important to detect these weaknesses before they are exploited.

Risk analysis is then conducted to determine the likelihood and impact of potential threats exploiting identified vulnerabilities. This step evaluates how severe a risk could be and how often it might occur. Risks are often categorized as low, medium, or high based on their potential impact on business operations, financial stability, and reputation.

Following analysis, risk evaluation and prioritization are carried out. Organizations prioritize risks based on their severity and focus on addressing the most critical ones first. This ensures efficient allocation of resources and timely implementation of security measures, which is particularly important for organizations undergoing rapid digital transformation.

Risk mitigation involves implementing appropriate security controls and strategies to reduce or eliminate identified risks.

These may include technical measures such as firewalls, encryption, intrusion detection systems, and multi-factor authentication, as well as administrative controls like security policies, employee training, and incident response planning.

Continuous monitoring and review are essential components of cybersecurity risk assessment. As technology evolves and new threats emerge, risks also change over time. Regular monitoring, auditing, and updating of security measures help organizations stay resilient against evolving cyber threats and ensure ongoing protection.

In the context of digital growth, effective risk assessment not only safeguards data and systems but also builds trust among users, customers, and stakeholders. It enables organizations to innovate confidently while maintaining compliance with legal and regulatory requirements. Thus, cybersecurity risk assessment is a foundational element for achieving secure and sustainable digital transformation.

4. Role of Cyber Forensic Investigator in Digital Economy

In the rapidly expanding digital economy, cyber forensic investigators play a crucial role in maintaining security, trust, and accountability across digital platforms. As businesses, financial systems, and communication networks increasingly rely on digital technologies, the occurrence of cybercrimes such as data breaches, fraud, and unauthorized access has also grown.

Cyber forensic investigators are responsible for identifying, collecting, analyzing, and preserving digital evidence to investigate such incidents and support legal proceedings.

One of the primary roles of a cyber forensic investigator is evidence collection and preservation. They ensure that digital evidence from computers, mobile devices, networks, and cloud systems is collected in a legally admissible manner without altering its integrity. Maintaining the chain of custody is essential so that the evidence can be presented in court without any challenge to its authenticity.

Another important responsibility is the analysis of digital evidence. Investigators use specialized tools and techniques to examine logs, files, network traffic, and system activities to reconstruct the sequence of events leading to a cyber incident.

This helps in identifying the source of the attack, the methods used, and the extent of the damage caused.

Cyber forensic investigators also play a key role in incident response and recovery. They work closely with cybersecurity teams to contain breaches, mitigate damage, and restore affected systems. Their findings help organizations understand vulnerabilities and prevent future attacks by improving security measures.

In the digital economy, financial transactions and online services are highly vulnerable to fraud. Cyber forensic experts assist in fraud detection and investigation by tracing illegal transactions, identifying fraudulent activities, and supporting financial institutions in resolving disputes. This helps in maintaining trust in digital financial systems.

Legal support is another significant role of cyber forensic investigators. They prepare detailed forensic reports and may act as expert witnesses in court, explaining technical findings in a clear and understandable manner. Their work assists

law enforcement agencies in prosecuting cybercriminals and ensuring justice. Furthermore, cyber forensic investigators contribute to policy development and compliance. Their insights help organizations design better security policies, adhere to regulatory requirements, and implement best practices for data protection. They also conduct awareness programs and training to educate employees about cyber threats and safe digital practices.

In conclusion, cyber forensic investigators are essential in ensuring the secure functioning of the digital economy. By uncovering cybercrimes, supporting legal processes, and strengthening cybersecurity frameworks, they help build a safe and trustworthy digital environment that supports continuous economic growth.

A. Methodology of cyber forensic Investigator

Cyber forensic investigation follows a systematic and structured methodology to ensure that digital evidence is properly identified, collected, analyzed, and presented in a legally admissible manner as shown in the figure 1.

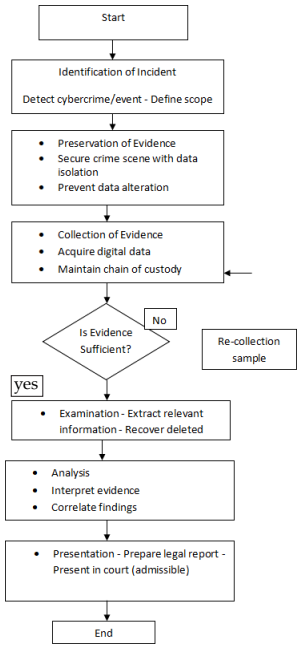


Fig. 1. Cyber Forensic Investigation Process

This process is essential for maintaining the integrity of evidence and supporting legal and organizational decision-making in the digital economy.

The first stage is identification, where the investigator determines the scope of the incident and identifies potential sources of digital evidence. These sources may include computers, mobile devices, servers, network logs, cloud storage, and other digital media. Proper identification helps in defining the objectives and direction of the investigation.

The next step is preservation, which involves securing and isolating the digital evidence to prevent any alteration, damage, or loss. Investigators create forensic copies (bit-by-bit images) of storage devices instead of working on the original data.

Maintaining the chain of custody is crucial at this stage to ensure that evidence remains authentic and admissible in court. Following preservation is the collection phase, where relevant data is acquired using specialized forensic tools and techniques. This may include extracting files, system logs, metadata, and deleted data. The process must be carried out carefully to avoid contamination or modification of evidence.

The examination phase involves processing the collected data to identify relevant information. Investigators filter, recover, and organize the data to make it suitable for analysis. Techniques such as keyword searching, file carving, and timeline reconstruction are commonly used during this phase.

Next is the analysis phase, where the investigator interprets the examined data to reconstruct events and draw conclusions. This includes identifying the attack vector, understanding the behavior of the attacker, determining the impact of the incident, and linking the evidence to specific individuals or activities.

The documentation and reporting phase is critical, as investigators prepare a detailed report outlining the procedures followed, tools used, findings, and conclusions. The report must be clear, accurate, and legally sound so that it can be understood by non-technical stakeholders such as lawyers and judges.

Finally, the presentation phase involves presenting the findings in a court of law or to organizational authorities. The investigator may act as an expert witness, explaining the evidence and methodology used during the investigation in a simple and credible manner.

In conclusion, the methodology of cyber forensic investigation ensures a structured approach to handling digital evidence. By following these steps—identification, preservation, collection, examination, analysis, documentation, and presentation—investigators can effectively uncover cyber incidents while maintaining the integrity and reliability of the evidence.

5. Conclusion and Future Direction

The digital economy has significantly transformed the way individuals, businesses, and governments operate, enabling seamless connectivity, innovation, and economic growth. However, this rapid digitalization has also increased exposure to cyber threats, making cybersecurity a fundamental pillar for sustaining trust and stability in digital systems. Effective cybersecurity measures not only protect sensitive data and critical infrastructure but also enhance user confidence, facilitate secure online transactions, and support the overall resilience of the digital ecosystem. Thus, cybersecurity is not merely a technical requirement but a strategic necessity for the sustainable development of the digital economy.

Looking forward, the future of cybersecurity in the digital economy will be shaped by emerging technologies such as artificial intelligence, blockchain, cloud computing, and the Internet of Things (IoT). There is a growing need for advanced threat detection systems, automated response mechanisms, and robust data protection frameworks to counter increasingly sophisticated cyberattacks. Additionally, strengthening international cooperation, developing adaptive regulatory policies, and promoting cybersecurity awareness and skill development will be essential. Future efforts should also focus on integrating proactive security-by-design approaches into digital infrastructures to ensure a secure, resilient, and trustworthy digital economy.

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Chapter

Greenwashing in India: The Role of Journalism in Shaping Corporate Sustainability Narratives

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Abstract

The chapter discusses greenwashing in India as a communication phenomenon shaped by the mediating role of journalism. Moving beyond a corporation-centric view, it argues that the credibility and circulation of sustainability claims depend significantly on how they are framed, amplified, or interrogated within news media. The analysis presents a conditional argument i.e. journalism can both accelerate and de-accelerate greenwashing. Drawing on literature from journalism studies, environmental communication, and political economy, the chapter analyses three interrelated dimensions—structural, professional, and cognitive. Structural factors such as advertising dependence and corporate ownership create incentives for non-critical coverage. Professional factors, including reliance on PR content and time constraints, facilitate unfiltered dissemination of corporate narratives. Cognitive factors, particularly gaps in environmental literacy among journalists, further reduce critical scrutiny. While investigative and data-driven journalism can challenge misleading

claims, such efforts remain episodic. Overall, journalism emerges as a site of contestation where greenwashing is both reproduced and resisted.

Keywords: *Greenwashing, Journalism, Corporate Sustainability, ESG, Political Economy of Media, PR Journalism, Environmental Communication*

Introduction

From the products we buy to the advertisements we see, environmental claims have become a common part of our everyday life. Labels such as “eco-friendly”, “green”, and “sustainable”, etc. appear frequently. However, the meanings of these terms, how they are measured, and whether these terms actually represent an environmental impact is very unclear (Advertising Standards Council of India, 2024; de Freitas Netto et al., 2020). Within this gap between claim and verification the problem of greenwashing emerges. Greenwashing broadly means the deliberate framing of misleading or exaggerated claims about environmental practices of the company. It has become an increasingly major feature of corporate communication, including in India (Delmas & Burbano, 2011; Yadav & Srivastava, 2024). As sustainability, ESG (Environmental, Social, and Governance) frameworks, and climate responsibility gain economic and reputational value, companies are motivated not only to improve environmental initiatives but also to actively influence how others perceive the company’s effort on environment (Gillan et al., 2021).

This is where journalism becomes crucial. Media does not simply pass the corporate claims about environment. But it plays an important role in shaping of those claims’ interpretation, reception in the public sphere. Through processes of priming and framing, media influences which corporate sustainability narratives get more attention and how those narratives are understood by audiences (Entman, 1993). Those claims receive consistent and uncritical coverage can develop a sense of credibility, even when their factual base remains weak (McCombs & Shaw, 1972).

Here, news coverage varies in degree. On one side, it can amplify the sustainability narratives from the corporate by presenting them as credible without questioning them. On the other side, it can question those claims by examining evidence,

and aligning the claims within broader environmental realities (Bednar, 2012; Miller, 2006; Pollach, 2014). Media's function in either of the roles depends not only on editorial choices but also on the conditions of news production (Tuchman, 1972). Thus, greenwashing is not only produced by corporations, but it is normalized, or challenged by the media (Lyon & Montgomery, 2015).

The current chapter presents a conditional argument in this context. As journalism can accelerate greenwashing by just reproducing corporate narratives without questioning, it also can de-accelerate greenwashing through investigative reporting, critical scrutiny, and deeper analysis of corporate environmental claims. Whichever the role media play, it is not fixed but conditional. To analyse this conditionality, the chapter discusses through three interconnected dimensions. Structural factors, such as the political economy of Indian media, advertising dependence, and media ownership pattern. These shape the broader environment within which journalism operates. Professional factors, such as newsroom practices, and the increasing reliance on PR-generated content. These factors determine how corporate sustainability narratives enter and circulate via news content. Cognitive factors, particularly journalists' knowledge and awareness about environment and sustainability. These factors affect whether such narratives are critically examined or reproduced.

The chapter is a literature-driven analysis that synthesises insights from journalism studies, environmental communication, and political economy of media in India. Rather than treating greenwashing as just an isolated corporate misconduct, the chapter tries to understand it within a broader communication system in which journalism functions as a key mediator of meaning and credibility.

Greenwashing in India: Context and Patterns

Greenwashing in India is no longer an occasional practice. It is now a prevalent concern among Indian companies. Research indicates that a high number of large companies in India engage in greenwashing. Almost half of NIFTY 50 companies show discrepancies between ESG disclosures and actual performance (Gidage et al., 2025). A similar estimate suggests that more than half of firms exhibit such tendencies (Sensharma et al.,

2022). These show that greenwashing is not an exception but a normalised feature of corporate sustainability communication in India.

There can be found few common patterns regarding greenwashing in India. One such prominent type is selective disclosure, in which companies highlight only positive environmental initiatives and omit the negative impacts of their operations. This practice is evident in ESG reporting, where companies' disclosure scores often exceed their actual environmental performance (Gidage et al., 2025). A second common pattern is the use of vague and ambiguous claims, such as terms like "eco-friendly" or "green," that lack measurable meaning. Studies on Indian advertisements show that a large proportion of environmental claims fall into this vague-claim category. Many claims are just shallow, non-specific, and difficult to verify (Fernando et al., 2014). A related pattern is credence-based communication. Claims that cannot be independently verified by consumers, such as "100% natural" or "environmentally safe", without any supporting evidence. Another common pattern is symbolic or executional greenwashing. In this pattern environmental claim is constructed through imagery and visual representation rather than actual facts. Advertisements often use imagery of nature, green colors, and environmental events to convey the sustainability message without providing concrete information (Prasad et al., 2017). Greenwashing also often takes place in the form of CSR (Corporate Social Responsibility) masking. In this practice companies use CSR initiatives to project environmental commitment while their core operations remain environmentally harmful (Mishra & Muraleedharan, 2020). Notably, greenwashing is not only limited to corporate communication. It is also present in regulatory processes. The conditions for environmental clearance in major infrastructure projects are often vague, and lacking scientific grounding, effectively producing a form of institutional or state-level greenwashing (Hegde et al., 2022).

Greenwashing practices by Indian corporates is combination of structural and institutional factors. One such important reason is weak regulation. Particularly the weak guidelines for CSR and environmental governance allows the companies to prioritise token compliance ahead of real action and change (Mishra & Muraleedharan, 2020). Another major factor is institutional

pressure. Economic incentives, regulatory expectations, social norms, and competitive dynamics push companies to take the shortcut of greenwashing to look sustainable. Companies may engage in greenwashing to gain the attention of investors, align with industry trends, or maintain legitimacy in a market where sustainability has increasing reputational value (Chakraborty et al., 2025).

The growth of ESG discourse and green finance has made these incentives even stronger. As sustainability becomes valuable for branding, and also financially, companies are more likely to manage their environmental image very tactically. Although, this has created a situation where sustainability initiatives do not reflect into actual environmental benefits. Studies suggest that even the use of sustainable technologies can fail to improve real environmental outcomes if it is embraced with greenwashing-driven system (Das et al., 2024). This emphasises that greenwashing can distort not just perception, but also the effectiveness of sustainability interventions.

In India, greenwashing is driven by weak guidelines, institutional pressures and the growing value of sustainability narratives. It is characterised by identifiable patterns such as selective disclosure, vague claims, symbolic representation, and regulatory ambiguity. It is sustained not only by corporate strategy but, more critically, by communicative conditions that shape how environmental claims are produced, circulated, and interpreted. Within this communicative process, journalism becomes a key mediating force. In India, this mediation is shaped by three dimensions—structural, professional, and cognitive—which together influence whether corporate environmental narratives are critically examined or simply reproduced.

Structural Factors: Political Economy of Business Journalism

The ability of journalism to critically analyse corporate sustainability narratives is fundamentally influenced by the structural conditions under which media functions. Indian media's political economy is decided by a high dependence on advertisement. A major share of media revenue comes from advertisement by corporates. And the same corporates are the subjects of coverage by media (FICCI-EY, 2024).

This conflict creates an inherent structural tension. It is expected that media organisations will act as watchdogs while also relying on the corporate they cover to stay in business. In practice, this

often results in soft or non-confrontational coverage of corporate actors, particularly those with significant advertising presence (Chadha, 2017). It becomes financially risky to be critical of environmental claims, while neutral or positive coverage fits with the incentives of institutions (Mishra, 2020).

The situation is made complex by how Indian media companies are owned. Many media organisations work as part of larger conglomerates with diverse business interests. Such cross-ownership structures make the boundary opaque between editorial independence and business strategy. When media houses are circled with a broader corporate network, there is a structural disincentive to pursue reporting that could conflict with allied business interests (Maheshwari & Sparks, 2021).

Greenwashing in this context rarely is result of direct editorial policies. But it happens because of incentive system. Coverage that makes corporate sustainability fit well with how media companies make money from ads. They also fit with what is the interest of the owners of these media companies. By contrast, critical environmental reporting remains structurally constrained (Ali et al., 2025). Thus, the political economy of Indian media does not simply influence coverage. It shapes the conditions under which corporate narratives are more likely to be reproduced rather than investigated.

Professional Factors: Newsroom Practices and PR Journalism

Apart from structural factors, the practices journalists embrace in their work influence the kind of news content they produce and share. In today's Indian media, newsrooms work under constant pressure to produce and circulate content quickly. The demand for continuous updates means high speed, efficiency, and volume. And this often push depth and careful verification at the back-seat (Batra & Upmanyu, 2023). This is closely related to the transformation of business journalism, where content increasingly reflects market-oriented priorities and real-time information flows rather than critical analysis.

In a constrained environment like this, business journalists often turn to readily available resources. Pre-packaged materials from PR (public relations) section of companies often become the source of news and journalists frequently reproduce press releases and briefings with minimal modification. Studies from Indian regional media contexts shows that this dependence can be so pronounced that large portions of business news

are directly shaped by PR inputs, with limited independent verification or reinterpretation (Sahoo & Nayak, 2021). As a result, journalism increasingly takes the form of “PR journalism,” where the distinction between reporting and promotion becomes structurally blurred.

This phenomenon is even compounded by news production cycle. The stress on fast, quick and immediate publication of news results only reproducing the claims by the corporates without enough scrutiny. The time and expertise required for investigative or interpretative journalism are often unavailable, particularly in understaffed or commercially driven news environments (Sahoo & Nayak, 2021). More broadly, the reliance on elite and institutional sources within the media system ensures that dominant narratives—especially those aligned with corporate interests—are reproduced with minimal contestation (Tripathi, 2024).

The increase of branded content, advertorials complicate the issue even more. Cases such as “medianet,” private treaties, and paid news establish the addition of promotional content within editorial spaces, often without clear disclosure (Tripathi, 2024). These paid content formats are designed to look and sound like news and difficult for readers to distinguish between news reporting and sponsored content.

Another important factor related to journalists’ practice is the decline and transformation of investigative journalism. Investigative reporting is almost always resource-intensive, requiring lot of fieldwork and technical expertise, making it difficult to sustain in fast-paced and resource-constrained news environments. Investigative journalism has not only declined but also shifted in form. What is presented as “investigative” increasingly becoming as selective or “pseudo-investigative” reporting aligned and favoured with dominant power (Chadha, 2022; Kumar & Bhat, 2025).

These professional practices are not just operational constraints but a systematic method of news publication. They normalise the reproduction of corporate narratives in news while limiting critical investigation. Thus, journalism not only just fail to challenge misleading or exaggerated environmental claims, but it structurally embraces their circulation, contributing to the wider reproduction of greenwashing within public discourse.

Cognitive Factors: Limits of Environmental and Sustainability Literacy

Environmental news reporting requires comparatively complex subjects such as ESG metrics, carbon accounting and regulatory frameworks. Analysing these topics calls for specialized knowledge about the domains. But in India, environmental news is often covered by general reporters without sufficient scientific training. This limits the scope of critically interpreting claims by corporates (Mishra, 2020; Ogadimma, 2024).

The situation creates a gap between the complexity of environmental reporting and journalistic ability. Research shows limited use of expert sources and a reliance on institutional sources in the environmental news. Studies also show the dominance of informational, event-based reporting rather than analytical reporting in environmental news (Parimala & Maheswari, 2025).

As a result, technically valid claims often go unquestioned when they are being presented in a misleading way. This reflects an epistemic vulnerability in journalism, where cognitive limitations, which is often independent of structural or professional pressures, enable the uncritical reproduction of greenwashing narratives.

When Journalism Accelerates Greenwashing

Structural, professional, and cognitive factors make journalism to facilitate greenwashing rather than challenge it. Sustainability claims by companies enter the news cycle through press releases or PR content. After that those claims get legitimacy, credibility by uncritical reproduction of those. Over time, this circulation normalizes such claims and shapes audience perceptions of their credibility.

In every stage of news publication cycle, the absence of critical interference becomes the crucial point for the acceleration of greenwashed content through media. Structural conditions—especially advertising dependence and ownership of media. Professional routines, including reliance on briefing or PR content provided by the companies. At the same time, cognitive limitations constrain journalists' ability to evaluate complex sustainability claims.

The result of all these is reinforcement of greenwashing. Sustainability narratives gain visibility and legitimacy regardless of their factual validity. Greenwashing becomes effective not primarily because corporates persuade it, but because of its repeated circulation. This reflects a systemic tendency in which media conditions privilege amplification over interrogation.

When Journalism De-Accelerates Greenwashing

With all the limitations, journalism can challenge greenwashing by shifting its focus from simply reproducing corporate claims to critically examining them. Investigative reporting plays an important role here. It can expose the gaps between corporate claims and actual practices of the companies through evidence-based analysis. Approaches that rely on data and systematic scrutiny of sustainability claims can further strengthen this role.

Structural pressures, resource constraints, and market-oriented news production restrict the essence of critical, investigative, analytical journalism. As a result, while journalism can challenge greenwashing, such efforts remain episodic rather than systemic. De-acceleration of greenwashing functions as a counter-tendency within Indian media environment that otherwise tends toward the amplification of corporate sustainability narratives.

Discussion: Journalism as a Place of Contestation

This chapter goes beyond a simple view of journalism as either an enabler of greenwashing or a force of greenwashing resistance. It sees journalism as a place of contestation shaped by structural, professional, and cognitive dimensions. Structurally, advertising dependence and corporate ownership set limits on critical reporting. These factors do not directly control the news content but influence what is commercially viable for the media house. Professionally, newsroom practices, such as reliance on press releases, PR content and fast-paced news publication make journalists to embrace corporate narratives within news output without critical inquiry. Cognitive limitations further reinforce this dynamic. The technical complexity of environmental reporting creates an epistemic gap, reducing journalists' ability to critically evaluate claims even in the absence of overt pressure.

These factors explain why greenwashing persists as a communicative phenomenon. It is not the result of a single facet but of numbers of constraints that favor narrative reproduction.

At the same time, instances of critical reporting show that journalism can disrupt this process, though such efforts remain contingent and uneven. Thus, journalism is best understood as a structurally embedded and professionally negotiated field, where both amplification and interrogation of greenwashing coexist.

Conclusion

Greenwashing in India exists not just simply as a corporate communication strategy but as a mediated phenomenon shaped by how sustainability claims are framed, legitimized, published across news media. Journalism plays a crucial role in this process, not as a passive transmitter but as an institution that actively conditions the credibility and reach of corporate narratives.

The analysis shows a combination of structural, professional and cognitive factors that collectively favor the reproduction of green claims. Economic dependence on advertising and corporate ownership of media organisations narrows the space for critical reporting. Newsroom practices, such as speed, resource constraints, and reliance on PR content ease the uncritical entry of corporate narratives into news output. At the same time, the complexity of environmental issues limits untrained journalists' capacity to rigorously scrutinise the sustainability claims by the corporates. These overlapping conditions make the normalization of greenwashing less an exception and more a systemic tendency.

The understanding is apparent that to fight with greenwashing in India requires transforming the conditions under which journalism functions, rebuilding investigative depth in reporting rather than fast publication, and increasing environmental domain knowledge among journalists. These are essential for shifting journalism from a tool of corporate narrative reproduction to a tool of scrutiny. Otherwise, greenwashing will continue to persist in India via media.

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17

Chapter

Role of Medical Imaging and Machine Learning Techniques in Assistive Disease Diagnosis

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Abstract

Healthcare is undergoing a transformative evolution driven by advances in digital technologies, with medical imaging and machine learning (ML) emerging as pivotal tools for improving disease diagnosis, treatment, and patient outcomes. Medical imaging modalities enable visualization of internal body structures, while ML algorithms facilitate automated, accurate, and efficient analysis of complex imaging data. The integration of ML with medical imaging has demonstrated remarkable success in early disease detection, personalized treatment planning, predictive prognosis, and continuous patient monitoring. This chapter provides a comprehensive overview of medical imaging techniques and ML approaches applied in healthcare, emphasizing their synergistic role in assistive disease diagnosis and management. The insights presented aim to guide researchers, clinicians, and policymakers in leveraging ML-driven medical imaging for improved, patient-centered care.

Keywords: Healthcare Technology; Medical Imaging; Machine Learning (ML) in Healthcare; Disease Diagnosis and Detection; Explainable Machine Learning.

1. Introduction

Healthcare is a fundamental pillar of human well-being, continually evolving with advancements in science and technology to improve the quality, accessibility, and efficiency of medical services. In recent decades, the integration of digital technologies into healthcare systems has transformed traditional practices, enabling more precise, data-driven, and patient-centered approaches. Among these advancements, medical imaging has emerged as a cornerstone of modern diagnosis and treatment, providing non-invasive visualization of internal body structures and functions. Techniques such as X-ray, computed tomography (CT), magnetic resonance imaging (MRI), and ultrasound play a crucial role in detecting and monitoring a wide range of diseases, including cancer, cardiovascular disorders, and neurological conditions.

The rapid advancement of digital technologies has significantly transformed the landscape of modern healthcare, giving rise to the concept of intelligent healthcare. Despite the remarkable capabilities of medical imaging, the increasing volume and complexity of imaging data present significant challenges for healthcare professionals. Manual interpretation of images is often time-consuming and subject to variability depending on the expertise of radiologists. This is where machine learning (ML) techniques have begun to play a transformative role. Fig. 1 presents a block diagrammatic representation of the diverse applications of machine learning in healthcare, with a central node labeled "Applications of Machine Learning in Healthcare." This central block acts as the core system, interconnected with multiple surrounding functional modules, each representing a key application domain. These include diagnosis and disease detection, where machine learning models assist in early identification of diseases; medical imaging, which leverages advanced algorithms for image analysis and interpretation; and predictive analytics, used for forecasting disease progression and patient outcomes. Additional blocks highlight patient monitoring through wearable devices and real-time data analysis, drug discovery for accelerating the development of new medicines, and personalized treatment that tailors therapies based on individual patient data. Another important component, healthcare operations, focuses on optimizing administrative and clinical workflows. Arrows connecting

these blocks emphasize the integration and continuous data flow between different components, illustrating how machine learning serves as a unifying framework to enhance efficiency, accuracy, and decision-making across the healthcare ecosystem.

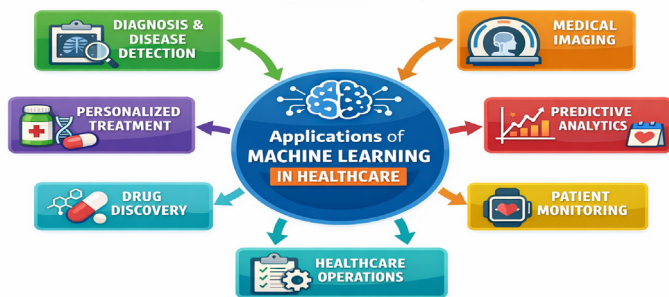


Fig. 1 Block Diagram Representing Applications of Machine Learning in Healthcare

Consequently, the integration of medical imaging and machine learning has demonstrated remarkable success in the early detection and diagnosis of critical diseases such as cancer, cardiovascular disorders, neurological conditions, and pulmonary infections. For instance, machine learning models can identify minute abnormalities in imaging scans, such as tumors, lesions, or tissue irregularities, often at stages earlier than conventional diagnostic methods. This early and accurate diagnosis plays a crucial role in improving patient outcomes and reducing healthcare costs. Detecting diseases at an initial stage allows for timely intervention, which can prevent disease progression, reduce complications, and increase survival rates. For example, early detection of cancers or cardiovascular diseases can significantly enhance the effectiveness of treatment strategies. Moreover, these technologies assist clinicians in reducing diagnostic errors, improving workflow efficiency, and handling the increasing demand for imaging-based evaluations. Beyond diagnosis, machine learning-driven imaging analysis plays a vital role in treatment planning, prognosis assessment, and disease monitoring. Predictive analytics can support personalized medicine by tailoring treatment strategies based on individual patient data, imaging biomarkers, and disease progression patterns.

This chapter aims to provide a comprehensive overview of the role of medical imaging and machine learning techniques in assistive disease diagnosis and treatment. It explores the fundamental concepts of medical imaging modalities and machine learning algorithms, highlighting their integration in healthcare applications. The insights presented in this chapter are intended to benefit researchers, practitioners, and policymakers interested in leveraging technology for improved healthcare delivery using the applications of machine learning.

2. Medical Imaging for Disease Diagnosis

Medical imaging modalities are essential tools in modern healthcare, enabling non-invasive visualization of internal body structures for diagnosis, treatment planning, and disease monitoring. Each modality is based on different physical principles and is suited for specific clinical applications. It supports early detection, accurate diagnosis, treatment planning, and continuous monitoring of a wide range of diseases, including cancer, cardiovascular disorders, neurological conditions, and musculoskeletal abnormalities. Over the years, advances in imaging technologies have significantly improved the precision and reliability of medical diagnosis. This subsection describes the medical imaging modalities and their properties of structural appearance for abnormality detection towards disease diagnosis.

X-ray Imaging. X-ray imaging is one of the oldest and most widely used medical imaging modalities, relying on ionizing radiation to produce images of internal body structures. When X-rays pass through the body, different tissues absorb varying amounts of radiation depending on their density. Dense structures such as bones absorb more radiation and appear white, while softer tissues appear in shades of gray, and air-filled spaces appear black. X-rays are commonly used for diagnosing fractures, infections, lung diseases such as pneumonia, and dental issues. The technology is relatively fast, cost-effective, and widely accessible, making it suitable for emergency situations. However, it provides limited soft tissue contrast compared to advanced modalities like MRI. Digital radiography has improved image quality and reduced radiation exposure compared to traditional film-based systems. Despite its advantages, repeated exposure to ionizing radiation can pose health risks, so its use is carefully controlled. Advances

such as computed radiography and portable X-ray devices have enhanced clinical workflows, especially in rural and critical care settings.

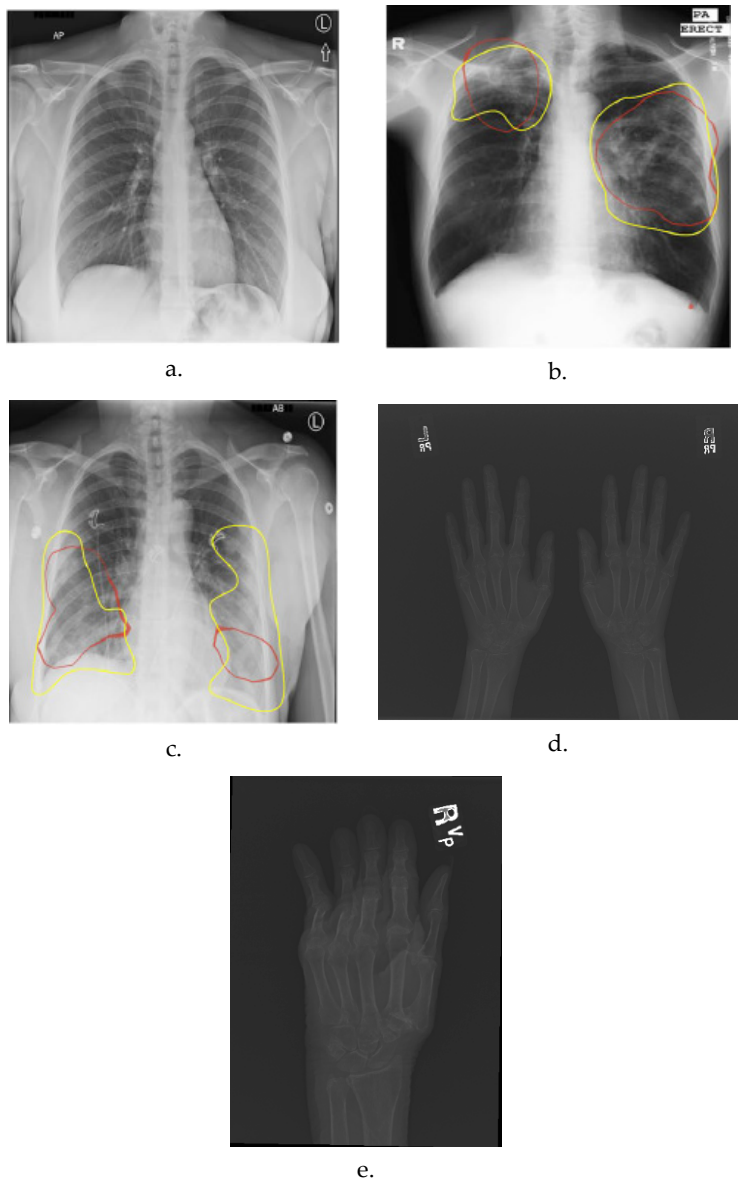


Fig. 2 X-Ray Imaging for Disease Diagnosis

Considering an example, a normal chest X-ray shows clear lung fields without opacities, indicating the absence of infection or fluid accumulation. The rib cage appears as bright white structures due to high calcium content, while the lungs appear dark because they are air-filled. The heart shadow is visible in the central region, with a normal cardiothoracic ratio. The diaphragm forms a dome-shaped boundary at the base of the lungs. This type of image is often used as a baseline reference for detecting abnormalities such as tumors, infections, or structural deformities [1][2]. On the otherhand, bone fracture X-rays reveal discontinuities or breaks in the bone structure, appearing as dark lines or irregularities across otherwise bright white bone regions [3]. Depending on the severity, fractures may be simple (clean break), comminuted (multiple fragments), or displaced (misaligned bones). X-ray imaging is the primary diagnostic tool for fractures due to its high sensitivity to bone density differences. These images are crucial for treatment planning, including casting or surgical intervention. Consequently, Tuberculosis X-ray images typically show upper-lobe opacities, cavitations, or nodular lesions in the lungs. In advanced cases, fibrosis and lung volume loss may be observed [4]. These abnormalities appear as irregular white patches or hollow spaces in lung regions. Chest X-rays play a critical role in early TB screening, especially in regions with limited access to advanced imaging. AI-based systems increasingly assist in automated TB detection from such radiographs.

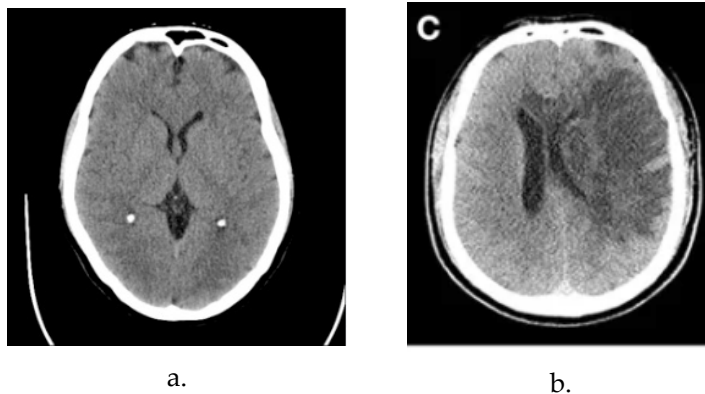


Fig. 3 Computed Tomography (CT) for Disease Diagnosis

Computed Tomography (CT). Computed Tomography (CT) is an advanced imaging technique that combines multiple X-ray measurements taken from different angles to produce cross-sectional images of the body. These images are reconstructed using computational algorithms to provide detailed visualization of bones, soft tissues, and blood vessels. CT scans are particularly useful for detecting tumors, internal bleeding, complex fractures, and lung diseases. The modality offers higher spatial resolution than conventional X-rays and can generate 3D reconstructions, aiding in surgical planning and diagnosis. Modern CT systems employ spiral (helical) scanning and multi-detector arrays to improve speed and accuracy. Contrast agents are often used to enhance the visibility of specific organs or vascular structures. However, CT scans involve higher radiation doses compared to standard X-rays, which is a concern for repeated imaging. Despite this, CT remains a cornerstone in emergency medicine due to its rapid imaging capability and diagnostic precision. Continuous advancements in low-dose CT and AI-based reconstruction techniques are improving safety and image quality.

For example reference, axial CT images of the brain are widely used in emergency diagnosis, especially for detecting intracranial hemorrhage, stroke, tumors, and traumatic brain injury. In these scans, dense structures like bone appear bright white, while cerebrospinal fluid appears dark. Acute hemorrhage is typically hyperdense (bright), making CT the first-line modality in suspected stroke cases. The symmetry of brain structures is also assessed to identify abnormalities such as edema or mass effect. Consequently, Chest CT scans provide detailed visualization of lung parenchyma and are extensively used for diagnosing lung infections, pulmonary nodules, fibrosis, and COVID-19-related abnormalities [5]. The lung window setting enhances contrast between air-filled spaces and soft tissue, allowing detection of ground-glass opacities, consolidations, and interstitial patterns. CT is far more sensitive than standard X-rays for early-stage lung disease. For instance, Contrast-enhanced CT scans of the abdomen help visualize organs such as the liver, kidneys, pancreas, and spleen, as well as vascular structures. Contrast agents improve differentiation between tissues, aiding in the detection of tumors, cysts, inflammation, and internal bleeding. These scans are commonly used in oncology and trauma cases [6].

Magnetic Resonance Imaging (MRI). Magnetic Resonance Imaging (MRI) is a non-invasive imaging modality that uses strong magnetic fields and radiofrequency waves to generate detailed images of internal body structures. Unlike X-rays and CT scans, MRI does not use ionizing radiation, making it safer for repeated use. MRI is particularly effective for imaging soft tissues such as the brain, spinal cord, muscles, and ligaments. It works by aligning hydrogen protons in the body and detecting the signals emitted as they return to their original state after excitation. Different tissues produce distinct signal patterns, allowing for high-contrast imaging. MRI is widely used in neurology, oncology, and musculoskeletal diagnostics. Functional MRI (fMRI) can even map brain activity by measuring changes in blood flow. However, MRI scans are relatively expensive and time-consuming compared to other modalities. Patients with metal implants or claustrophobia may face limitations. Recent innovations include faster scanning techniques, open MRI systems, and AI-assisted image reconstruction, which enhance diagnostic accuracy and patient comfort.

T1-weighted MRI images provide high anatomical detail of brain structures. In these images, white matter appears brighter than gray matter, while cerebrospinal fluid (CSF) appears dark. These scans are widely used to assess brain anatomy, detect tumors, structural abnormalities, and neurodegenerative changes. T1 images are particularly useful for evaluating normal anatomical structures and post-contrast enhancement in tumor diagnosis. Conversely, T2-weighted MRI images highlight fluid-containing regions, where CSF appears bright. These images are highly sensitive to edema, inflammation, infections, and lesions. They are commonly used in diagnosing conditions such as multiple sclerosis, stroke, and brain tumors. The contrast difference helps clinicians identify abnormal tissue more clearly compared to T1-weighted images. For instance, Functional MRI (fMRI) measures brain activity by detecting changes in blood oxygenation (BOLD signal). Active brain regions appear highlighted during specific tasks such as movement, speech, or visual processing. fMRI is widely used in neuroscience research, brain mapping, and pre-surgical planning to identify critical functional areas [7].

Ultrasound Imaging. Ultrasound imaging, also known as sonography, uses high-frequency sound waves to produce real-time images of internal organs and tissues. A transducer

emits sound waves that reflect off tissues, and the returning echoes are used to construct images. Ultrasound is widely used in obstetrics for monitoring fetal development, as well as in cardiology, abdominal imaging, and vascular studies. It is safe, non-invasive, and does not involve ionizing radiation, making it ideal for repeated use and sensitive populations such as pregnant women. Doppler ultrasound can assess blood flow and detect abnormalities such as blockages or clots. The modality is portable and relatively inexpensive compared to CT and MRI. However, image quality can be operator-dependent and may be limited in patients with obesity or excessive gas. Despite these limitations, ultrasound remains a versatile and widely used diagnostic tool, especially in point-of-care and emergency settings. Advances in 3D/4D ultrasound and AI-based interpretation are further enhancing its capabilities.

Obstetric Ultrasound (Fetal Imaging) shows typical prenatal ultrasound scans used to monitor fetal growth and development. The fetus appears as a bright structure within the darker amniotic fluid. Key anatomical features such as the head, spine, and limbs can be visualized. These scans are essential for assessing gestational age, detecting congenital anomalies, and monitoring fetal health. Real-time imaging allows clinicians to observe fetal movement and heartbeat [8]. Consequently, Doppler ultrasound images show blood flow within vessels using color mapping (typically red and blue). These colors indicate the direction and velocity of blood flow relative to the transducer. This technique is crucial for detecting vascular disorders such as stenosis, thrombosis, and abnormal circulation. Spectral Doppler waveforms can also quantify flow velocity [9].

Positron Emission Tomography (PET). Positron Emission Tomography (PET) is a functional imaging modality that provides insights into metabolic and biochemical processes within the body. It involves the injection of a radioactive tracer, typically fluorodeoxyglucose (FDG), which accumulates in metabolically active tissues. As the tracer decays, it emits positrons that interact with electrons, producing gamma rays detected by the scanner. PET images are often combined with CT or MRI to provide both functional and anatomical information. This modality is widely used in oncology for detecting cancer, monitoring treatment response, and identifying metastases.

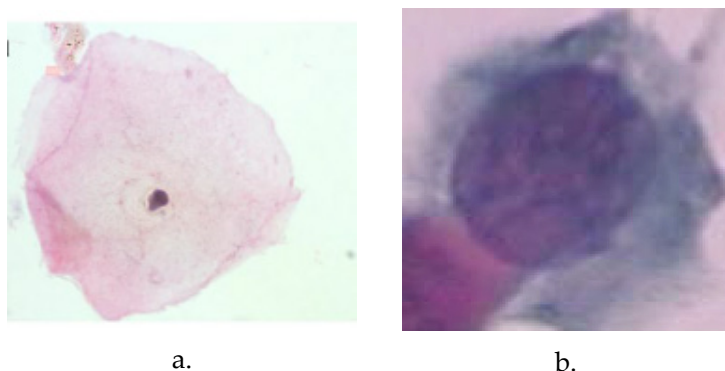


Fig. 4 Pap-Smear (Cytological Imaging) for Disease Diagnosis

It is also used in neurology and cardiology to study brain activity and heart function. PET scans are highly sensitive but relatively expensive and involve exposure to radioactive materials. The resolution is lower than CT or MRI, but the functional information is invaluable for diagnosis and treatment planning. Advances in hybrid imaging systems like PET/CT and PET/MRI have significantly improved diagnostic accuracy. Brain PET imaging shows metabolic activity across different brain regions. In neurodegenerative diseases like Alzheimer's, reduced FDG uptake (hypometabolism) is observed in the temporal and parietal lobes. PET is valuable for early diagnosis and differentiation of dementia types [10]. Cardiac PET evaluates myocardial perfusion and viability. Areas with reduced tracer uptake indicate ischemia or infarction. It helps in assessing coronary artery disease and determining whether damaged heart tissue can recover after treatment [11].

Pap-Smear (Cytological Imaging). Pap-smear is a cytological screening technique used primarily for the early detection of cervical cancer. Unlike other imaging modalities, it involves microscopic examination of cells collected from the cervix. The sample is stained and analyzed to identify abnormal or precancerous cells. This method has significantly reduced cervical cancer mortality through early detection and intervention. In modern healthcare, Pap-smear analysis is increasingly supported by digital imaging and machine learning techniques for automated cell classification. High-resolution microscopy images are processed to detect abnormalities such

as changes in cell shape, size, and nucleus structure. While the procedure is simple, cost-effective, and minimally invasive, it requires skilled interpretation. False negatives can occur if abnormal cells are missed. Integration with HPV testing has improved diagnostic accuracy. Recent advancements include AI-based cytology systems that enhance screening efficiency and reduce human error, making Pap-smear a critical component of preventive healthcare. Pap-smear imaging begins with the identification of normal cervical epithelial cells, which serve as a baseline for detecting abnormalities. Normal samples typically contain superficial and intermediate squamous epithelial cells with small, uniform nuclei and abundant cytoplasm [12]. The nucleus-to-cytoplasm (N:C) ratio is low, and chromatin is evenly distributed. These cells appear flat and polygonal under light microscopy after staining using the Papanicolaou stain, which enhances nuclear detail and cytoplasmic transparency. In abnormal cases, cytological samples show marked irregular nuclear shapes, and prominent nucleoli. Cells lose their normal architecture and appear disorganized. Highly irregular cells with enlarged, hyperchromatic nuclei and distorted shapes. Background may contain necrotic debris and inflammatory cells, indicating tumor invasion [13][14].

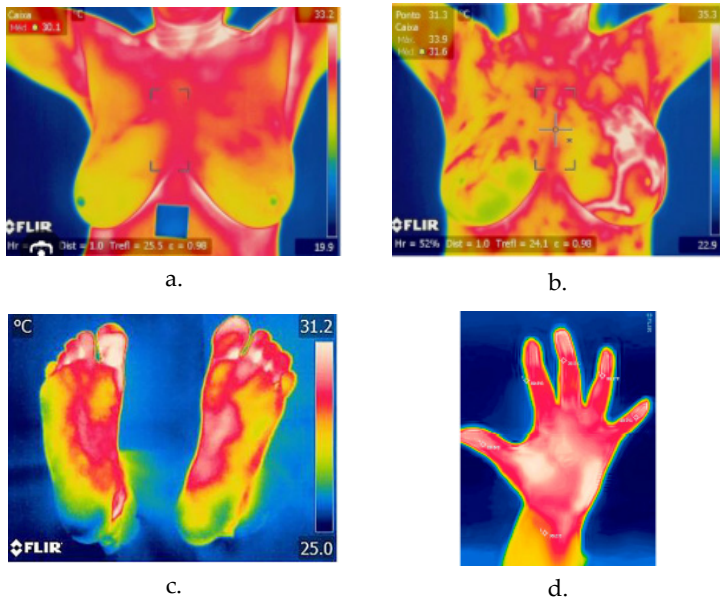


Fig. 5 Infrared Thermography for Disease Diagnosis

Infrared Imaging (Thermography). Infrared imaging, also known as thermography, detects heat patterns and blood flow in body tissues using infrared radiation. It captures temperature variations on the skin surface, which can indicate underlying physiological changes. Areas with increased blood flow, inflammation, or abnormal metabolic activity often appear warmer in thermographic images. This modality is non-invasive, radiation-free, and painless, making it suitable for frequent monitoring. Infrared imaging has applications in breast cancer screening, vascular disorders, musculoskeletal injuries, and inflammation detection. However, it does not provide structural details like CT or MRI and is often used as a complementary tool rather than a standalone diagnostic method. The accuracy can be influenced by environmental conditions and patient preparation. Advances in image processing and AI have improved pattern recognition and diagnostic reliability. Despite its limitations, thermography is valuable for early detection and monitoring of conditions associated with temperature changes. Breast thermography images typically display temperature distributions across both breasts using a color-coded scale, where warmer regions appear in red, orange, or white, and cooler regions appear in blue or green. In normal cases, the thermal pattern is bilaterally symmetrical. However, in abnormal cases—such as suspected breast cancer—localized hotspots or asymmetric vascular patterns are observed (as shown in Fig. 5 (b)). These hotspots indicate increased metabolic activity and angiogenesis associated with tumor growth. Studies have shown that thermography can detect physiological changes even before structural abnormalities become visible in modalities like mammography. However, due to variability in sensitivity and specificity, it is primarily used as an adjunct screening tool rather than a standalone diagnostic method [15][16]. For instance, in diabetic patients (as shown in Fig. 5 (c)), thermography can reveal early signs of diabetic foot complications by detecting subtle temperature differences before visible ulcers develop [17]. Further, thermographic imaging is highly effective in identifying musculoskeletal injuries, inflammation, and pain-related conditions. Injured or inflamed tissues exhibit elevated temperatures due to increased blood flow and metabolic activity, which appear as bright red or white regions in thermograms. For example, in cases of arthritis [18], tendonitis, or sports injuries, thermography can highlight affected joints or muscles even before swelling becomes clinically evident.

Histopathological Imaging. Histopathological imaging involves the microscopic examination of biological tissues to study the manifestations of disease, particularly cancer. Tissue samples are collected through biopsy or surgical excision, processed, and stained using techniques such as Hematoxylin and Eosin (H&E) staining to highlight cellular structures. These stained slides are then observed under a microscope or digitized using whole-slide imaging systems for computational analysis. Histopathology is considered the gold standard for definitive diagnosis of many diseases, as it provides detailed insights into cellular morphology, tissue architecture, and pathological abnormalities. In recent years, digital pathology has enabled the integration of machine learning and deep learning algorithms for automated detection, segmentation, and classification of abnormal cells. Convolutional Neural Networks (CNNs) are widely used to identify cancerous patterns, grade tumors, and assist pathologists in decision-making. Despite its high diagnostic accuracy, the process is time-consuming and requires expert interpretation. Variability in staining and imaging conditions can also affect analysis. However, advancements in AI-assisted pathology, cloud-based platforms, and high-resolution scanners are transforming histopathological imaging into a scalable and efficient diagnostic tool. In normal tissue, cells exhibit uniform shape, well-organized, and clearly defined nuclei stained in blue (hematoxylin), while cytoplasm appears pink (eosin). In contrast, cancerous tissue shows pleomorphism (variation in cell size and shape), enlarged nuclei, hyperchromasia (dark staining), and disrupted tissue architecture. These morphological abnormalities are critical indicators used by pathologists to identify malignancy. Machine learning models, particularly CNNs, learn these patterns for automated classification of benign vs malignant tissues [19][20].

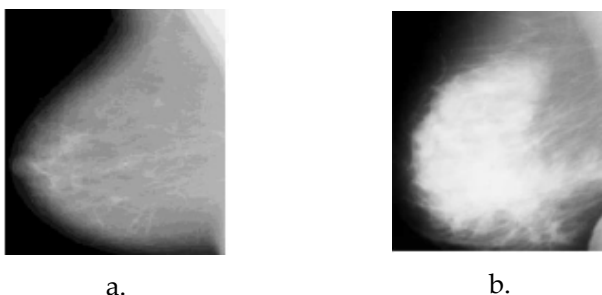


Fig. 6 Mammography for Disease Diagnosis

Mammography. Mammography is a specialized medical imaging modality that uses low-dose X-rays to examine breast tissue, primarily for the early detection and diagnosis of breast cancer. It is capable of identifying microcalcifications, masses, and structural abnormalities that may not be palpable during physical examination. There are two main types of mammography: screening mammography, used for routine check-ups in asymptomatic individuals, and diagnostic mammography, used when abnormalities are suspected. Digital mammography has largely replaced traditional film-based systems, offering improved image quality, enhanced contrast, and easier storage and transmission. Advanced techniques such as Digital Breast Tomosynthesis (DBT), also known as 3D mammography, provide layered images of the breast, improving lesion detection and reducing false positives. Mammography plays a critical role in reducing breast cancer mortality through early detection. However, it involves exposure to low levels of ionizing radiation and may have reduced sensitivity in dense breast tissues. Recent developments include AI-based computer-aided detection (CAD) systems that assist radiologists in identifying suspicious regions, improving diagnostic accuracy and efficiency in large-scale screening programs. Here, a normal mammogram typically shows homogeneous fatty or fibroglandular tissue with no suspicious masses, distortions, or calcifications. In contrast, abnormal mammograms may reveal irregular masses, architectural distortion, or clustered microcalcifications [21]. Radiologists assess these features based on shape, margin, and density to classify findings using BI-RADS (Breast Imaging Reporting and Data System). Consequently, masses in mammography are evaluated based on shape (round, oval, irregular), margins (circumscribed, obscured, spiculated), and density. Malignant masses often exhibit irregular shapes and spiculated margins due to invasive growth patterns. Benign tumors such as fibroadenomas usually present as smooth, well-defined lesions. Mammography enables early visualization of these masses, even when they are too small to be clinically detected, thus playing a crucial role in early diagnosis and treatment planning [22].

3. Challenges in Medical Imaging Data for Building Decision Support Systems Towards Diagnosis of the Disease

Medical imaging data presents a wide range of challenges that significantly affect the performance, reliability, and generalization of machine learning models. Below is a detailed discussion of key challenges beyond noise, artifacts, class imbalance, and annotation issues:

Noise and Signal Variability. Medical images often suffer from modality-specific noise, such as Gaussian noise in MRI or Poisson noise in low-dose CT scans. Variability in acquisition parameters (scanner type, resolution, patient movement) further introduces inconsistencies. This degrades image quality and complicates feature extraction, often requiring sophisticated denoising techniques or robust model architectures.

Imaging Artifacts. Artifacts arise due to hardware limitations, patient motion, or reconstruction errors. Examples include motion blur in MRI, beam hardening in CT, and speckle noise in ultrasound. These distortions may mimic pathological patterns, leading to false positives or reduced diagnostic confidence. Artifact removal remains a complex preprocessing challenge.

Class Imbalance. Medical datasets are typically skewed, with significantly fewer abnormal/pathological samples compared to normal ones. This imbalance biases models toward majority classes, reducing sensitivity to rare but critical conditions. Techniques like weighted loss functions, oversampling (e.g., SMOTE), and focal loss are often used to address this.

Data Annotation and Labeling Issues. Accurate annotation requires domain expertise from radiologists or pathologists, making it time-consuming and expensive. Inter-observer variability leads to inconsistent labels, especially in borderline cases. Additionally, pixel-level annotations (e.g., segmentation masks) are labor-intensive, limiting the availability of high-quality labeled datasets.

Limited Data Availability and Privacy Constraints. Medical data is highly sensitive and governed by strict privacy regulations (such as HIPAA and GDPR). This restricts data sharing across institutions, resulting in small, fragmented datasets. Deep learning models, which require large-scale data, often struggle to generalize under such constraints.

Heterogeneity Across Imaging Devices and Protocols. Images acquired from different hospitals or scanners vary in resolution, contrast, and acquisition protocols. This domain shift leads to poor cross-institutional generalization. Models trained on one dataset may fail when applied to another due to this distribution mismatch.

High Dimensionality and Computational Complexity. Medical images, especially 3D modalities like CT and MRI, have high spatial resolution and volumetric depth. This leads to large data sizes, increasing memory requirements and computational cost. Efficient architectures and dimensionality reduction techniques are necessary to manage this complexity.

Multi-Modality Data Integration Challenges. Combining information from multiple imaging modalities (e.g., MRI, CT, PET) can improve diagnostic accuracy, but aligning and fusing such heterogeneous data is non-trivial. Differences in spatial resolution, orientation, and intensity distributions complicate multimodal learning.

Interpretability and Explainability Issues. Deep learning models in medical imaging are often black boxes. Lack of transparency reduces trust among clinicians, especially in high-stakes decision-making. Developing explainable AI (XAI) methods, such as saliency maps or attention mechanisms, is critical but still evolving.

Overfitting and Poor Generalization. Due to limited and imbalanced datasets, models tend to memorize training data rather than learn generalizable features. This results in high training accuracy but poor performance on unseen data. Regularization techniques, cross-validation, and data augmentation are commonly used to mitigate this issue.

Ethical and Bias Concerns. Datasets may not represent diverse populations, leading to biased models that perform poorly on underrepresented groups. This raises ethical concerns, especially when AI systems are used in clinical decision-making. Ensuring fairness and inclusivity is a major ongoing challenge.

4. Machine Learning Foundations for Medical Imaging

Machine Learning is playing a transformative role in healthcare by augmenting the power of medical imaging. These techniques can process vast amounts of imaging data with remarkable speed

and accuracy, assisting in early detection, disease classification, and prognosis prediction. Machine Learning systems can identify subtle patterns and anomalies that may be overlooked by human observers, thereby enhancing diagnostic precision. Furthermore, AI-driven tools support personalized medicine by tailoring treatment plans based on individual patient data. As these technologies continue to evolve, the integration of early diagnosis, digital imaging, and machine learning is paving the way for a smarter, more efficient, and patient-centric healthcare ecosystem.

Machine Learning Techniques. Machine learning techniques in medical imaging are broadly categorized into supervised, unsupervised, and reinforcement learning paradigms, each addressing different clinical and computational challenges. Supervised learning is the most widely used paradigm in medical imaging, where models are trained using labeled datasets consisting of input images and corresponding annotations (e.g., tumor boundaries, disease labels). These methods are particularly effective in tasks such as classification, segmentation, and detection. Deep supervised models, especially convolutional neural networks (CNNs), have demonstrated high accuracy in identifying pathological patterns due to their ability to learn hierarchical feature representations directly from imaging data [23]. However, their performance heavily depends on the availability of large, well-annotated datasets, which are often expensive and time-consuming to obtain in healthcare settings. Unsupervised learning addresses the limitation of labeled data by discovering intrinsic patterns in unlabeled datasets. Techniques such as clustering [24], autoencoders [25], and generative models [26] are used to learn data distributions and latent representations. In medical imaging, unsupervised learning is useful for anomaly detection, image reconstruction, and feature extraction, particularly when annotated data is scarce [27]. It plays a critical role in radiomics, where high-dimensional imaging features are extracted to characterize disease phenotypes. Despite its potential, unsupervised learning may produce less clinically interpretable results due to the absence of explicit supervision. Reinforcement learning (RL) is an emerging paradigm in medical imaging, where an agent learns optimal decision-making strategies through interaction with an environment. RL has been applied to tasks such as landmark

detection, image navigation, and adaptive image acquisition [28]. Although less commonly used compared to supervised methods, RL shows promise in optimizing sequential decision processes in imaging workflows. Recent studies highlight its application in improving diagnostic accuracy and automation, though challenges such as complexity and limited clinical adoption remain.

Deep Learning Architectures. On the otherhand, deep learning architectures form the backbone of modern medical image analysis systems, enabling automated feature extraction and high-level representation learning. Convolutional Neural Networks (CNNs) are the most dominant architecture in medical imaging due to their ability to capture spatial hierarchies through convolutional filters [23]. CNNs are extensively used for image classification, segmentation, and detection tasks. Architectures such as U-Net and ResNet have significantly improved performance in clinical applications by enabling precise localization and robust feature extraction [29]. Their success lies in exploiting local spatial correlations and translation invariance in images. Consequently, Recurrent Neural Networks (RNNs) are designed for sequential data processing and are particularly useful when temporal or contextual information is involved, such as in longitudinal imaging studies or video-based diagnostics (e.g., ultrasound or endoscopy). Variants like Long Short-Term Memory (LSTM) networks address issues like vanishing gradients and enable learning long-term dependencies [31]. In medical imaging, RNNs are often combined with CNNs to incorporate both spatial and temporal features. Transformers represent a newer class of architectures that rely on self-attention mechanisms to capture global contextual relationships in data. Unlike CNNs, which focus on local receptive fields, transformers model long-range dependencies effectively. Their application in medical imaging has grown rapidly, particularly in segmentation, classification, and multimodal learning tasks. Recent surveys highlight that transformers are increasingly integrated with CNNs to leverage both local and global feature representations.

2D vs 3D Deep Learning Models. Medical imaging data can be processed using either 2D or 3D deep learning models, depending on the modality and application. 2D models operate

on individual image slices and are computationally efficient, making them suitable for large-scale datasets and real-time applications [32]. They are widely used in modalities such as X-rays and histopathology images. However, 2D models may fail to capture volumetric context, which is critical in many diagnostic tasks. 3D models, on the other hand, process volumetric data (e.g., CT, MRI scans) and can capture spatial dependencies across multiple slices. These models provide more comprehensive anatomical information and often achieve higher accuracy in segmentation and detection tasks. For example, 3D CNNs have been successfully applied to tumor characterization and volumetric analysis in clinical studies. However, they require significantly higher computational resources and memory, limiting their scalability [33][34].

Feature Engineering vs Representation Learning. Feature extraction is a critical step in medical image analysis, traditionally performed using handcrafted methods but increasingly replaced by automated representation learning. Feature engineering (handcrafted features) involves manually designing features based on domain knowledge, such as texture, shape, intensity, and statistical descriptors [35][36]. Radiomics is a prominent example, where quantitative features are extracted from medical images to support clinical decision-making [37]. These features can reveal subtle patterns not visible to the human eye, aiding in diagnosis and prognosis. However, handcrafted features are often task-specific and may lack generalization across datasets. Representation learning (deep features), enabled by deep learning, automatically learns hierarchical feature representations directly from raw data. CNNs and other deep architectures eliminate the need for manual feature design by learning discriminative features during training. These learned features are more robust, scalable, and adaptable to different tasks. Studies have shown that deep features outperform handcrafted features in various medical imaging applications, particularly in complex tasks such as tumor detection and multi-class classification. The transition from handcrafted to deep features represents a paradigm shift, allowing models to capture complex, non-linear patterns and improving overall diagnostic performance.

5. Explainable Machine Learning Techniques for Building Medical Imaging Guided Decision Support Systems

The integration of machine learning (ML) into medical imaging has significantly advanced computer-aided diagnosis, enabling automated detection, classification, segmentation, and prognosis of diseases. However, the adoption of ML models in clinical practice is often hindered by their “black-box” nature, particularly in deep learning architectures such as convolutional neural networks (CNNs) and transformers. In high-stakes environments like healthcare, clinicians require transparency, interpretability, and trust in automated decisions. This has led to the emergence of Explainable Artificial Intelligence (XAI), a subfield within Machine Learning, focused on making model predictions understandable and justifiable as shown in Fig. 7. Medical imaging-guided decision support systems (DSS) rely on explainable ML techniques to provide not only accurate predictions but also interpretable insights into the reasoning behind those predictions [38][39]. These systems are critical in domains such as radiology, histopathology, and cardiology, where decisions directly impact patient outcomes. Explainability is essential in medical imaging DSS for several reasons. First is the clinical trust and adoption where clinicians are more likely to trust systems that provide visual or feature-based explanations rather than opaque predictions. Second is the regulatory compliance. Healthcare regulations increasingly require transparency in AI-driven decision-making. Third is the error analysis and debugging. Explainability helps identify model biases, data leakage, and failure modes. Fourth is the ethical considerations. Transparent models reduce the risk of biased or unfair decisions, particularly in sensitive populations. Explainability bridges the gap between complex computational models and human-understandable reasoning, facilitating collaborative decision-making between AI systems and clinicians. Explainable Machine Learning (XML) techniques can be broadly categorized based on how interpretability is achieved either inherently through model design or externally through post-hoc analysis. These categories are particularly important in medical imaging applications, where transparency and trustworthiness are critical for clinical decision-making.

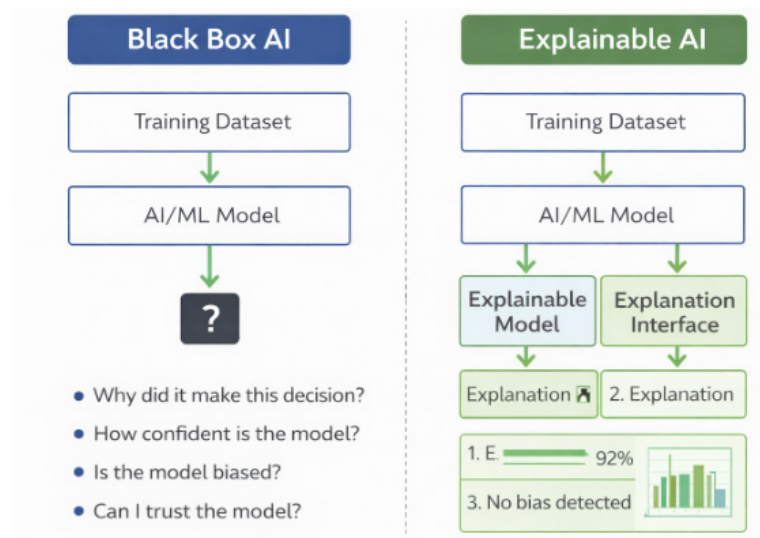


Fig. 7 Need for Explainable Machine Learning in Disease Diagnosis

Intrinsic Interpretability (White-box Models). Intrinsic interpretability refers to models that are inherently transparent in their structure and decision-making processes [40]. Such models, often termed white-box models, include decision trees, linear regression, logistic regression, and rule-based systems. These approaches enable direct understanding of how input features contribute to predictions through explicit mathematical relationships or decision rules. For instance, in linear models, feature coefficients provide a clear indication of feature importance, while decision trees visually represent hierarchical decision paths. Despite their interpretability advantages, these models often struggle to capture the complex, high-dimensional patterns present in medical imaging data, such as those found in MRI, CT, or histopathological images. Consequently, their predictive performance may be inferior compared to more complex models like deep neural networks.

Post-hoc Explainability Methods. Post-hoc explainability methods are designed to interpret predictions after a model has been trained, particularly when dealing with complex and opaque models such as deep learning architectures [41][42][43]. These techniques do not alter the original model but instead provide insights into its behavior, making them highly valuable

in medical imaging tasks where accuracy and interpretability must coexist. Feature attribution methods constitute a major class of post-hoc techniques. These methods assign importance scores to input features or image pixels to quantify their contribution to a model's prediction. Techniques such as SHAP (SHapley Additive exPlanations) [44] leverage principles from cooperative game theory to fairly distribute the contribution of each feature, offering both global and local interpretability. Similarly, LIME (Local Interpretable Model-agnostic Explanations) [45] approximates the behavior of complex models in the vicinity of a specific instance using simpler, interpretable surrogate models. In medical imaging, these methods are extensively used to highlight regions of interest that influence classification outcomes, thereby aiding clinicians in understanding model reasoning. Another important category is gradient-based visualization techniques, which are particularly suited for deep neural networks. These methods utilize gradients flowing through the network to identify influential regions in the input data. For example, Grad-CAM (Gradient-weighted Class Activation Mapping) [46] generates class-specific heatmaps that localize important areas in an image, while techniques like guided backpropagation and integrated gradients provide fine-grained pixel-level explanations. Such spatial visualizations are especially useful in radiology and histopathology, where identifying disease-relevant regions is essential. Perturbation-based methods offer an alternative approach by analyzing how systematic modifications to the input affect the model's output. Techniques such as occlusion sensitivity involve masking different parts of an image to observe changes in prediction confidence, while permutation importance evaluates the impact of shuffling feature values. These approaches help identify critical regions or features that significantly influence model decisions, providing intuitive and model-agnostic explanations. Overall, the choice of explainability technique depends on the application requirements, model complexity, and the level of interpretability needed, especially in sensitive domains like medical imaging where both accuracy and transparency are paramount. Further, the explainability module bridges the gap between complex model outputs and clinical interpretation, enhancing reliability, accountability, and adoption of AI-driven medical imaging systems.

6. Conclusion

The convergence of medical imaging and machine learning represents a significant advancement in modern healthcare, enabling more accurate, efficient, and patient-centered diagnosis and treatment. By leveraging advanced imaging modalities along with machine learning algorithms, clinicians can detect diseases at earlier stages, monitor progression, and personalize treatment strategies based on individual patient data. This integration not only enhances diagnostic accuracy and workflow efficiency but also supports predictive analytics, treatment planning, and outcome assessment, thereby improving overall patient care and reducing healthcare costs. Looking forward, ongoing research in explainable AI, multimodal data integration, and sustainable machine learning promises to further transform healthcare systems, enabling proactive, precise, and personalized medical care. The collaboration between medical imaging and machine learning holds immense potential to improve global health outcomes and redefine the future of disease diagnosis and management.

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An Ideal approach for Digital Transaction Fraud Detection using Machine Learning

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Abstract

This paper highlights the importance of machine learning-based solutions for finding the optimal approach for detecting credit card fraud. With the increasing number of digital transactions, identifying fraudulent activities has become a critical challenge. In this study, several machine learning models, including Random Forest, XGBoost, and LightGBM, are applied to detect fraudulent transactions. The experiments are conducted on the ULB Credit Card Fraud Detection dataset, which contains 284,807 transaction records with a fraud rate of 0.172%, making it a highly imbalanced dataset. The models are evaluated using performance metrics such as Precision–Recall Area Under the Curve (PR-AUC) and Receiver Operating Characteristic Area Under the Curve (ROC-AUC). The results show that all models perform effectively in fraud detection; however, LightGBM achieves the best performance with the highest PR-AUC score of 0.8764. Therefore, LightGBM is identified as the most effective model among the evaluated approaches for this dataset.

Keywords: *Credit Card Fraud, XGBoost, LightGBM, Random Forest, PR-AUC, Anomaly Detection. Machine Learning, Random Forest, LSTM*

1. Introduction

Considering the rapid advancement of technology and the availability of online services, digital transactions have become an essential part of our lives. There is an aspect of convenience and significant time savings that make digital transactions extremely convenient for livelihood. Aside from that, each digital transaction generates a record, which provides transparency and makes digital transactions easier to follow.

Nowadays, digital transactions serve as a support mechanism for small and online businesses, ultimately contributing to economic growth. As the quantity of digital transactions increases, so does the number of fraud incidents. According to reports, internet-based transactions account for a large portion of total bank fraud instances, indicating systemic vulnerabilities. There is a need for a solid security architecture to reduce or regulate the growth of fraud. User awareness and advanced technology engagement in the research of digital payment for fraud detection.

Digital payment platforms offer financial services like as money transfers, bill payments, and cashless transactions (Calderon, 2025). Digital transactions are the transfers of cashless funds using digital payment channels.

Digital transactions have become an essential part of everyday life, playing a significant role in activities ranging from small businesses to large-scale industries. The growth of digital payments has been influenced by several factors, including government initiatives promoting digitization, increased internet access, and the widespread use of smartphones. The expansion of online business and e-commerce has further accelerated this trend. In the context of the Indian economy, demonetization played a major role in boosting digital transactions. A study by [14] highlights the significant increase in the adoption of digital payments across India during this period. Due to the shortage of cash, platforms such as Google Pay, Paytm, and BHIM experienced rapid growth, making demonetization a catalyst for the expansion of digital payment systems in India.

However, with the rapid rise of digital payment mechanisms, cases of fraud have also increased. Among these, credit card fraud has emerged as a significant challenge in digital financial transactions. This paper focuses on exploring and developing a fraud detection mechanism for credit card transactions using machine learning algorithms.

This studies focus on finding an optimal model for detection of fraud in credit card data. Machine learning is widely used standard approaches for the model which is complex, non-linear patterns. The considered dataset is highly imbalanced, SMOTE mechanism is applied. The experiment make used of Random Forest, and Gradient Boost technique, LightGBost and XGBoost.

2. Literature Survey

In recent years, research on digital transactions has grown in importance. With the fast rise of online payment systems, assuring security and reliability has become a major concern. In this context, Artificial Intelligence (AI) has emerged as a critical solution provider for solving these difficulties, particularly in identifying and preventing fraudulent activity in digital financial systems.

According to [7] AI plays a crucial role in preventing fraud and maintaining trust in digital payment systems. Several studies, including [12], suggest that machine learning and deep-learning algorithms can effectively detect fraud in digital transactions. Another study by [13] compares the performance of several machine learning approaches on digital transactions.

Numerous studies demonstrate that artificial intelligence has demonstrated encouraging results in addressing the issue of fraud detection in online transactions. Credit card fraud is growing dramatically in the context of digital transactions [10]. A comparative analysis and a promising outcome are shown in [1] work on fraud detection using AI machine learning algorithms. Another study by [2] uses a granular computing framework that combines fuzzy rough set theory with reasoning techniques to detect credit card fraud. The study [16] explores several boost techniques, such as XGBoost and CatBoost. Because of its self-learning capabilities and algorithm-based detection approaches, artificial intelligence has become more important in credit card fraud detection [10, 1, 14]. Researchers

are concentrating more on creating AI-based models to enhance fraud detection systems. A report on a hybrid approach for detecting fraud in digital transactions may be found at [1]. In recent years, there has been a lot of interest in research on the use of machine learning algorithms and artificial intelligence for fraud detection. Traditional rule-based systems are no longer adequate to identify sophisticated fraudulent activities due to the explosive rise of digital payments and online transactions. Because of this, researchers are concentrating more on AI-based models [4] that can learn patterns from big datasets [8], adjust to new fraud tactics, and enhance the precision and effectiveness of fraud detection systems[17, 10].

This research focuses on implementing different machine learning algorithms and performing a comparative study to analyze their performance in credit card fraud detection.

3. Model

Credit card transactions done by European cardholders over two days in September 2013 are included in the ULB Credit Card Fraud Detection dataset. It is one of the most often mentioned benchmark datasets in the literature on fraud detection and is freely accessible on Kaggle (mlg-ulb/creditcardfraud).

The dataset exhibits a canonical extreme imbalance issue with a fraud rate of 0.172%. The degenerate strategy of forecasting all-legitimate is incentivized by optimizing for accuracy, and traditional metrics (accuracy, ROC-AUC)[9] provide an unduly optimistic image of model quality. For this reason, the main statistic used in this work is Precision-Recall AUC, which is only sensitive to minority-class performance.

3.1 Methodology

The first and most important stage in creating the fraud detection system is preprocessing. In order for machine learning algorithms to function well and yield trustworthy results, this step makes sure that the dataset is appropriately prepared. Feature scaling, which standardizes the range of the input variables, is the first step in the preprocessing procedure. Although it enhances model performance and prevents features with bigger values from dominating those with smaller values during training, this phase is very crucial.

To accurately assess the model's performance, the dataset is split into training and testing sets after the preprocessing step is finished. An 80:20 ratio is used to divide the data in this investigation. Consequently, 56,962 samples are set aside for testing, while 227,845 samples are used to train the model, enabling it to discover patterns and relationships within the data. The testing set is used to gauge the trained model's efficacy in identifying fraudulent transactions as well as how effectively it generalizes to new data. This methodical data preparation contributes to a trustworthy and objective assessment of the fraud detection model.

Over viewing the dataset, it is observed that the dataset possesses a class imbalance problem, which is one of the issues in most of the classification problems and eventually becomes biased toward the prediction model and eventually reduces the efficiency of the model. To overcome the issue, this model makes use of the SMOTE[5] (Synthetic Minority Oversampling Technique), which is applied over training samples in order to create a balanced class set over distribution to the ML (machine learning) models. Generally SMOTE creates synthetic samples of the minority class by interpolating among existing minority class samples. After the application of SMOTE, the training sample obtains uniform class distribution among the samples. Balancing the dataset plays an important factor in defining model performance. A balanced set allows models to effectively learn the patterns for the distinct class, helps in capturing better decision boundaries, and eventually reduces the risk of bias, overprediction, and improves the metrics score.

However, the testing remained unprocessed in order to reflect the true class distribution and retain the originality over class distribution. The evaluation remains unbiased and representative of real-world performance, which allows reliable comparison over models.

However, for XGBoost and LightGBM[11], they are trained upon the original imbalanced dataset; these models address class imbalance through cost-sensitive learning. Parameters responsible for XGBoost[6] and LightGBM are *scale_pos_weight* and *class_weight*, which adjust the learning process by managing greater weight for the underrepresented class instances.

This work considers 3 different models, namely Random Forest (RF)[3], for the detection mechanism. Table 1 gives the

ideas about the different parameters considered by the model for the experiment. *n_estimators* defines the total numbers of trees employed; 100 trees are considered with *class_weight* as balanced to compensate for the class imbalance, prioritizing the importance of minority samples, and *n_jobs=-1* with utilization of all available CPU cores.

XGBoost and LightGBM adopt 200 estimators to strengthen the boosting effectiveness, with a learning rate of 0.05 for a stable approach to learning to prevent overfitting and *max_depth* of 6 to control the model complexity.

Table 1. Model hyperparameters configurations

Model	n_estimators	Key Configuration
Random Forest	100	class_weight='balanced', n_jobs=-1
XGBoost	200	lr=0.05, max_depth=6, scale_pos_weight=ratio
LightGBM	200	lr=0.05, max_depth=6, class_weight='balanced'

4. Result and Discussion

Receiver operating characteristic-area under curve (ROC-AUC) is the performance statistic used in this experiment’s performance evaluation. Based on the sensitivity and specificity thresholds, the ROC assesses the model’s performance. However, the AUC provides an overview of the model’s overall performance based on class scores between 0.00 and 1.00. The outcome of the experiment is shown in figure 2. Metrics that take into account various aspects of the efficacy of the experiment in fruit detection are used to evaluate it.

Precision and recall are another mechanism for performance evaluation. Precision plays a vital role when errors are high, and recall reduces the false negatives. Figure 3 represents the place of the response of the model over the precision-recall graph.

The LightGBM model achieves the maximum PR-AUC of 0.8764 during training, with an execution time of 5.48 seconds , making it a natural fit for fraud production. It can identify intricate fraud patterns rapidly according to its histogram-based leaf-wise tree growth. Recall score of 0.8776 shows that 88% of the fraud cases in the collection could be identified. Conversely, out of all the models, the Random Forest model yields a strong F-score of 0.81

and precision of 0.81, indicating that the transactions that have been reported are fraudulent. However, as seen in figure 3, RM has an execution time of 242.88s, which is 49 times slower than LightGBM.

The XGBoost result is the fastest among the models, with 4.98 seconds of execution time, which is fractionally faster than LightGBM and robust. Overall model performance is shown in figure 1.

Table 2: Performance score of the models

Model	ROC-AUC	F1	Precision	Recall	Time (s)
LightGBM	0.9754	0.7611	0.6719	0.8776	5.48
Random Forest	0.9688	0.8103	0.8144	0.8061	242.88
XGBoost	0.9754	0.8000	0.7664	0.8367	4.98

5. Conclusion

This paper explains the process to use the ULB benchmark dataset to identify the optimal machine learning algorithm for credit card fraud detection. With the highest PR-AUC score of 0.8764, recall value of 0.8776, and training time of 5.48, LightGBM performed better than the other models during the testing as tabulated in table 2. However, gradient boosting XGBoost produced the fastest model (4.98 seconds) with accuracy on par with LightGBM. Random Forest, on the other hand, has the highest precision and F1-Score; but, due to the significant speed cost, it is better suited for offline batch scoring than real-time inference.

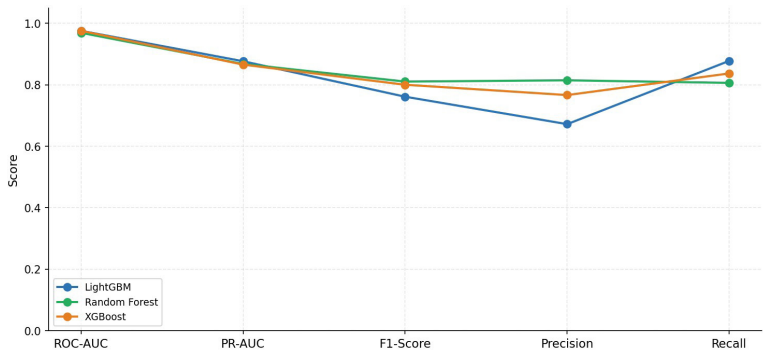
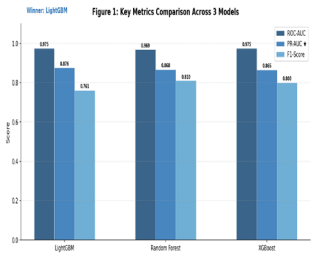
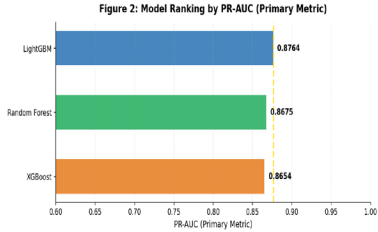


Fig. 1: Total metrics profile for the models

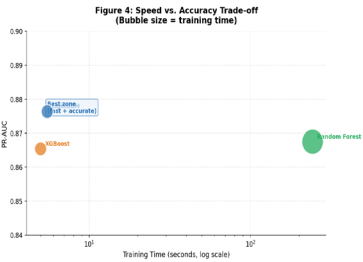


a. Metrics chart

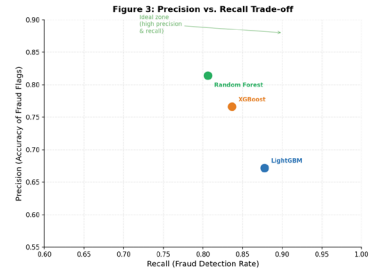


b. PR-AUC

Fig. 2: Models performance charts PR-AUC, RO-AUC AND F1-score



a. Speed vs accuracy trade graph



b. Models comparative analysis over Precision verse Recall

Fig 3: Models comparative analysis over Precision verse Recall

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