

**Innovative Research for Inclusive Growth
&
Integrated Transformation
IRIGIT**

KVM. Prof. Dr. R. Ganesan

Innovative Research for Inclusive Growth & Integrated Transformation

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Published By



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Clear roads will not teach you to handle hurdles only rugged road teaches you to overcome hurdles after then you will become Clear

- KVM. Prof. Dr. R. Ganesan

Foreword

The growth of any nation depends upon the facilitating platforms it enables to foster research innovation at all levels and layers within its system. Today, inclusivity gains significance more so in the post pandemic scenario. Moreover, integrated transformation is very much indispensable for global prosperity. This is possible only through innovative researches across the world with utmost continuity alongside having a constant vigil for maintaining its ethicality.

The researches' conducted in interdisciplinary and multidisciplinary areas contribute phenomenally to the overall well-being of mankind towards gaining progression and vouching for a sustainable socio-economic development. The congregation of various research perspectives, theoretical frameworks and conceptual views presented in this edited book are much needed to understand the technology advancements and address future requirements.

This edited book has included selective book chapters in science, management, arts and humanities to facilitate the integrated transformation in terms of learning and gaining wisdom. Furthermore, 'NFED Publications' professes to the publishing community that it is very much conscious and cautious about quality rather than quantity. The research chapters contributed by each author in this edited book are quite unique, wherein they adopted different kinds of methods and approaches in presenting their respective book chapters.

I view this edited book titled 'Innovative Research for Inclusive Growth & Integrated Transformation' as one of the important intellectual resources with all fact-finding information that provides an irrefutable knowledge sharing for research communities at large.

I heartily appreciate the Chief Editor's conscientious efforts in organizing, editing and compiling the research chapters of various authors from different states of India and abroad in this edited book.

I am sure this aforesaid edited book will enlighten the readers, researchers, academicians and practitioners.

Sd/-

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Preface

Today, the researchers are focusing on domains enhancing human development with sustainability. Hence, its approaches are interdisciplinary in nature for bringing in a phenomenal change within the society. The development of any nation depends mainly on its intellectual resources within it who are the fountainheads of research strength. These intellectual sources have to focus more on ecosystems that foster ergonomic livelihood, socio-economic prospects and enabling eco-friendly environment for achieving a perpetual growth. This is possible only through creating an appropriate scientific platform at large and encouraging budding researchers towards socio-technological innovations.

The present edited book titled ‘Innovative Research for Inclusive Growth & Integrated Transformation’ envisions in its mission of congregating the book chapters on various disciplines of study viz., Human Resource Management, Industrial Policies, Technology Innovation, Applied Psychology, Entrepreneurship, Brand Management, Public Administration, Rural Development, Plant Biotechnology, Healthcare, etc. for gaining an integrated transformation towards societal progression.

This edited book by itself is a holistic learning platform, which emphasizes on knowledge dissemination among research communities across the globe. The inclusive growth of any society is possible only through conducting innovative research. The results and discussions presented in various book chapters paves the way for gaining a radical understanding on new vistas in research. The aforesaid research disciplines are quite indispensable for better understanding of issues and provides the roadmap to face the upcoming challenges of developing and underdeveloped countries across the world.

I sincerely thank all the chapter authors of this edited book for placing their splendid research contributions.

I am sure all the readers will benefit from this edited book.

Jai Hind!!!

Sd/-

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Understanding the Influence of Demographic Variables on Employee Engagement: Evidence from SMEs in Anand at Gujarat

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Abstract

Employee Engagement in simple terms applies as to how employees stay connected and willing to put more effort with the organization and its goals. It is pertinent that there is a wealth of information about large and organized sectors while less is known about employees in Small and Medium Enterprises (SMEs). This research study explores on employee engagement in SMEs in Anand within Gujarat with a focus on demographic influences. The findings showed that engagement varies across gender, age, education and work experience. Female employees, middle-aged workers, undergraduates and those with long tenure displayed stronger engagement, while newcomers and employees at the end of their careers reported lower levels. In contrast, place of birth, job role and enterprise size had little impact. The results clearly bring the importance and need in forming the engagement strategies based on the profile of each employee group towards improving employee motivation to build organizational performance

Keywords: Employee Engagement, Demographics, Occupational Factor, Gender, Age, Education.

Introduction

In India, SMEs act as the backbone of economy and are considered the second largest employment generator after agriculture. The HRD of small and medium enterprises also should have similar level of care, support and professional development as in the case of public and large private organizations. Moreover, it should focus more on creating the job satisfaction, growth opportunities, seek recognition and a sense of belongingness amongst employees. It is to be noted that regardless of the size, organizations need extensive business skills, technical know-how and committed and engaged human resources. Employees' ability to connect with their jobs and workplace has become increasingly important due to the rapidly changing economy, where issues such as attrition, disengaging from work/job, resignation and absenteeism are among the greatest threats to an organization. Therefore, businesses should concentrate more on their efforts in maximizing the level of employee engagement with an aim to develop a competent workforce. Although, several positive employee and organizational

outcomes of employee engagement in terms of productivity, profitability, safety and turnover (Wagner & Harter, 2006) are in practice, but no consensus exists on what factors exactly drive the employee engagement (Cooper-Thomas et al., 2018).

According to the Micro, Small and Medium Enterprises (MSME) Annual Report 2024-25, a total of 83,349 small and 8,538 medium enterprises have been registered through the newly launched online portal 'Udyam' under the Ministry of MSME, Government of India. With more registration, there would be an increase in employment. As per the aforementioned report, the small-scale and medium-scale sector employed 14,994,229 and 6,739,936 people respectively. It is imperative that these employees are connected to their work and workplace to perform and give best of their abilities, which in turn contribute to organizational success over years. Despite the low research activity around employee engagement in SMEs as compared to large companies (Harney & Alkhalaf, 2021), the literature highlights that intense levels of employee engagement in SMEs can significantly influence employee motivation, retention and consequently company performance. Consequently, employee engagement deserves greater emphasis in small organizations seeking competitive advantage and improved profitability (Harney & Nolan, 2022). Compared to larger firms, SMEs continue to lag behind in regards to employee education, income, skills and competence levels, consequently resulting in inefficient and unmotivated employees (Moen, 1999). They share a unique employment relationship, making it more interesting to find the status of engagement in these organizations. Employee engagement does not necessarily require substantial financial investment or elaborate strategic frameworks; instead, it is often fostered through practices that enhance employees' sense of psychological safety (Edmondson, 1999). Furthermore, the workers in SMEs feel that they are not getting sufficient perceived organizational support (Eisenberger & Huntington, 1986) from their work contribution (Kahn, 1990).

Literature Review

Theory of Employee Engagement & Types

Employee engagement refers to an optimal level of work involvement by an employee which consists of three types of engagements; namely, physical, cognitive and emotional engagement. In furtherance, an engaged employee contributes his/her best towards his/her job. Kahn (1990) demonstrated that involved workers demonstrated all elements of humanity in their work. This paves opportunities for employees to utilize their mental, physical and emotional state within their roles. The literature recognizes that there are three major elements of employee engagement (Harter & Schmidt., 2002).

Components of Employee Engagement:

1. **Energy-vigour:** Where employees are energized, feel they have mental endurance, willing to exert effort and stick with it in spite of obstacles.
2. **Enthusiasm-dedication:** Where employees feel their work has meaning, exhibit enthusiasm, have inspiration for the work they perform and take pride in their work.

3. Absorption: Where employees are completely focused and very happy while they work (time goes by quickly) and employees cannot separate themselves from their job during the day.

Linking Engagement to Business Outcome

Harter et al. (2002) explored that the association between employee engagement with the business outcome variables in a variety of different organizations and departments are statistically significant. Moreover, the meta-analysis has found that employee engagement and customer satisfaction, profitability, productivity, employee turnover and safety outcomes are positively correlated. Also, it provided evidence for managers' strategic mandate, especially for SME managers to create and apply systematic engagement drivers analytically. Another research study reported that employee engagement as one of the factors for Nifty 50 companies 2014 annual report, which exhibited as evidence of improving awareness among Indian companies regarding the necessity for engaged employees (Srivatsava, 2014). Many research studies revealed that the employee engagement impacts customer satisfaction, profitability, productivity and safety than overall job satisfaction.

Drivers of Engagement

Recognition is often identified as a potential element in driving employee engagement by Srivastava et al. (2014) in their survey of managerial employees in private hospitals. Moreover, Sarangi and Srivastava (2012) carried out an experiment on 247 private banking executives in India and they concluded that psychological empowerment had a positive correlation with employee engagement and individual meaning and competence were key determinants of employee engagement. Also, Singh and Sanjeev (2013) found positive correlation between employee engagement and performance in their study on employee engagement in an Indian Public Sector Undertaking. Task meaningfulness, support, cooperation, recognition and employee motivation were all key contributors to engagement, according to Singh and Sanjeev (2013). Balakrishnan and Masthan (2013) concluded that communicating internally is critical factor in employee engagement in their study of employees at Delhi Airport. Similarly, Biswas and Bhatnagar (2013) reported that job satisfaction has a positive correlation towards employee engagement among 246 managers from India. Mohanty and Anuprasad (2021) conducted an extensive study involving 812 executives from Indian power companies. Trust, as a factor that drives employee engagement, was the second most salient finding from their analysis and included coworker, supervisor and organizational trust. Finally, Joshi and Sodhi (2011) offered a comprehensive analysis of engagement drivers among both executive and non-executive employees in Indian organizations. They identified work-life balance, recognition, job content and monetary rewards as some of the most important considerations to take into account when it comes to employee engagement.

Rationale for Demographic Variables

The basic demographic factors like age, gender, education and organizational tenure are basic dimensions that provide background information to the organization and its members. These

factors are frequently integrated into organizational behaviour models as control variables to account for existing variance in engagement levels. However, limiting the analysis of demographics to mere controls overlooks their potential as weak antecedents or crucial moderators that condition the efficacy of other engagement drivers. Elderly employees above the age of 50 are more engaged with a higher degree of involvement and work for the success of the organization. This was against the general perception that elderly employees demonstrate low engagement (Douglas & Roberts, 2020; James et al., 2011). According to Dammam & Alkahtani (2011), employees invest less when they are about to retire as they start planning their post-retirement life. Muntaha et al. (2013) emphasized that work engagement is a gendered concept and female employees find it difficult to display physical, emotional and cognitive engagement. Yet another study conducted by Suan and Mohd Nasurdin (2016) on hotel employees found that male employees' engagement level increases with the increase of supervisor support, which does not happen to the female employees. Also, Ravikumar (2013) focused on Indian MSMEs in the manufacturing sector and revealed that demographic variables, particularly work experience, significantly influenced engagement levels; employees with greater experience exhibited higher engagement.

This challenges the notion that ageing leads to disengagement, although some research indicated that employees approaching retirement may reduce investment in work as they begin planning for life after employment (Dammam & Alkahtani, 2011). Gender has also been a salient factor in engagement research. Muntaha & Rashid (2013) concluded that work engagement is a gendered construct, with women sometimes facing barriers in displaying engagement through physical, cognitive and emotional means. Similarly, Suan & Mohd Nasurdin (2016) in their study on hotel employees found that male employees' engagement increased with supervisor support, whereas female employees have not demonstrated the same pattern, suggesting differential responses to managerial practices. Other scholars argued that women's engagement may be influenced by work–family balance and organizational support for flexibility (Rothbard, 2001; Karatepe et al., 2010). Table 1 indicated below outlines some of the significant research in which demographic factors are analysed and how they are related to employee engagement.

Table 1: Demographic Variables & Employee Engagement

Author(s) & Year	Study Context / Country	Demographic Variables Examined	Major Findings on Employee Engagement	Key Outcomes
Albdour & Altarawneh (2014)	Jordan (Banking Sector)	Age, Gender & Education	Older and more educated employees showed higher engagement; gender difference insignificant	Cultural influence moderates' engagement patterns
Bhatnagar (2007)	India (IT Sector)	Experience & Education	Engagement rises with tenure and learning opportunities	Education enhances affective engagement
Saks (2006)	North America	Age & Experience	Age and experience moderate job engagement via organizational support	Engagement linked with organizational citizenship
Schaufeli et al. (2006)	Multinational sample	Age & Gender	Age positively correlated with vigour; gender differences minimal	Established UWES (Utrecht Work Engagement Scale)
Menguc & Boichuk (2012)	U.S. (Sales Sector)	Age & Experience	Experience enhances engagement in customer-centric roles	Job identity strength moderates' impact
Memon et al. (2017)	Malaysia	Education & Experience	Higher education and longer tenure predict stronger engagement	Training satisfaction mediates engagement
Shuck & Wollard (2010)	Conceptual Review	Age, Gender & Education	Demographic factors contextualize engagement antecedents	Proposed HRD framework including demographics
Karatepe & Karadas (2015)	Turkey (Hospitality)	Education & Experience	Experience significantly increases engagement; education indirectly linked	Psychological capital mediates engagement

Menguc et al. (2013)	Multisectoral (Services)	Age & Gender	Older employees more engaged; gender moderates role stress impact	Gender gaps shrink with supportive culture
Kundu & Lata (2017)	India	Age & Education	Older, educated employees more engaged and committed	Work environment moderates' engagement-retention link

Methodology

This study is based on the effect of demographic variables such as age, gender, education and experience of employees on employee engagement. The study adopted descriptive research design for discussing the results accordingly. A total of 353 employees working in the SME sector under engineering and agro/food processing industries holding non-managerial positions within Anand City at Gujarat are included in this study through convenient sampling.

The results of the examination of the responses (353) on the Utrecht Work Engagement Scale (Schaufeli, 2002) showed that the responses follow a normal distribution as indicated by the skewness and kurtosis values. Therefore, researcher can utilize the sample data as representation of the total population, wherein all are within the range of -3 and +3 as suggested by Kline (2010) and Hair & Risher (2019). The kurtosis for the employees' engagement has been found as 1.310. The difference between the demographics of employees is tested using ANOVA and independent samples t-tests.

Results & Discussion

1. Employee Engagement Score:

The employee engagement score is an instrument used to assess the Employee Engagement (EE) of employees in the Small and Medium Enterprises (SMEs) of Gujarat was evaluated for its reliability using Cronbach's Alpha statistic which is a measure of the internal consistency of items on a scale. The UWES 17-item instrument used to conduct the study produced an alpha of ($\alpha = 0.916$) which indicated a high level of trustworthiness and therefore confirms that there is a very high degree of internal consistency in the way that all items assessed employees' engagement within their workplaces. All other things being equal, measurement scales that have an alpha above 0.70 are generally considered acceptable (Hair et al., 2019). Therefore, the UWES has been determined to be a suitable measurement scale for conducting other statistical analyses.

The descriptive analyses demonstrated that the mean level of employee engagement (EE) for employees working in SMEs of Gujarat was 3.92 (SD = 0.54). This means that overall, employees demonstrated a moderately high level of employee engagement in their respective workplaces. The three dimensions of employee engagement demonstrated the following mean

levels of employee engagement: Vigour (VI) ($M = 4.03$, $SD = 0.56$); Absorption (AB) ($M = 3.86$, $SD = 0.58$); and Dedication (DD) ($M = 3.85$, $SD = 0.70$).

The higher vigour score suggests that employees generally feel energetic and resilient at work, which is a positive sign of emotional and physical investment in their roles. Slightly lower scores for dedication and absorption may reflect the contextual realities of SMEs, whereas employees often manage multiple responsibilities and operate under resource constraints that can limit deep engagement or prolonged focus.

The result of the current research appears consistent with findings from several previous studies on employee participation in small and medium-sized enterprises (SMEs) and similar settings. The moderately high degrees of employee participation among SMEs in Gujarat matches with Harney and Nolan (2022) viewed that levels of employee participation will enhance sustainability and motivation of employees even when there is a lack of structured human resource systems. Additionally, that vigour is among the most dominant dimensions and supports the observation of Schaufeli et al. (2006), which highlighted that energetic involvement and resiliency are the most pronounced indicators of employee participation in all workplace environments. Furthermore, the research study conducted by Harter et al. (2002) also supported the finding by mentioning that engaged employees are more productive, loyal and positively contribute to the success of the organization. Furthermore, since small and medium enterprises tend to operate with limited resources (compared to larger entities) and most employees must perform at least two responsibilities, lower levels of absorption and dedication may be a reflection of the organizational context as noted by Dundon et al. (2009).

Demography & Engagement

The same set of data are analyzed using SPSS to check if there were any statistically significant differences in employee engagement among age, gender, educational level and years of work experience. The normality assumption was tested beforehand and it was confirmed that all the constructs had acceptable values of skewness and kurtosis in the range of -3 to $+3$.

The one-way ANOVA demonstrated a statistically significant difference in the level of employee engagement between varying age groups, $F(4,348) = 9.173$, $p < 0.05$. As such, these data indicated that employees engaged in SMEs of Gujarat vary significantly depending on the age demographic that they fall into. The finding suggested that age plays an important role in shaping engagement, possibly because employees in different life and career stages perceive work meaning, organizational support and growth opportunities differently. Also, younger employees may display enthusiasm driven by career ambition, whereas older employees may exhibit engagement linked to job security and organizational loyalty.

The current finding regarding the age of the employee is confirming prior documents that discuss how the degree of employee participation differs based on the stage of life and career (Banihani et al., 2013; James et al., 2012). According to Douglas and Roberts (2020), older employees usually demonstrate higher levels of engagement largely due to their increased commitment and emotional connection to the workplace. James et al. 2011 in their study noted

that older employees generally exhibit higher levels of overall participation and contribution to the organization than other employees. However, this finding is partially contrary to the viewpoint expressed by Damman & Henkens (2011), which revealed that employees are likely to reduce their participation prior to retirement and preparation for retirement. Therefore, age affects participation depending upon the stage of employee's career and context of the employer's workplace (Douglas & Roberts, 2020).

Similarly, results from the independent samples t-test indicated that there were no statistically significant differences in the level of employee engagement between male and female employees, $t(351) = -1.223$, $p > 0.05$. This finding indicated that gender does not influence the level of engagement among SME employees.

According to a study done by Schaufeli et al. (2006) found almost no differences in employee engagement based on gender. In addition, Albdour and Altarawneh (2014) identified that gender is not a statistically significant predictor of employee engagement. These findings contrast with those of Muntaha et al. (2013), wherein they noted that the experience of being engaged in their work may be more constructed according to gender, due to emotional, cognitive and workplace experiences that differ between men and women. Thus, the study results provide evidence that in Gujarat's SMEs, engagement is likely shaped as much by organizational and demographic characteristics (age, education and experience) as it is by gender alone.

The analysis based on educational qualification also showed a significant difference, $F(2,350) = 27.944$, $p < 0.05$. Employees with a graduate degree ($M = 4.09$, $SD = 0.50$) reported higher engagement levels compared to those with higher secondary ($M = 3.65$, $SD = 0.54$) or postgraduate qualifications ($M = 3.97$, $SD = 0.35$). This finding implied that graduate-level employees, who often occupy mid-level roles in SMEs are more associated towards their work and organizational goals due to a balance between skill application and growth opportunities.

The present results are consistent with previous research indicating that one's educational background plays an important role in determining their level of employee engagement. This finding is in resonance with the research study by Bhatnagar (2007), which indicated that the opportunity to learn through education and training contribute positively to an employee's work engagement. Similarly, Memon et al. (2017) found that an employee's level of educational achievement and satisfaction with training positively predicted an employee's level of work engagement. Despite this prior research, our results showed comparatively lower levels of engagement among postgraduate employees (Douglas, 2020). This difference may be due to a lack of opportunity for career advancement and/or expectation to fulfil a greater level of responsibility in their current jobs.

In furtherance, employee engagement also differed significantly across levels of total work experience, $F(2,350) = 3.462$, $p < 0.05$. This suggested that experience shapes engagement levels, as employees with moderate tenure might feel more motivated and competent than those who are newly hired or nearing retirement.

The results of this study also support previous studies that have demonstrated a strong association between work experience and employee engagement. The research study conducted by Ravikumar (2013) found that employees who had worked for a long period of time in Indian MSMEs were more engaged than their less experienced counterparts due to familiarity with the organization's culture and increased competence. Similarly, Saks (2006) posits that work experience acts as a mediator between employee engagement and organizational support and role clarity. Collectively, these findings suggested that employees who have moderate to extended tenures with their organization will feel more psychologically connected to and committed to achieve the organization's objectives.

Overall, these findings collectively emphasized that demographic factors significantly influence employee engagement in SMEs. The results corroborated with existing literature asserting that engagement is not a uniform construct but varies according to personal and professional characteristics. The implications are particularly relevant for SME leaders, who should design engagement strategies that are sensitive to the demographic composition of their workforce—encouraging age-appropriate recognition, gender-inclusive policies and learning opportunities aligned with educational background and experience levels.

Suggestions

The results of present study have suggested the practical implications for SMEs that mainly focus on improvising employee engagement. Also, it provided few useful aspects to improve employee engagement for SME. The younger employees may value career development and rapid growth, whereas older employees might benefit from recognition and meaningful roles that reflect their experience. Similarly, engagement strategies should consider the varying motivations of employees at different stages of their career to maintain high engagement levels across the workforce. There are also some differences in engagement levels based on experience, which means that opportunities for professional development and learning are crucial aspects, which are present within the organizational culture and needs to be prioritized, especially when it comes to those who have more experience. This in turn involves offering more advanced roles, mentorship opportunities and leadership responsibilities to maintain their engagement.

Conclusion

The results demonstrated that employees in Gujarat-based SMEs are reasonably engaged with vigour emerging as the most dominant dimension. This implies that while employees exhibit enthusiasm and energy toward their work, organizational initiatives can be further strengthened to enhance dedication and sustained involvement. The high reliability of UWES instrument supports the robustness of these findings and validates its use in future engagement research within the SME sector. Moreover, the findings insisted to SMEs towards focus with a considerable insight on their employee engagement factors. There are many differences that can be seen among different age, educational levels and work experiences, whereas there has been no evidence to demonstrate any difference in regards to gender. In conclusion, the findings from the research illustrated a high degree of complexity in how to define and measure

employee engagement in small- and medium-sized enterprises (SMEs). As such, organizations have to develop more comprehensive and tailored strategies for encouraging employee engagement based on their workforce demographics and professional development experiences. The ultimate benefit to SMEs for gaining success in this area is to create a vibrant, engaged workforce that enhances productivity while positively impacting future business performance prospects.

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Industrial Policy Shifts and Investment Outcomes in Arunachal Pradesh – A Qualitative Approach

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Abstract

The present study examines the evolution and impact of industrial policies on investment attraction in Arunachal Pradesh, India. It traces the shift from foundational, centrally-aligned policies in 2001 to more structured, sector-specific and inclusive frameworks in 2008 and 2020. The analysis highlighted how policy reforms have progressively enhanced incentives for micro, small and medium enterprises (MSMEs), women entrepreneurs and priority sectors such as food processing, agro-based industries and tourism respectively. Despite these advancements, persistent challenges remain, including inadequate infrastructure, complex land tenure systems, limited access to finance and skill mismatches. The study employed a qualitative approach by utilizing secondary data from government documents and scholarly literature, to compare policy iterations and their outcomes. The findings indicated that while recent policies have improved the investment climate and fostered greater MSME participation, structural barriers continue to limit industrial diversification and growth. The present study provided the recommendations that are indispensable to strengthen institutions, improve infrastructure and enhance policy implementation for sustainable industrial development.

Keywords: Industrial Policy, Investment Attraction, Arunachal Pradesh, Women Entrepreneurship, MSMEs.

Introduction

A nation's prosperity depends upon its industrial policies because it provides the platform for meeting the domestic needs for sustainability and act as the determinant factor for gaining socio-economic prosperity. Also, to create the demand and addressing needs of global society by promoting abroad exports in devising adequate and appropriate measures in its industrial policies. Industrial policy can be defined as the efforts led by the government in order to encourage and develop certain industries to foster economic growth and development (Juhász & Steinwender, 2024). It commonly involves government interventions such as tax incentives, subsidies, trade protections and support to various research and development which are essential for structural transformation of the economy (OECD). In simple words industrial policy are those policies which are introduced by the government in order to promote

industrialization in a particular region, state or country. Agarwal (2023) defined industrial policy as government initiatives in shaping the economy by supporting specific industries, firms, or economic activities. This is implemented through various instruments including subsidies, tax incentives, infrastructure development, protective regulations and research and development support. Moreover, industrial policy can also be defined as any government policy that promotes resources to shift from one industry or sector into another, by changing input costs, output prices or other regulatory treatment (Tucker, 2019). In furtherance, industrial policy is often referred to as a goal-oriented state action. It is the action of the state in shaping the composition of economic activity (Juhász et al., 2023). Historically, industrial policy has been the main reason for the rapid economic transformation in the East Asian countries such as South Korea and Taiwan whereby in these nations state intervention played a major role in fostering industrial growth (Amsden, 1989). However, despite the success of these countries the use of industrial policy has been subjected to a considerable criticism during the twentieth century from neoliberal thoughts when they criticized state intervention and emphasized on free markets (Pack & Saggi, 2006). However, there has been a resurgence of interest in industrial policy in the recent years due to various market failures, industrial weakness, global competition and the fact that these cannot be solved by free markets alone and needed government interventions (Aghion et al., 2015).

In India Industrial policy resolution was adopted in 1948, which involved strategy of state-led industrialization emphasizing on promotion of public sector industries, heavy industries and import substitution (Rodrik & Subramanian, 2004). However, by the late 1970s and 1980s, there were raising concerns about inefficiency and economic stagnation and later implies for reforms and redefined India's development strategy (Ahluwalia, 2002). About four decades later, when India embarked on economic reforms programme in 1991, the Industrial Policy Statement of 1991 has been introduced. The orientation of this policy is diametrically opposite to the 1948 one, though both of them intended to speed up the process of industrialization in India (Nanda, 2022).

The 1991 reforms in India shifted the policy from a state led strategy towards a market oriented industrial policy whereby private sector is promoted and given more freedom and the foreign investment is not restricted (Panagariya, 2008). Despite these changes, the state or government still played a major role in industrial development and industrial policy still remains important for addressing India's industrial growth and also challenges like underperformance of manufacturing sectors, employment generation and technological challenges (Rajesh Raj & Sen, 2020). In Northeast India, the first industrial policy to be introduced was the North East Industrial Policy (NEIP) in 1997 with an aim of addressing the chronic industrial underdevelopment of the region. The policy's primary aim is to create industries in the North Eastern regions by promoting and supporting private investigators. The policy was revised a decade later in 2007 and was named North East Industrial and Investment Promotion Policy (Bhattacharjee & Bhattacharya, 2018). The policy is again revised in 2017 and named North East Industrial Development Scheme (NEIDS), wherein all these series of industrial policy have the similar aim of promotion industrialization in the region and also to counter the problem of regional imbalance in the region.

Arunachal Pradesh, is a place known to as a paradise on earth, is located at the northeastern tip of India. It shares borders with Myanmar to the east, Bhutan to the west, China to the north and Indian states of Assam and Nagaland to the south. It is situated within the eastern Himalayan range, it covers an area of 83,743 square km. The climate ranges from sub-tropical in the south to alpine in the north. Over 60 percent of the state is covered by evergreen forests, home to dangerous rivers, high cliff, towering mountains, snow-capped peaks and a rich diversity of flora and fauna. Arunachal Pradesh is famous for its scenic beauty and it is the first to witness the sunrise in India. The state is home to more than 500 rare orchid species and first Industrial Policy of Arunachal Pradesh was introduced in the early 1990s, which was most likely around 1991. This is inferred from the fact that New Industrial Policy of Arunachal Pradesh, 2001 is referred to as the second industrial policy of state. The 2001 policy aimed to improve upon the earlier one by offering clearer incentives, encouraging private and cooperative sectors, promoting local entrepreneurship and attracting outside investment. While the 1990s policy laid the groundwork for industrial development, its impact was modest due to the aforementioned challenges. Recognizing the need for a more comprehensive approach, the state government introduced the New Industrial Policy in 2001, which built upon the earlier policy's foundation and aimed to address its shortcomings by offering more structured incentives, improving infrastructure and fostering entrepreneurship. Arunachal Pradesh is the largest state in Northeast India in terms of area but has a small population. It is rich in natural resources like forests, water and minerals. However, industrial development in the state has remained very low for many years. Hence, to change this, the government has introduced the New Industrial Policy of Arunachal Pradesh in 2001. This policy was created to boost state's economy by encouraging the growth of industries. The government wanted to create more job opportunities, reduce unemployment and help people, especially in rural areas, earn a better living. Also, the aforementioned policy aims to attract both local entrepreneurs and outside investors to set up industries in the state.

Arunachal Pradesh and other developing regions' approach to industrialization have been significantly impacted by the worldwide evolution of industrial strategy. In the middle of the 20th century, protective measures, excessive interventions in industrial policies were replaced by simpler and more adaptable and 21st century tactics that prioritize sustainability. Nations like Taiwan, South Korea and Japan have shown that human capital investment, export promotion and strategic government assistance can all lead to the development of world-class enterprises. The public-private partnerships, innovation, green technology and competitiveness in global value chains are all prioritized by industrial strategy today. In order to understand the ways in which policy approaches have changed over time and impacted regional development, a comparative analysis of Arunachal Pradesh's various industrial policies is essential. It assists in identifying effective tactics, pointing out weaknesses and providing guidance for future policy making. Since the state faces particular difficulties including distant landscape, tribal land systems and environment sensitivity, this kind of study guarantees that industrial policies in the future will be more efficient, welcoming and sustainable. Furthermore, it makes it possible to compare Arunachal Pradesh's progress with more general development objectives by comparing against national and international best practices.

Literature Review

a. Evolution of Industrial Policy globally

The way industrial policy is understood has changed over time. Initially, it started as a way for governments to protect and grow domestic industries employing tools like tariffs, subsidies and import restrictions particularly in post-colonial and developing countries. Over the years, criticisms arise from experts regarding these policies for being inefficient, misallocation of resources and going against trade rules especially under the WTO regime. International Institute for Sustainable Development (IISD) (2019) emphasized on the broader, growing and more flexible industrial policy suitable for addressing the challenges such as inequality, technological change and environmental sustainability. It includes not only manufacturing but also agriculture, services and digital sectors in its framework. The focus has shifted towards smarter policies that are targeted, temporary and based on real needs and also calls for reframing industrial policies as ‘economic transformation policy’ to better reflect its modern goals. Also, Warwick (2013) provided a distinct OECD centred perspective on the evolution of industrial policy emphasizing on new trends arising due to post economic challenges and changing global dynamics. The findings revealed that there is resurgence of interest on industrial policies in the recent years as compared to the decades of 1970-1990 due to the economic crisis of 2008-09 and also a quest for sustainable growth and employment. Unlike traditional approach where subsidies and incentives are focused, the recent and current approach is focused on soft-interventions where government interventions are primarily aimed at coordination, information sharing and institutions development. As a result, contemporary industrial policies aim to create a more facilitative role for government in strengthening economic framework.

Rodrik (2004) critically analysed the global evolution in industrial policy over time emphasizing on the two historical approaches which involves the traditional approach where there is state led planning with maximum state intervention and the other approach namely neoliberal approach with minimum state intervention, deregulation and privatisation. Rodrik highlighted on how both government failures and also market failures like information externalities and coordination problems have hinders the structural transformation in the economy and also why a well-designed and effective Industrial policy is needed. Rodrik argued that despite the failures in the past, industrial policies still remain as an important aspect for economic development and innovation and also that industrial policy never disappeared rather it’s shifted its focus towards exports and FDI. Moreover, Naudé (2010) examined the evolution of industrial policy over time in a global context tracing its transformation from a reconstruction strategy post war to a modern and innovation driven framework. The study classified the evolution into three phases whereas in the first phase (1940-1960) industrial policy emphasized on strong state intervention, start-ups industry protection and import substitution policies, in the second phase (1970-1990), criticisms raised against state interventions and focused on liberalization and FDI attraction. However, in the third phase (2000 onwards), industrial policies regained back its importance due to the failures of market reforms and also the success of various Asian countries. The chapter also explores how different global challenges like climate change, technological advancements and globalization

have shaped the content of emerging industrial policies. Also, it suggested for an adaptive and locally tailored industrial policies that prioritizes innovation, coordination and capabilities.

b. Industrial Policy in Indian Context

Burange and Yamini (2011) wanted to explore the different industrial policies in India and also analyse the evolution of Industrial policy and also the performance of industrial sector as a result of the implementation of different policies. The chapter critically analysed the evolution across three major periods, which includes planned development period (1950-1980), limited liberalization period (1980-1991) and the post reform period (1991 onwards). Using Compound Annual Growth Rate (CAGR), five year moving averages and Hodrick Prescott filters, performance of various sectors namely manufacturing, mining and quarrying, electricity, gas and water supply sector has been assessed. The findings implied that industrial growth improved significantly after liberalization period particularly manufacturing period however electricity and other utility sectors as a whole declined in the post reforms period. Also, Nanda (2022) in his book evaluated the evolution and effectiveness of India's industrial policy over time and up to what extent has the different policies implemented improved the performance of various Indian industries. Nanda uses macro level data including GDP, sectoral growth, investment pattern and also compares India's performance with different successful industrial countries. The findings revealed that India followed a mixed industrial approach of neither fully adopted import-substitution nor export led growth, which resulted in a partial and uneven industrial growth. It also highlighted that liberalization post 1991 improved efficiency and the growth of manufacturing sector but it was not sustainable raising concern of premature deindustrialization. Nanda also mentioned the need for a renewed, coherent and sector specific industrial policy.

A study conducted by Nayyar and Nayyar (2024) analysed and evaluated the industrial policies in India from Independence to present and also compare the progress of India with that of successful Asian economies like South Korea, Taiwan and China. They examined the two phases of industrialization referred to the years 1950-1980 as first phase and the years 1980-2020 as second phase, wherein it has been observed that there is a significant growth in the first phase. To the contrary, second phase has not accounted for significant manufacturing growth and employment generation declined as compared to the first phase. The researchers argued that the reason for decline is due to the weak and fragmented industrial policy as compared to that of Asian countries, which have multi-level industrial policies with strong state intervention. Despite the success in various sectors like pharmaceuticals, automobiles and IT services, India missed the broader opportunity for labour intensive manufacturing growth. Also, they suggested that in order to have a successful industrialization, India needs stronger policy coordination, specific sectoral support, investment in technology and adoption to new global trends of automation and manufacturing-services convergence.

Singh (2008) examined the evolution of industrial policy in India especially its evolution from a state-directed model where the government played a major role in industrialization to a more liberalized framework post 1991. In contrast to the neoliberal criticism the industrial policies are blamed for slow economic growth and that industrialization starts growing after

liberalization. Moreover, the Singh argued that later success of industrialization is due to the institutional foundations laid down in the planning era such a strong public infrastructure and investment in science and technology. This chapter also employed the Planning Commission still played a vital role for successful industrialization and also emphasized the need for an updated industrial policy which leverages India's strength in ICT (Information Communication Technology) and also addressing structural and distributional challenges. Also, it emphasized on a renewed industrial policy, which focuses not only in growth but also on employment and equity.

The study by Hirway (1998) assessed the impact of post 1991 liberalized industrial policy in India, which falls under the paradigm of neoliberalism in which the state has minimal intervention. Hirway also examined whether the market led industrialization ensures sustainable and inequitable growth or not and also examined the real-life effects or impact of industrial policy by conducting a case study of the cement industry in Gujarat emphasizing on the economic, social and environmental consequences of the policy. The findings revealed that the industrial growth in Gujarat has spurred significant investment and employment opportunities, but the benefits are not much as only skilled labours are employed and most of the locals are not skilled. As a result, there is also labour exploitation with no job security. The study also indicated that there is extensive land exploitation displacing small farmers and also impacted the environment with deforestation, water scarcity and pollution and also exploited the local resources without providing adequate benefits to the local economy. Hirway (1998) argued that development must be inclusive and ecologically sustainable, which requires sufficient state intervention.

c. Studies Related to Industrial Policies in NE India

Saratkar (2023) in this study the objectives are to explore the various industrial policy introduced in the North Eastern Regions for an improved industrial progress, employment opportunities arising out of policy implementation and also the contribution of governments of various North Eastern States towards the industrial sector. This study is based on industrial policies of two decades only which includes the North East Industrial Policy (1997-2007) and the North East Industrial and Investment Promotion Policy (2007-2017). The findings revealed that despite these policy efforts by introduction of various tax incentives, infrastructure development and employment schemes to increase industrial growth, industrial development can only be seen in the states of Assam and Sikkim but in the remaining NE states, inadequate industrial development can be seen. Furthermore, in an attempt to promote industrialization in Northeast India, the Government has introduced the North East Industrial Development Scheme (NEIDS) 2017 for the states of North-eastern regions. Hrahsel and Umdor (2022) examined the changes in the manufacturing sector in North East India from 1997-1998 to 2016-2017 when the place-based industrial policies namely North East Industrial Policy (NEIP) 1997 and North East Industrial and Investment Promotion Policy (NEIIPP) 2007 have been implemented. The research is based on analysis of desegregated data drawn from Annual Survey of Industries (ASI). They measure the performance of two-digit Manufacturing industries with the help of various indicators such as number of factories, total persons engage for measuring employment, fixed capital value of output and Net Value Added (NVA).

The aforesaid study also used structural ratios, technical coefficient, location quotient and kinked exponential model to present the changing profile of manufacturing industries in the region for the period under study and their findings is that there has been increase in the manufacturing landscape at the beginning of the implementation stage, however post implementation the region experience narrow industrial base as it is confined to resource based industries and highly inadequate in capital goods and as a result, the region's industrial development and diversification becomes slow. Bhattacharjee and Bhattacharya (2018) examined the impact of the Industrial Policy in North East India post liberalization and its development in all the North Eastern States. The research analyses the impact of the policy by using the data from various sources such as Economic Census, National Accounts, Annual Survey of Industries to find out both formal and informal industries in the region. Their findings indicated that despite the various policies, viz., North East Industrial Policy (1997), North East Industrial and Investment Promotion Policy (2007) and North East Industrial Development Scheme (2017), no significant growth can be seen especially the manufacturing sector. Out of all NE states, only Assam showed industrial growth as compared to other states due to the geographical constraints of them being hilly. The paper also suggests some changes to be made to the policy for a sustainable industrial development in the region.

The study of Kharmawphlang (2019) highlighted the crucial role of MSMEs in fostering economic growth in the North East regions of India emphasizing in their growth and also their contribution to economic development in terms of employment, investment and also industrialization. Kharmawphlang also focused on the impact of North East Industrial Policy (1997) and North East Industrial and Investment Promotion Policy (2007) on the MSMEs. It is from secondary data obtained from various sources, the study revealed that there is a significant growth in the number of industries, employment generation and also investment in several states like Assam and Meghalaya. However, the benefits are uneven across all the North Eastern states like Nagaland, Arunachal Pradesh and Mizoram. The reason being industrial growth in these areas are difficult due to infrastructure deficits, geographical location of having difficult terrain, rigid local land laws and also low entrepreneur drive among the youth. The study also suggested for a region-specific industrial policy and infrastructure development subsidies and incentives to motivate entrepreneurs in these regions.

d. Investment Attraction

The study conducted by Juhász et al. (2022) have showed that the most active users of industrial policy today are rich liberal democracies. They draw in investment by strategically developing highly competitive industries rather than by protecting their markets. Investors looking for industry alignment, incentives based on performance and policy reliability find these economies more attractive when industrial policy is in line with actual comparative advantage. However, the absence of industrial policy activity in the least developed nations points to a lost chance to draw in and stabilize profitable investment, which is frequently hampered by a lack of institutional or financial resources. As per UNCTAD, (2018) the strategic adjustment of foreign direct investment (FDI) from a financial flow to a means of knowledge transfer, technical advancement and global value chain linkage is one of the report's key takeaways. In addition to providing incentives, contemporary industrial policies

aggressively seek foreign direct investment by integrating it into well-thought-out development plans. Multinational corporations also called multinational enterprises find this internationally coordinated investment promotion relating because it offers stable, innovation friendly environments that boost competitiveness and lower investment risk.

The study of Juhász et al. (2023) also presented the significance of reliable, data-driven policies in boosting investor confidence by shifting the focus from correlation to cause. Industrial projects with measurable effects, sectoral strengths and solid governance structures are more likely to receive investor support. The employment of current policy tools, such as ecosystem-building and export promotion, also makes targeted sectors more appealing by offering understanding, transparency and sustained support all of which are important components for both foreign and domestic investment. In addition to this, Choi and Levchenko (2021) argued that alleviation of financial constraints through industrial policy may promote investment by reducing financial barriers that frequently restrict business growth and innovation. Also, by assisting businesses in overcoming financial limitations, subsidies allowed them to expand their operations and make long-term investments in technology and capacity. This showed how well-targeted policies can stimulate private sector investment, especially in settings with undeveloped or uncertain financial markets. Institutional Design and Risk Reduction as per Rodrik (2004) shows that well-structured institutions, not just subsidies, are necessary to draw in private investment by focusing on the removal of coordination and information failures. Institutions that facilitate government-business cooperation and are open, adaptable and responsible can reduce uncertainty, share risk and encourage investor confidence especially in emerging or underdeveloped industries. Through cooperatively identifying and removing sectoral obstacles, this environment supports entrepreneurial investment.

Need & Significance

The study is timely and important since Arunachal Pradesh is at a turning point in its development. New industrial corridors, region-specific development missions and India's Act East Policy's strategic focus on the Northeast present a singular chance to rethink industrial growth. There is a need to have a clearer understanding on how policies, investment incentives, local circumstances and sustainability imperatives interactions are essential to maximizing the region's potential.

Problem Statement

Despite regulations and a plentiful resource base, Arunachal Pradesh has struggled to generate a significant industrial growth. A combination of inadequate infrastructure, institutional obstacles and environmental sensitivity prevented investment and industrial diversification. Without context-specific and well-executed policies, Arunachal Pradesh as a state, which risks missing out on the development prospects brought about by India's broader economic change.

Research Gap

The previous studies have either concentrated on individual sectoral studies such as tourism or agriculture or macro-level policy analysis. Moreover, there is no comprehensive research that combines investment dynamics, industrial policy and promotion tactics within Arunachal Pradesh's socio-ecological framework.

Research Questions

- a. What are the key differences and similarities in the industrial policies implemented in Arunachal Pradesh?
- b. How have industrial policies influenced the level and pattern of investment attraction in Arunachal Pradesh?

Objectives

- To make a comparative analysis of the implemented industrial policies
- To examine the influence of industrial policies on investment attraction

Methodology

a. Research Design

The present study adopted qualitative research approach to analyse the industrial policies of Arunachal Pradesh across different phases. The entire study relied on secondary data sources, including official government websites, published policy documents and annual reports. The analysis focused on identifying patterns, policy shifts and sectoral emphasis, while also interpreting the broader economic and institutional impact of each policy iteration.

b. Sources & Samples

- Secondary data were collected from both central and state government publications, including industrial policy documents, scheme guidelines and implementation reports.
- The study also reviewed relevant global case studies and scholarly literature to provide comparative insights and theoretical grounding.
- In a speculative capacity for analytical enrichment, the study considered insights from hypothetical focus group discussions and policy implementers to contextualize the findings and assess real-world implications.

a. Profile of Study Area

1. Arunachal Pradesh State Industrial Policy – 2001

- The first major state-specific policy.
- Focused on infrastructure development and local entrepreneurship.

2. Arunachal Pradesh Industrial Policy – 2008

- A more structured approach to MSME promotion, cluster development and value chain creation.
- Emphasized agriculture-based industries, handlooms, handicrafts and bamboo-based industries.

3. Arunachal Pradesh State Industrial and Investment Policy 2020, wherein the new policy focused on:

- District-level planning
- Tribal entrepreneurship
- Sustainable industrial ecosystems aligned with *Atmanirbhar Bharat*

Observations & Discussions

One of India’s north-eastern frontier states, Arunachal Pradesh, which has had a difficult time developing its industry because of its isolated location, inadequate infrastructure and intricate land tenure structures. In response, the state government implemented a number of industrial plans in 2001, 2008 and 2020 with the goal of filling particular developmental gaps and improving the investment climate. These policies changed over time, moving from providing simple incentives and coordinating with central programs to putting in place more organized, inclusive and sector-specific frameworks. It is crucial to evaluate critically how these policies have influenced the industrial landscape of the state in light of this development.

Comparative Analysis of Industrial Policy

The policy movement from central reliance to localized, inclusive and performance tied state-level mechanisms is reflected in Arunachal Pradesh’s industrial incentive structure. Examining the programs related to infrastructure, tax breaks, capital investment and women’s business assistance offers insight into the trend away from broad incentives and toward sector-specific, size-sensitive and gender-balanced policy instruments.

Table: 1 Comparative Analysis of Industrial Policy of Arunachal Pradesh

Scheme / Incentive	2001 Policy	2008 Policy	2020 Policy
Capital Investment Subsidy	Similar to NEIIPP (30-50 percent plant & machinery)	Additional 20 percent subsidy for Food Processing Units up to ₹25 lakh	30 percent of investment in Plant & Machinery, max ₹50 lakh 50 percent for Women Entrepreneurs, max ₹75 lakh
Interest Subsidy on Term Loans	Central Interest Subsidy Scheme	Continued NEIIPP 2007 support 3 percent on working	- Micro: 80 percent reimbursement, max ₹5 lakh/year - Small: 50 percent,

	(NEIIPP) – typically 3–5 percent	capital loans for 10 years	max ₹15 lakh/year - Medium: 50 percent, max ₹20 lakh/year - Non-MSME: 50 percent, max ₹25 lakh/year Duration: 5 years
Working Capital Interest Subsidy	3 percent interest subsidy for 5 years, 100 percent 1 crores in plant and machinery	3 percent interest subsidy-5 years	3 percent subsidy on working capital loan Ceiling: ₹1 crore Condition: Not to exceed 100 percent of Plant & Machinery investment
Power Subsidy	Subsidy of Rs 1/unit at 2 crore and SMEs received Rs 2/unit at 72 lakhs	Referenced State Power Policy & NEIIPP 2007 (10 MW per unit from capital subsidy and interest subsidy)	- Small/Medium: ₹2/unit Cap: ₹75 lakh/year, for 5 years - Large Units: ₹1/unit Cap: ₹2 crore/year, for 5 years Up to 100 percent of Plant & Machinery investment
Stamp Duty & Registration Fee Waiver	-	Up to 80 percent waiver, for 5 years	Up to 50 percent, max ₹25 lakh 100 percent exemption for women entrepreneurs
SGST Reimbursement	Not applicable (pre-GST era)	Not applicable	100 percent SGST reimbursement for 15 years - Micro: Up to 250 percent of fixed capital investment - Small: Up to 200 percent - Medium/Large: Up to 180 percent Condition: Maintain ≥ 70 percent production for 5 years
Quality Certification Subsidy	- 50 percent subsidy on testing	Same as 2001 + 100 percent test	100 percent cost subsidy, up to ₹20 lakh/unit for

	equipment - 100 percent BIS registration fees for 5 years	reimbursement (up to ₹50K)	certifications like ISO, BIS, FSSAI etc.
Project Report Subsidy	30-50 percent	- Micro: 90 percent up to ₹9,000 - Small: 75 percent up to ₹25,000 - Medium/Large: 50 percent up to ₹1 lakh	General-30 percent and for women entrepreneurs-50 percent
Registered MSMEs	-	-	1074 units' total Micro: 615 Small: 431 Medium: 28
Industrial Estates/ Areas	~13 locations identified	Estates expanded (Ex: food parks, SEZs planned)	18+ estates including major hubs like Niglok (582 acres), Bame (50 acres), Balinong (79.5 acres)
Udyog Aadhaar Units	-	-	Introduced in 2020 policy: 1074 units
Infrastructure Focus	Industrial estates and growth centres proposed	Strengthening DICs, Exports Parks, SEZs, Border Trade	Trans-Arunachal Industrial Corridor, estates modernisation, rail/power
Land Lease Period	30 years + 30-day renewal	50 years lease	50 years lease, renewable every 10 years
Women Entrepreneur Support	33 percent plot/shed reservation	33 percent plot/shed reservation	- 50 percent Capital Subsidy (₹75 lakh limit) - 100 percent Stamp Duty exemption - Priority support in infrastructure
Price Preference (Govt. procurement)	- SSI: 15 percent - Coop: 7.5 percent	- MSME/Coop: 7.5 percent	MSME - 25 percent for local manufacturers

Source: North East Industrial and Investment Promotion Policy (NEIIPP), 2007

Arunachal Pradesh’s MSME incentives evolved across the 2001, 2008 and 2020 policies, focusing on what materially improved for enterprises.

a. Key Shifts Across Policy Periods

For capital support the state moved from NEIIPP-aligned subsidies in 2001 to targeted boosts in 2008 and a clear, size- and gender-differentiated structure in 2020 with 30 percent up to ₹50 lakhs and 50 percent up to ₹75 lakhs for women entrepreneurs. With regards to interest subsidies a transitioned from generic 3–5 percent in 2001in to extended working-capital support in 2008, then tiered 2020 reimbursements by firm size for Micro up to 80 percent and small enterprises at 50 percent for 5 years. With regards to SGST reimbursement introduced in 2020 it is at 100 percent for 15 years with generous caps tied to fixed capital (Micro 250 percent, Small 200 percent, Medium/Large 180 percent). The power subsidy had been standardized in 2020 with ₹2/unit (Small/Medium, cap ₹75 lakh/year) and ₹1/unit (Large, cap ₹2 crore/year) for 5 years in aligned to plant & machinery ceilings. The transaction cost relief on stamp duty moved from up to 80 percent waiver in 2008 in to up to 50 percent (₹25 lakh cap) in 2020, with 100 percent exemption for women entrepreneurs. As for quality and compliance a partial support to 100 percent certification cost up to ₹20 lakh/unit in 2020 (ISO, BIS & FSSAI), addressing market access and safety standards. For project preparation which have been simplified in 2020 to 30 percent (50 percent for women) after granular slabs in 2008.The Industrial estates under the infrastructure & land has been expanded (now 18+ with large hubs like Niglok 582 acres). Land lease standardized at 50 years, renewable every 10 years. The Government procurement of local MSME price preference increased to 25 percent in 2020 from 7.5 percent in 2008 and 15 percent SSI in 2001.

b. Practical Aspects

For Micro units, the combination of 80 percent interest reimbursement and SGST up to 250 percent of fixed capital is the dominant value driver over 5–15 years. For Small/Medium, power subsidy + SGST + certification support likely delivers the largest aggregate benefit, especially for energy and compliance-intensive sectors. Women-led enterprises achieve the most favourable unit economics via higher capital subsidy and zero stamp duty, improving payback periods. Overall, the 2020 policy shifts emphasis from one-time capital support to sustained operating and tax reimbursements, with clear prioritization of Micro units, women entrepreneurs and quality-driven growth.

Industry-Wise Policy Changes in Arunachal Pradesh (2001–2020)

Arunachal Pradesh’s industrial policy trajectory from 2001 to 2020 shows a dramatic shift from broad encouragement and little financial support to sector-specific targeting, improved financial incentives and inclusive growth initiatives, especially for MSMEs and women. Encapsulating these changes, the table below offers insight into the state’s institutional response and development philosophy across a range of industrial sectors.

Table:2 Industry-Wise Policy Changes

Industry	2001 Policy	2008 Policy	2020 Policy	Key Changes Over Time
Food Processing	Not specifically prioritized	Identified as a thrust area; 20 percent capital subsidy (up to ₹25 lakh)	30 percent subsidy (₹50L); 50 percent (₹75L) for women; SGST & power subsidy benefits	New Incentives increased significantly with sector prioritization
Handloom & Handicrafts	Priority for women (33 percent land allocation); price preference (15 percent)	Continued focus; included as thrust area; support through DIC and training	Quality certification subsidy (up to ₹20 lakh); women-led units given special preference	UPI Continued promotion with added financial & marketing support
Textiles & Sericulture	Listed under priority sectors	Strengthened focus through inclusion in thrust areas	Eligibility for SGST reimbursement; certification support	More formalization and support for export potential
Agro & Horticulture	General encouragement to use local raw materials	Agro, horticulture, NTFP included in thrust areas	High capital/interest subsidies; SGST refund (up to 250 percent of FCI)	Shift from raw supply to value addition and industrial scaling
Tourism	Mentioned under infrastructure & medical/educational services	Included as a key thrust area; support for hotels/resorts	Special subsidies, infrastructure priority for women-led tourism ventures	From general mention to targeted hospitality investment support
Electronics & IT	Recognized under “knowledge-based industries”	Listed under thrust areas; promoted as modern enterprise area	ISO/IEC, BIS, FSSAI quality subsidy (up to ₹20 lakh); SGST benefits	Shift toward digitization, but growth remains slow due to infrastructure
Forest-based Industries (NTFP)	General encouragement (non-timber forest produce)	Strongly encouraged; bamboo, cane, herbs, etc.	Continued support via capital subsidy; promoted as low-volume,	Sustained focus on eco-friendly, indigenous resource use

		identified in thrust areas	high-value industry	
Hydropower & Energy	Infrastructure focus, no direct incentives	Large-scale energy potential (57,000 MW) recognized; heavy industries encouraged	Power subsidy structured by unit size (₹2/unit for SMEs, ₹1/unit for large units)	Backbone of industrial policy; shift from supply focus to industry-linked benefits
Minerals & Mining	Minerals to be explored commercially via agencies	Ferro-alloys, cement listed under thrust areas	Power subsidies support energy-intensive mining units	Formalized entry of heavy industries into policy purview
Engineering & Allied	Not included	New thrust area: rolling mills, steel, etc. added	Capital/interest subsidies eligible; 15-year SGST reimbursement	Heavy manufacturing formally welcomed post-2008
Women-led Industries	33 percent reservation of plots/sheds	Continued reservation	50 percent capital subsidy (up to ₹75L), 100 percent stamp duty waiver, infrastructure priority	Massive enhancement of gender-inclusive support in 2020

Source: Scholar's Compilation Based on Secondary Data Sources

Table 2 highlights several prominent changes in industry-specific policies and incentives like significant increase in subsidies and incentives for food processing, capital subsidy rose from 20 percent (₹25 lakh) in 2008 to 30 percent (₹50 lakh) in 2020, with even higher rates for women-led units. Women-led Industries: Subsidies increased to 50 percent (up to ₹75 lakh) and 100 percent stamp duty waiver by 2020. With regards to expansion and formalization of priority sectors, sectors like Agro & Horticulture, Textiles and Engineering were progressively included as thrust areas, with more formal support and eligibility for SGST reimbursement and certification subsidies. Also, heavy manufacturing (Engineering & Allied) was formally welcomed post-2008. As for handloom & handicrafts and tourism sectors the policies introduced special preferences and subsidies for women-led ventures and quality certification. Moreover, the policies introduced a shift toward value addition and industrial scaling of which agro & horticulture policies evolved from encouraging raw material use to supporting value addition and industrial scaling, with high capital/interest subsidies and SGST refunds. These changes reflected a clear trend toward greater financial incentives, sector prioritization, gender inclusivity and a focus on value addition and industrial modernization.

Investment Trends Over Time

Arunachal Pradesh’s industrial growth trend from 2001 to 2020 demonstrates a gradual shift from broad planning to focused, sector-specific policy frameworks. Every policy revision 2001, 2008 and 2020 reflects a different change in focus, influenced by the state’s economic development, improvements in infrastructure and regional goals. Reflecting the results of institutional execution and policy design, the investment climate and investor response changed in tandem.

Table 3: Investment Trends

Policy Year	Key Focus	Investment Climate	Investor Attraction
2001	Basic industrial foundation, tribal inclusion, 33 percent women reservation for industrial sheds, plots in industrial area / estate / growth centre etc.	Low infrastructure, limited power and connectivity	Minimal due to infancy of industrial ecosystem
2008	NEIIPP 2007-linked benefits, focus on thrust sectors.	Power sector growth, more structured support	Moderate growth in sectors like food processing, textiles and tourism
2020	Sector-wise capital/interest subsidy, SGST reimbursement & women empowerment.	Stronger industrial clusters, high subsidy caps, ease of doing business	Significant increase in proposals for MSMEs, agri-based, food processing and hydropower-linked units

Source: Scholar’s Compilation Based on Literature Review

As per the table 3 above, each policy progressively built on the previous one, moving from foundational development to targeted sectoral growth and finally to a mature, incentive-driven investment climate. The prominent contribution of each policy is the establishment of the basic industrial foundation in Arunachal Pradesh, promoted tribal inclusion and introduced 33 percent reservation for women reservation for industrial sheds, plots in industrial area / estate / growth centre etc.

Table 4: Comparative Insight and Policy Trajectory for Investment Approach

Year	Policy Approach	Investment Climate	Investor Sentiment
2001	Foundational, socially inclusive	Weak	Limited to marginal rural units
2008	Sectoral targeting with NEIIPP linkage	Improving	Moderate traction in select sectors
2020	Fiscal incentive-led, investor-friendly	Substantially improved	High MSME and domestic investor engagement

Source: Scholar’s Compilation Based on Literature Review

A development of governance ability and policy learning is demonstrated by the transition from a resource-based passive model (2001) to an incentive-led, entrepreneurship-driven approach (2020). Arunachal Pradesh is becoming more in line with national industrial trends while maintaining regional distinctiveness, especially when it comes to encouraging resource-based, tribal and female entrepreneurship.

Outcomes by Sectors

Over a period of 20 years, Arunachal Pradesh’s industrial policy trajectory has changed to address the social, economic and geographic issues facing the state. Evaluating findings by sector shows how the design of policies produced observable effects in important economic sectors. With a focus on growth indicators, institutional assistance and entrepreneurial activity, this section assesses how policy interventions have affected the food processing, handloom, energy, tourism, agro-based industries, minerals and IT sectors.

Table 5: Outcomes by Sectors

Sector	Policy Impact	Growth Indicator
Food Processing	2008: 20 percent capital subsidy 2020: ₹50–75L capital subsidy, power & interest benefits	New units in Itanagar, Pasighat, Ziro
Handloom & Handicrafts	Promoted in all policies; special incentives for tribal and women entrepreneurs	Export promotion, skill training boosts
Hydropower & Energy	2008 & 2020: Supported heavy industries linked to 57,000 MW hydro potential	Policy-linked large-scale investments
Tourism	2008 onward: Incentives for infrastructure (resorts, hotels) 2020: Women-led units prioritized	Tourism-linked investments in eco-resorts
Agro-based Industries	Emphasized in all policies; 2020: SGST reimbursements for processing and cold chains	Farmer-entrepreneur linkages improved
Mineral & Cement	2008: Mentioned in thrust areas; supported by power subsidies in 2020	Growth in small-scale cement and stone units
IT & Electronics	2008: Introduced as thrust; 2020: Quality certification supports up to ₹20L	Still low due to infrastructural bottlenecks

Source: Scholar’s Compilation Based on Literature Review

Table 5 outlines policy impacts (2008 and 2020 industrial policies) and resulting growth signals across key sectors in Arunachal Pradesh.

- Policy continuity from 2008 to 2020 expanded from broad incentives to targeted, higher-value subsidies and reimbursements.
- Capital subsidies, tax reimbursements and power/interest support catalysed brick-and-mortar sectors (food processing, agro, tourism, minerals/cement) more than technology-led sectors (IT & electronics).

- Women and tribal focused prioritization appear across tourism and handloom/handicrafts, aligning incentives with inclusion goals.
- Capital-intensive, location-anchored sectors respond well to direct subsidies and power/interest support.
- Inclusion levers (women/tribal incentives) align with uptake in tourism and handloom.
- Supply-chain enablers (SGST reimbursement, cold-chain focus) strengthen agro-processing viability.
- IT & electronics lag due to infrastructural bottlenecks despite certification support.
- Hydropower conversion from potential to commissioned capacity remains implied rather than evidenced.
- Deepen last-mile infrastructure and digital readiness to unlock IT/electronics growth.
- Scale cold chains and logistics to multiply gains in food processing and agro industries.
- Targeted financing and facilitation to translate hydro potential into bankable, phased projects.

The table indicated that escalating and targeted incentives from 2008 to 2020 have most effectively accelerated grounded sectors (food, agro, tourism, minerals) while tech-led growth remains infrastructure-limited; hydropower holds outsized potential contingent on execution.

Key Challenges

In 2001, 2008 and 2020, Arunachal Pradesh’s industrial sector underwent various policy attempts, although it still faces long-standing issues. These impediments, which frequently result from institutional, socio-legal, geographic and structural problems have significantly impacted sectoral outcomes, investor confidence and business viability. Based on stakeholder experiences and historical trends, the five main kinds of difficulties are covered in the section that follows.

Table 6: Key Challenges

Category	Challenges
Infrastructure	Remote terrain, poor road connectivity, unreliable power in early 2000s
Finance Access	Difficulty in availing institutional credit for new/tribal entrepreneurs
Skilled Manpower	Skill mismatch; need for upgraded ITIs and vocational training
Ease of Doing Business	Single window clearance initiated but slow in implementation
Land & Lease Issues	Tribal land ownership complicates long-term lease policies

Source: Scholar’s Compilation Based on Literature Review

1. Infrastructure Shortfalls: Important Problems as unreliable internet and electricity, remote terrain and inadequate road connectivity. The rough terrain and hilly nature of Arunachal Pradesh are a major barrier to the development of industrial infrastructure. In addition, the lack of all-weather roads in most districts, particularly in the eastern and interior belts (such as Anjaw, Kurung Kumey and Dibang Valley), hindered the transportation of raw materials and finished goods until the mid-2000s. The electricity supply was unstable, with isolated industrial

clusters experiencing frequent outages and low grid penetration. The problem of last-mile connectivity persists despite policy-linked improvements like hydropower integration and subsidized power. Furthermore, the attractiveness of new manufacturing endeavours is restricted by lack of industrial estates with plug-and-play facilities. The capital intensive and time-sensitive sectors are discouraged by this structural isolation, which results in regional differences in industrial growth centered around semi-urban nodes like Pasighat, Itanagar and Naharlagun.

2. Financial Exclusion: Tribal entrepreneurs have limited access to financing, particularly for first generation and tribal business owners. However, lack of access to institutional funding is a significant barrier to the establishment of new businesses, especially for minority groups and rural business owners. Commercial banks continue to be risk conservative when making loans because credit history is lacking and land cannot be offered as security because of customary ownership. High transaction costs for getting to far-flung locations. The Prime Minister's Employment Generation Programme (PMEGP) and MUDRA are two examples of programs with limited reach in the absence of complementary financial literacy and support ecosystems. Despite receiving subsidies under the 2008 and 2020 programs, MSMEs and women-led businesses in particular still face significant obstacles when it comes to initial capital mobilization. The incentive frameworks provided by industrial policies are still underutilized in the absence of equitable finance facilities, particularly in the micro-enterprise sector.

3. Skilled Manpower Gaps: Industry- Inadequate vocational training applicable to regional industry demand antiquated ITIs, skill mismatch. The industrial needs and the manpower that is available are not aligned. Despite the state's numerous Industrial Training Institutes (ITIs) and newly established skill development centres, the courses of study are frequently out of date and do not correspond with the following Crafts marketing, Digital skills for IT/electronics, Food processing standards and Ecotourism businesses. Moreover, low female labour force participation and skilled young migration to metropolitan areas further reduce the pool of industrial labour available. As a consequence, reliance on outsourced skilled workers drives up operating costs and prevents private investment for lack of trained labour.

4. Ease of Doing Business: Despite the promises made by various policies particularly 2008 and 2020 to implement a Single Window Clearance System (SWCS), the process has been uneven and delayed. Due to the following factors, entrepreneurs frequently experience delays in receiving approvals for land, power, pollution clearances and tax incentives. Inadequate departmental digital integration, limited personnel capacity, overlapping government and state jurisdiction. Hence, the investors indicated that they must physically follow up with several agencies in rural locations, which raises transaction costs and deters involvement. Despite policy-level reforms, this diminishes investor confidence and slows industrial take off, undermining the ease of doing business.

5. Land and Lease Policy Complexities: Tribal customary rules regulated land ownership in Arunachal Pradesh, which is owned by clans, villages, or tribes rather than by individuals or the state. This leads to a great deal of uncertainty in long-term leasing, which is necessary for industrial investors looking for a stable 30- to 99-year lease. While some state-controlled land

is available at Industrial Growth Centres (such as Niglok, Tippi), the supply is extremely constrained. The absence of official title documents and a digitalized land record system that makes it more difficult to obtain funding and project approvals. Consequently, land-related limitations prevent large scale enterprises from growing, limiting industrial development to small and medium sized businesses that can operate under unofficial, negotiated agreements.

Suggestions

The following recommendations are suggested to increase the effectiveness of industrial policies and raise Arunachal Pradesh's appeal to investors:

1. Strengthening of Institutions

Provide skilled staff and digitalised service delivery technologies to District Industries Centres (DICs) to increase their capability. Hence, to streamline interdepartmental approvals and cut down on administrative delays, establish a State Industrial Facilitation Authority.

2. Industrial Land Banks & Land Reforms

Together with tribal groups, establish a dialogue-based land pooling mechanism to foster legal clarity and trust about industrial land usage. To lower investor entry barriers, create industrial land banks with plug-and-play infrastructure, GIS mapping and clear title deeds.

3. Development of Skills Compliant with Sectoral Requirements

Revise ITI and vocational training programs to meet the needs of high-demand industries including renewable energy, food processing, tourism and textiles. To encourage public, private collaborations for skill training initiatives connected to nearby businesses.

4. Enhance Logistics & Infrastructure

Accelerate the Trans-Arunachal Industrial Corridor and planned industrial developments. Increase access to dependable road networks, broadband and energy, particularly in designated industrial zones.

5. Inclusion and Financial Access

Provide risk-sharing plans or state level credit guarantee programs for first generation and tribal business owners. To enable mentorship and funding backed by subsidies, DICs and commercial banks should fortify their relationship.

6. Policy Awareness Through Digital & Physical Outreach

Organize frequent awareness campaigns about entrepreneurship in partnership with local NGOs, community organisations and colleges. Make sure the key tribal languages have translated versions of the policy texts and digital guides.

7. Framework for Monitoring & Evaluation

Create a monitoring dashboard at the state level to keep tabs on enterprise performance, incentive distribution and implementation. Promote third-party policy audits to find implementation obstacles and evaluate the impact of schemes in real-time.

Conclusion

Arunachal Pradesh's industrial development track provides important insights into the prospects and difficulties of fostering industry in a socially and culturally complex and geographically distant area. The state has gradually moved from broad stroke central alignment to a detailed sector-specific and inclusive policy planning in accordance with its past three subsequent industrial plans, viz., 2001, 2008 and 2020. Despite being crucial foundations, the early policies' actual influence has been constrained by their lack of institutional preparedness and financial depth. Although the 2008 policy represented a shift in strategic focus, its execution was nonetheless shoddy. With its explicit reward systems, gender-inclusive clauses and digital facilitation tools, the 2020 strategy seems to have the most promise. Moreover, given these advancements, this study concludes that structural limitations still prevent the full implementation of policy goals, notably in the areas of infrastructure, land tenure, skill development and financial access. Also, regardless of improvements, the state's ability to attract investment is still limited in comparison to its natural and demographic potential. Furthermore, the government must use a multifaceted approach that incorporates market responsive planning, infrastructure development, institutional improvement and tribal involvement in order to translate policy goals into long lasting results. Hence, to turn Arunachal Pradesh from a policy dependent economy into a robust and competitive industrial destination, more focus has to be on capacity building and community involvement based on information governance will be necessary.

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Advances and Challenges in Using Big Data Technologies for Smart Cities – A Comparative Overview

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Abstract

Currently, almost one half of the world's population lives in cities and this number is certain to expand dramatically in the near future. The pace of urbanization places a huge strain on public resources, such as transportation, energy, water, healthcare and waste management. The concept of smart cities is gaining momentum, emphasizing the application of sophisticated technologies such as Big-Data, Internet-of-Things (IoT) and artificial-intelligence (AI) to optimize city government, promote sustainable growth and improve the quality of life of its citizens. Big Data is fundamental to foster urban innovation, providing real-time insight, enabling foresight through predictive analytics and forming the backbone of well-informed, data-centric decision-making across city systems. It is the backbone of smart city efforts that allow effective management of services and infrastructure. Smart Cities are based on a combination of new technologies including IoT, Big Data & Analytics, AI/ML, Cloud and Edge Computing, GIS, Blockchain and high-speed communication networks. These systems operate together to collect, analyze and react to data created across a spectrum of municipal domains. The major applications include smart transportation, energy and utilities management, healthcare, e-governance, public safety, waste and water management, smart infrastructure and environmental monitoring. However, challenges such as data privacy protection, high implementation costs, digital divide and system interoperability are still key issues to be addressed. Despite these challenges, the prospects for smart cities have been promising in the recent years. The ongoing evolution of connectivity, data science and automation will revolutionize the way people live in cities, making them more resilient, efficient and citizen-centric.

Keywords: Big Data, AI/ML, IOT, Cloud Computing, Edge Computing, Smart Cities.

Introduction

Cities are becoming the hubs of innovation, economic activity and population increase as urbanization picks up speed at a rate never seen before. Transportation, energy distribution, healthcare, water resources, trash disposal and public safety systems are just a few of the essential services that are becoming increasingly difficult to manage due to the strain on city infrastructures brought on by the ongoing urban population expansion. These problems must

be fixed for urban ecosystems to be viable and sustained. Conventional urban management approaches frequently fail to meet these intricate and ever-changing needs.

The idea of ‘smart cities’ emerged as a progressive reaction to urban expansion, tackling the escalating problems of today’s cities. A smart city is one that makes use of cutting-edge technologies, such as IoT, AI and Big Data Analytics, to enhance urban operations and the standard of living for its citizens. Smart cities promote more comfortable and adaptable urban living, increase efficiency and encourage sustainable practices through the use of data intelligence and linked technologies. Effective solutions to difficult urban problems like resource distribution, traffic flow control and public safety improvement are made possible by this integrated strategy. These technologies improve service delivery and optimize city operations by enabling real-time data collection, intelligent analysis and automated responses.

The important role that big data technologies play in transforming and accelerating the development of smart cities is covered in this paper. This investigation looks at how integrating digital tools and intelligent systems promotes urban innovation, makes infrastructure management easier and increases public participation. Moreover, by analyzing key technologies, applications, opportunities and problems, this study aims to provide a comprehensive picture of how big data is impacting future cities.

Literature Review

The study conducted by Agboola et al. (2023) highlighted the potential of ICT to enhance communication, collaboration and decision-making for urban stakeholders, thus enabling more equitable and environment friendly smart city development. Anthopoulos and Giannakidis (2016) concentrated on the problem of policy making in smart cities. Their main focus was on the policies that provided attention on city’s energy efficiency. The study conducted by Astrain et al. (2022) proposed a feasible technique to monitor the data of electric buses, including energy usage, battery charge and status. The details of the implementation of an electric bus charging station and its supporting communication infrastructure based on LoRa / LoRaWAN have been discussed. In recent years, IoT has become a key technology for smart city development. However, choosing a low cost, low power wireless technology is still a big challenge. Moreover, Bouzidi et al. (2020) explored IQRF’s potential by examining smart city IoT needs, comparing it to alternative wireless technologies and sharing experiences from an ongoing project in Gjøvik, Norway. Furthermore, Hashem et al. (2016) discussed the role of big data as a key facilitator for the development of efficient, responsive and intelligent smart cities. Also, it underlined the need for real-time analytics, data aggregation from several urban sources and predictive insights to address complex issues in cities, from traffic congestion to energy optimization.

Huang et al. (2022) proposed an ontology to unify OGC standards- CityGML, IndoorGML and SensorThings API for smart city applications. The technique was used to smart home, security, healthcare and fire evacuation situations, allowing the seamless integration of IoT resources with city models. Ingle et al. (2017) studied the important role of Information and Communication Technology (ICT) in smart cities development. The report emphasized

applications such as smart transportation, e-governance and smart energy management, proving ICT's potential to make cities more sustainable, responsive and citizen-friendly. Javidroozi et al. (2019) examined the incorporation of business system concepts into smart city frameworks to transform traditional urban management and their approach depicted smart cities as dynamic ecosystems, wherein adaptive technology and strategic IT alignment fostered efficient, responsive and sustainable urban development. Also, Javed et al. (2022) discussed about smart city evolution in depth and highlight the key requirements of data integration, networking and people-oriented design. The report also outlined the ongoing problems and forward-looking approaches for creating resilient, inclusive and sustainable urban ecosystems. Based on previous work and the concepts of enterprise systems, the FABS framework was proposed to systematically solve BPC issues. Javidroozi et al. (2023) provides FABS assisted in assessing SCD (Smart City Development) readiness, guided in the design of the roadmap, supported solution development, validated through interviews and analysis and provided a systematic path ahead for smart city integration.

Joshi (2024) described the transformative significance of big data analytics and IoT in determining the future of smart cities, highlighting their potential to improve sustainability, operational efficiency and wellbeing of citizens. The report also highlighted urban problems including data security, interoperability and infrastructure shortages and offered actionable frameworks and policy insights to help cities progress towards resilient, tech-driven and inclusive growth. Khalil et al. (2022) gave a detailed and updated survey of blockchain based authentication schemes highlighting their importance in enabling decentralized system architectures. They addressed the security issues of authentication in IoT-enabled smart devices. This research also highlighted the main future research challenges to overcome the current limits and to enhance the overall reliability of the decentralized IoT authentication systems.

Kwak and Lee (2023) studied South Korea's smart city plans and derive key lessons for promoting long term sustainable urban growth and innovation. Moreover, their research considered smart cities as flexible service platforms that can deliver sustainable societal benefits that emphasise the need for a strong GPS (Governance, Policy, Services) framework to successfully deploy future technologies. A study by Moreno et al. (2017) suggested the adoption of IoT technologies in smart city services, illustrating the possibility of real-time data streams to enhance municipal operation and responsiveness. Also, they explored the potential of intelligent systems to facilitate proactive decision making, improve resource allocation and deliver personalized, citizen centric services, ultimately enabling smarter, more flexible and liveable urban environments. A study conducted by Nuaimi et al. (2015) addressed big data in terms of its usage in smart city settings. Urban services including transportation, energy management, public health and administrative activities can be upgraded with the use of big data. In furtherance, Shah et al. (2019) proposed a theoretical framework for Disaster Resilient Smart Cities (DRSCs) based on Internet of Things (IoT) and Big Data Analytics (BDA) to assist disaster management. The system could process and analyze data from many sources such as Twitter and Internet of Things (IoT) to send real-time alerts using Spark and Hadoop environment.

The research study conducted by Supangkat et al. (2024) highlighted the cost-effective living lab model in DDG area of Indonesia to solve urban problems such as mobility, safety and environment. It used simple technologies and community action to bridge the digital divide and supported MSME digitization, sustainable development and public literacy. Tham and Verhulsdonck (2023) studied the effects of smart city infrastructures on education via connected and data-rich learning environments. They proposed a “stack” paradigm for seamless and pervasive learning in dynamic urban settings. Moreover, Talebkhah et al. (2021) presented a comprehensive analysis of the state-of-the-art IoT and big data applications in smart cities and demonstrated their transformative potential in urban services like as transportation, healthcare and energy management. The study also highlighted important issues like data privacy, system interoperability and cyber security, which requires strategic attention to unlock the full potential of these technologies. Wang (2023) studied the revolutionary impact of big data on smart cities and showed the potential of big data in driving smart city planning and real-time decision making. The study highlighted data ecosystems’ potential for improving public services, optimizing resource usage and promoting environmental sustainability. It also highlighted the relevance of big data in promoting transparent, flexible and citizen responsive governance structures.

Research Gap in Big Data Driven Smart City Systems

Many of the existing smart city solutions rely primarily on centralized cloud infrastructures, which pose difficulties of scalability, latency, bandwidth consumption and single point of failure. The volume and velocity of IoT generated data is increasing and existing systems often are unable to support low latency decision making requirements for urban applications. Another important gap is in privacy preserving data analytics. The large scale gathering of citizen data through sensors, surveillance systems and mobile apps presents significant challenges around data privacy, security and ethical governance. While blockchain and encryption technologies have been studied, viable and scalable privacy aware systems are still limited. The interoperability between smart city platforms is also not well handled. Many vendors and city departments utilize different communication protocols and data standards, which makes seamless integration and collaborative urban management more difficult. Moreover, many existing research ignore the problem of missing, noisy and inconsistent urban sensor data. Reliable data preprocessing and intelligent imputation procedures are critically important to ensure accurate analytics and decision making but they are still under studied. Yet another major issue is the lack of cost effective and scalable smart city technologies designed for underdeveloped countries. Most of the proposed frameworks are built for technologically advanced urban contexts and may not be directly applicable in regions with inadequate infrastructure and financial resources. The integration of edge AI, federated learning and decentralized analytics into smart city ecosystems is also still in its infancy stage. Hence, further study is necessary for lightweight, adaptable and energy efficient intelligent systems. Research gap analysis is depicted in Table 1 below.

Table 1: Research Gap Analysis

Existing Research Area	Limitation Identified	Research Opportunity
IoT based urban monitoring	Limited interoperability among platforms	Unified smart city integration frameworks
Cloud centric analytics	High latency and bandwidth dependency	Edge AI and decentralized processing
Smart surveillance systems	Privacy and ethical concerns	Privacy preserving AI frameworks
Real-time traffic systems	Incomplete and noisy sensor data	Robust data imputation techniques
Centralized smart city architectures	Scalability and single point failure issues	Distributed and federated architectures
Smart healthcare analytics	Data security and confidentiality risks	Secure federated healthcare analytics
Energy management systems	Limited adaptive intelligence	AI driven predictive optimization
Developing smart city models	High infrastructure and deployment costs	Cost effective scalable frameworks

Table 1 summarizes the major limitations observed in existing smart city research and highlights potential research opportunities for developing intelligent and interoperable, which secure urban systems. Filling these gaps is required for a successful operation of sustainable smart city architecture represented in Fig 1.

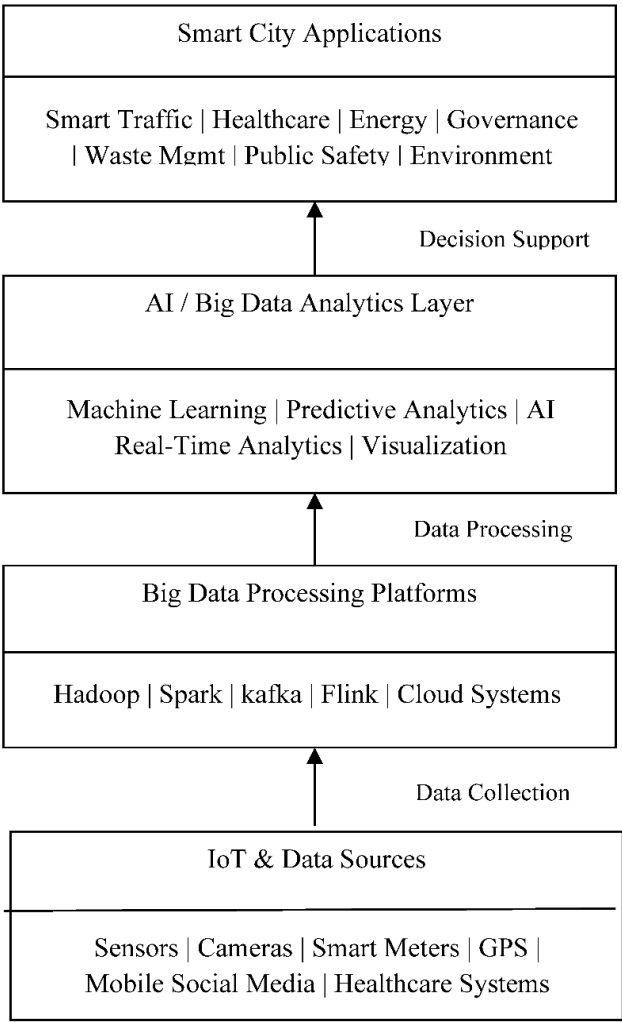


Fig. 1. Big Data-Driven Smart City Architecture

Need & Significance

Most of the existing research (ex: transportation, healthcare, energy management or surveillance systems) are mainly focused on individual smart city domains. The creation of unified and interoperable frameworks that are able to integrate diverse data sources in real-time has received little attention. There is a need to understand various aspects that are required in smart cities to secure the urban systems using big data technologies.

Objectives

- To compare and analyze the big data frameworks, platforms and processing techniques used in smart cities
- To identify the major challenges associated with big data driven smart city systems

Methodology

The entire study is based on secondary data from scholarly articles, conference proceedings and technical reports. The existing big data frameworks and processing techniques are studied through literature synthesis, comparative analysis and thematic evaluation to identify the major difficulties, research gaps and to recommend future paths for developing efficient and sustainable smart city systems. Also, conceptual and comparative review has been conducted to analyze the advancements and problems faced during the implementation of big data technologies in smart cities. Hence, the study adopted descriptive research method to discuss and explain the observations accordingly.

Conceptual Overview

Big Data Technologies

The development of smart cities is driven by the efficient use of Big Data technologies to collect, store, process and analyze vast and diverse streams of urban data. These technologies offer the infrastructure to enable data driven decision making and efficient administration of urban environments.

1. Data Collection Technologies

- a) Internet of Things (IoT): This refers to interconnected technologies like sensors and GPS enabled trackers, smart meters and surveillance cameras that continuously collect data from urban environments, providing valuable insights into various conditions and activities.
- b) Mobile and Social Media Platforms: This makes use of user generated data from mobile apps and social networks, helps track behaviour patterns, sentiments and service usage.

2. Data Storage Technologies

- a) Hadoop Distributed File System (HDFS): This is a dynamic, high efficiency architecture designed to handle massive amounts of unstructured and semi-structured data.
- b) NoSQL Databases (e.g., MongoDB, Cassandra): These handles large scale, schema less data ideal for diverse smart city datasets such as logs, sensor data and citizen feedback.
- c) Cloud Storage Services (e.g., AWS, Azure, Google Cloud): These offer elastic storage solutions with global access and disaster recovery features.

3. Data Processing Technologies

- a) Apache Hadoop: This is a versatile, open-source ecosystem enabling large scale distributed data processing through the MapReduce paradigm.
- b) Apache Spark: This is a high speed, in memory processing engine that is expertly engineered for real-time analytics and machine learning in smart city applications.
- c) Apache Kafka: This is a scalable, distributed system engineered to handle real-time, high-volume data streams with efficiency and precision.

4. Data Analytics & Machine Learning

- a) Apache Flink & Storm: These are real-time stream processing technologies, essential for traffic control, emergency alerts and energy management.
- b) TensorFlow & Scikit-learn: These are the libraries used to develop machine learning models for predictive analytics and intelligent decision systems.
- c) Geospatial Analytics (using tools like ArcGIS): These tools are meant for spatial data visualization, land use planning and infrastructure development.

5. Visualization & Dashboard Tools

- a) Tableau, Power BI & Grafana: These tools help city administrators and decision makers interpret data through interactive dashboards and visual reports.

6. Security & Governance Tools

- a) Data Encryption & Blockchain: These tools ensure secure data sharing and traceable transactions, vital for maintaining citizen trust and transparency.
- b) Identity & Access Management (IAM): These tools manage who has access to what data and when, especially in sensitive public systems.

7. Integration with 5G, Edge AI & Emerging Technologies

With the Next-gen technologies, smart city infrastructure is developed by increasing speed, responsiveness and autonomy in decision making systems.

- a) 5G Connectivity is suitable for ultra-low latency communication, essential for autonomous vehicles, remote healthcare and real-time surveillance.
- b) Edge Computing & Edge AI tools allow data processing at the device level (e.g., traffic cameras, sensors), reducing dependency on central data centers.
- c) Quantum Computing from emerging technologies has potential for solving complex optimization problems in urban logistics and energy distribution.

Example Use Cases:

- Smart intersections that adapt in milliseconds using 5G + Edge AI.
- Edge AI-enabled drones for crowd monitoring during city events.
- Predictive load balancing in energy grids using AI-enhanced quantum solvers.

Table 2. Comparison of Big Data Technologies Used in Smart Cities

Technology	Use Case	Advantages	Limitations
Hadoop	Distributed data storage and processing	High scalability and fault tolerance	High latency for real-time processing
Apache Spark	Real-time analytics and machine learning	Fast in memory processing	Higher memory consumption

Apache Kafka	Real-time data streaming	High throughput and low latency	Complex cluster management
IoT Sensors	Urban data collection	Real-time monitoring	Security and privacy concerns
Cloud Computing	Centralized storage and analytics	Elastic scalability and remote access	Dependency on internet connectivity
Edge Computing	Localized real-time processing	Reduced latency and bandwidth usage	Limited computational resources
Blockchain	Secure data sharing and authentication	Transparency and immutability	High computational overhead
AI/ML Models	Predictive analytics and automation	Intelligent decision making	Requires high quality datasets

The proposed bigdata framework for smart cities is depicted in Fig. 2.

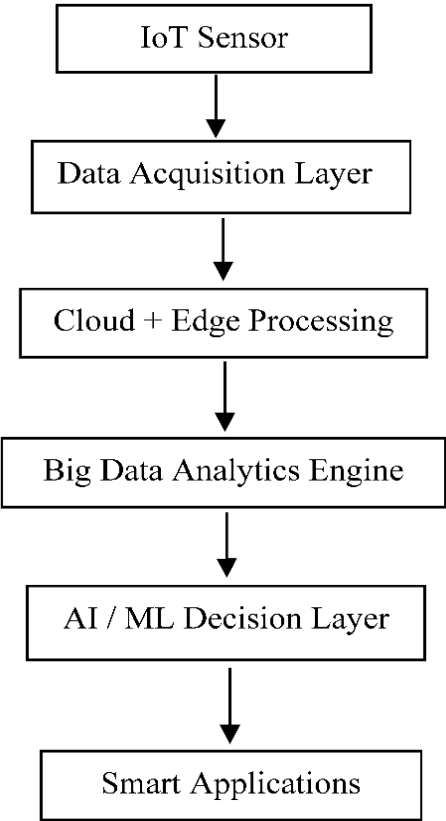


Fig 2. Proposed Integrated Bigdata Framework for Smart Cities

Applications & Case Studies

1. Applications

Big data is crucial for determining the creation and transformation of smart cities, encouraging innovation in infrastructure, streamlining public services and promoting more efficient and sustainable urban living. Its main uses in smart cities are:

a) Traffic Management & Smart Transportation

- i. This is real-time traffic analysis employing GPS, sensors and cameras to achieve optimal traffic flow and reduced congestion.
- ii. This helps in predictive maintenance of the vehicles and infrastructures.
- iii. This optimizes public transit by analyzing how it is used to enhance routes and schedules.
- iv. This ensures Uber and other ride sharing / mobility services to employ big data to dynamically match supply and demand.

b) Energy Management

- i. This helps smart grids, analyze the usage trends to balance energy generation and consumption.
- ii. This makes use of smart meter data to optimise energy consumption in homes and enterprises.
- iii. Integration of renewable sources by predicting production and consumption trends.

c) Waste Management

- i. Smart Bin scan report fill levels with the help of sensors, allowing optimized waste collection routes.
- ii. Predictive analytics can be utilized to identify peak times and locations for waste generation.

d) Water Management

- i. Monitor water quality, leakages and consumption patterns using sensor data.
- ii. Predictive models help in drought management and flood risk analysis.

e) Public Safety & Crime Prevention

- i. Predictive policing by analyzing historical crime data to anticipate crime hotspots.
- ii. Real-time surveillance using video analytics and facial recognition.
- iii. Disaster response and emergency management via sensor data and social media analytics.

f) Healthcare & Epidemic Monitoring

- i. Tracking disease outbreaks and managing public health emergencies using social media, hospital records and sensor data.
- ii. Improving urban health services through demographic and health data analysis.

g) Environmental Monitoring

- i. Air quality monitoring is conducted using IoT sensors to provide real-time data on pollution levels.
- ii. Tracking noise levels, temperature and other environmental metrics.

h) Urban Planning & Development

- i. Analyze land use, population growth and housing patterns to support sustainable development.
- ii. Use data from mobile networks and satellites to plan infrastructure projects.

i) Smart Governance

- i. Big data driven e-governance platforms for effective service delivery and public involvement.
- ii. Measuring citizen satisfaction and feedback through analysis of sentiment on social media and public forums.

j) Smart Buildings & Infrastructure

- i. Optimize lighting, heating and cooling with data from building management systems.
- ii. Space use and energy efficiency by means of occupancy sensors.

k) Maturity Models of Smart Cities

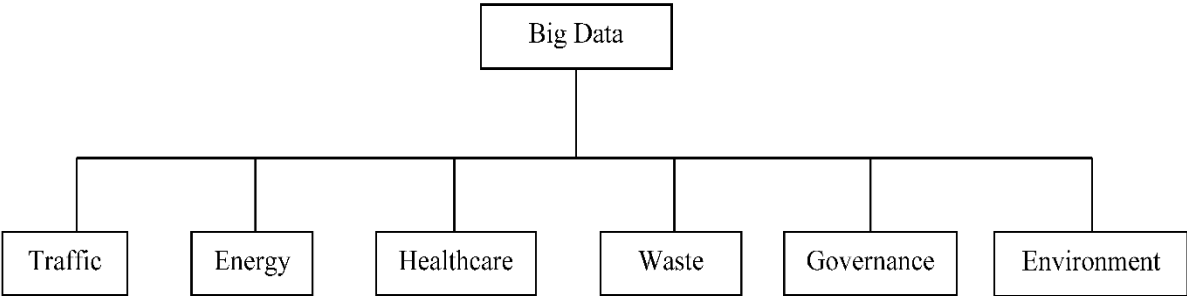


Fig 3. Big Data Applications in Smart Cities

These models describe phases of evolution from simple digital services to fully integrated intelligent systems.

Some popular frameworks include:

- i. IBM Smart City Maturity Model (Stages: Instrumented, Interconnected, Intelligent).
- ii. IDC Smart City Index (includes 6 dimensions: governance, IT, innovation, infrastructure, data and public involvement).
- iii. Smart City Assessment Framework, Ministry of Housing and Urban Affairs, India.

These models are:

- i. Diagnostic tools for preparedness benchmarking.
- ii. Roadmaps for investment and integration.
- iii. KPIs to assess sustainability, inclusivity and resilience.

2. Case Studies

The summary of effective use of big data technologies in smart cities such as Barcelona, Singapore, New York City, Amsterdam and their outcomes and impact analysis are highlighted below:

a) Barcelona, Spain

i. Big Data Applications:

- Intelligent traffic signal and parking systems employing real-time data.
- IoT enabled garbage containers reporting fill levels.
- Smart water irrigation of parks with soil and meteorological data.

ii. Outcomes & Impact:

- Reduced traffic congestion by around 21 percent.
- Smart irrigation to reduce water consumption by 25 percent.
- Improved efficiency in waste collection, leading to 10-15 percent reduction in operational expenses.

b) Singapore

i. Big Data Applications:

- Smart Nation program embeds sensors and big data analytics into all services.
- Real-time analysis of transportation and movement of people.
- Predictive healthcare systems based on national health data.
- Intelligent utility grids and residential energy management.

ii. Outcomes & Impact:

- Adaptive transport systems cut commuter wait times by 8-12 percent.
- Improved public safety through predictive analysis and surveillance mechanisms.

- Early detection of diseases with AI and big data improves healthcare services.

c) Smart Cities in Developing Countries

Pune, India – A Data-Driven Urban Transformation

i. Initiatives:

- Development of the Pune Smart City Data Platform, combining data from transport, water and solid waste services.
- Citizen feedback and grievance redressal via the ‘PMC Care’ smart phone app.
- AI for water shortage prediction and tanker route optimisation.

ii. Impact:

- 20 percent increase in water delivery efficiency.
- 35 percent decrease in time to resolve complaints.
- Enhanced public participation through open dashboards and digital kiosks.

Cities may still be smart despite budgetary challenges by focusing on low-cost data linkages and community involvement.

Observation & Discussion

This study has showed that big data technologies have a significant role in the evolution of smart cities, enabling effective data acquisition, storage, processing and analytics in different application areas such as transportation, healthcare, energy, environmental sustainability and public safety. The real-time decision-making capability, enhancement of operational efficiency and optimization of resource usage have been further consolidated in the smart city infrastructures through the synergistic integration of IoT, cloud computing, edge computing and artificial intelligence.

As per observation of Ingle et al. (2017) ICT is a key element in the creation of smart cities, providing connectivity, information exchange and efficient service delivery. The results indicated that ICT boosts urban administration, e-governance, smart transportation and energy systems. Also, Agboola et al. (2023) observed that ICT facilitates effective communication, collaboration and information sharing among various urban stakeholders, including government agencies, businesses and individuals. The findings suggested that the integration of ICT contributes significantly to the development of equitable and environmentally sustainable smart cities. The research conducted by Hashem et al. (2016) emphasized the role of big data in smart city development and analysed the huge data generated by sensors; IoT devices, social media platforms and urban services can be properly used to improve city operations and enable appropriate decision making.

A research study by Anthopoulos and Giannakidis (2016) pointed out, technology alone is not sufficient to achieve energy efficiency in smart cities, but effective regulations and well-organized governance frameworks are also important. The proposed task-based modeling

technique in this research gives a systematic approach to relate energy management activities to more generic urban development goals. The cities may improve resource efficiency, reduce energy waste and increase overall urban performance using standard operating procedures and clear regulatory standards. In furtherance, the report by Javidroozi et al. (2019) emphasized on the necessity of integrating enterprise system techniques into smart city frameworks to revolutionize traditional urban management processes. The findings show that the adoption of enterprise systems integration methodologies can improve coordination, interoperability and adaptability in complex urban contexts and hence promote more effective and sustainable city operations. But successful implementation requires strong governance, engagement with stakeholders and continual technical innovation to adapt to changing urban demands.

The research work by Bouzidi et al. (2020) explored the implementation of IQRF technology on the Internet of Things (IoT) based smart city applications as a low power wireless communication solution. The results revealed that IQRF is suitable for the connection of a large number of smart devices in the urban environments. Hence, these capabilities make it suitable for applications like traffic management, environmental monitoring, smart lighting and public safety systems. Huang et al. (2022) emphasized on the efficiency of ontology-based integration for the interconnection of city models and IoT systems using open standards such as CityGML, IndoorGML and SensorThings API. The results showed better data sharing and decision making. The research study conducted by Javed et al. (2022) offered a broad view on the history of smart cities and emphasizes the crucial prerequisites for establishing sustainable, intelligent and citizen-oriented urban ecosystems. The results indicated that successful implementation of smart city relies on the convergence of modern technologies such as Internet of Things (IoT), artificial intelligence (AI), big data analytics, cloud computing, blockchain and next-generation communication networks. In furtherance, the proposed architecture by Astrain et al. (2022) integrates sensors, IoT technologies and communication networks to achieve real-time monitoring of electric bus operations such as energy usage, battery status and vehicle performance. The results indicated that continuous collection and analysis of data can improve efficiency, reliability and management of public transportation systems in smart city scenarios.

The research study conducted by Khalil et al. (2022) indicated blockchain technology as a potential way to use decentralized authentication and trust management techniques to secure IoT enabled smart devices in smart cities. The results highlighted the necessity of lightweight, scalable and interoperable blockchain architectures to facilitate the construction of safe and sustainable smart cities. The report by Kwak and Lee (2023) emphasized that integrating technical innovation with robust governance frameworks, efficient policy frameworks and citizen focused services is necessary for the establishment of sustainable smart cities. The results of South Korea's smart city projects show that creating resilient, adaptable and sustainable urban ecosystems requires long-term planning, institutional backing and stakeholder cooperation. Moreover, FABS (Framework for Addressing Business Process Change Challenges) framework is proposed by Javidroozi et al. (2023) as a systematic strategy for business process transformation management during smart city construction.

The results indicated that implementation of a smart city entails substantial organizational and operational changes are needed for organized planning, appraisal and coordination. The FABS framework allows assessing the smart city readiness, helps the formulation of strategic roadmaps and gives guidance on the integration of technological solutions into current municipal processes and governance structures. The research study by Joshi (2024) highlighted that IoT and big data analytics have huge potential to increase citizen wellbeing, operational effectiveness and urban sustainability in smart cities. The findings underscore the need for integrated technological, financial and policy frameworks to build sustainable, resilient and data-driven smart cities. Moreover, Shah et al. (2019) in their research emphasized the potential of IoT and big data analytics in creating disaster-resilient smart cities through real-time monitoring, predictive analytics and intelligent decision-making. The results indicated that incorporating data from multiple sources can have a substantial impact on disaster preparedness, response and recovery processes.

Nuaimi et al. (2015) in their research showed the possibility of big data analytics to improve the efficiency, sustainability and intelligence of smart cities. The results mentioned that big data applications can improve urban services, such as transportation, health care, energy management and governance, by providing real-time analysis and predictive decision making. The study by Moreno et al. (2017) pointed the transformative potential of big data analytics to power intelligent and responsive smart city services by means of real-time data processing and predictive decision making. The results indicated that big data methods have the potential to enhance urban efficiency, optimize the management of resources and assist sustainable development.

The real-time decision-making capability, enhancement of operational efficiency and optimization of resource usage have been further consolidated in the smart city infrastructures through the synergistic integration of IoT, cloud computing, edge computing and artificial intelligence. Moreover, comparative reviews have revealed that frameworks such as Hadoop are most suitable for large scale batch processing, whereas Spark and Flink are more suitable for real-time and stream processing applications. Hybrid architectures combining cloud and edge computing have recently gained increasing attention due to their capacity to reduce latency and increase scalability. The choice of a suitable platform depends on the requirements of the application, the amount of data, the speed of processing and the computational resources. Talebkhah et al. (2021) in their report demonstrated the potential of IoT and big data technologies to revolutionize the delivery of intelligent, efficient and sustainable smart city services. Such findings highlight their significant roles in transportation, healthcare, energy management and environmental monitoring through real-time data analytics and decision-making. Also, Tham and Verhulsdonck (2023) in their study showed how smart education may change smart city ecosystems through networked, tailored and omnipresent learning environments. The findings implied that the integration of digital technologies and urban infrastructure can improve access to education, collaboration and lifetime learning opportunities.

The study conducted by Wang (2023) has focused on the need towards big data applications for intelligent decision making, effective resource management and sustainable urban growth

in smart cities. Big data analytics may improve urban planning, public services and governance through real-time analysis and predictive insights, according to the research. Supangkat et al. (2024) in their research demonstrated the success of the living lab method to collaborative, inclusive and sustainable smart city development. The suggested framework improves urban services, encourages digital inclusion and enhances the quality of life of the residents by merging the technology innovation, community participation and stakeholder’s collaboration. The findings highlighted the need for participatory and low-cost smart city approaches in the development of resilient and sustainable urban ecosystems.

Despite these advancements, several challenges continue to obstacle the widespread adoption of big data technologies in smart cities. Data privacy and security are still important issues because of the large amount of sensitive data generated by interconnected devices. Other implementation challenges are data heterogeneity, interoperability, scalability and expensive infrastructure costs. In addition, the absence of standardized data governance frameworks presents significant challenges to efficient data sharing and management. The aforesaid extensive literature reviews have pointed various gaps in the current research. Therefore, the existing studies predominantly focus on technical performance, whereas energy efficiency, explainability, ethical concerns and sustainable data management have received less attention. Emerging technologies such as federated learning, digital twins, explainable artificial intelligence and blockchain-based architectures offer promising directions for addressing these challenges and enabling the development of more resilient and sustainable smart city ecosystems. The reviews have showed that big data technologies have a significant role in the evolution of smart cities, enabling effective data acquisition, storage, processing and analytics in different application areas such as transportation, healthcare, energy, environmental sustainability and public safety.

Smart City Challenges

Smart cities are designed to employ technology and data to make urban living better, but there are plenty of challenges and negatives as well, which are indicated in Fig 4.

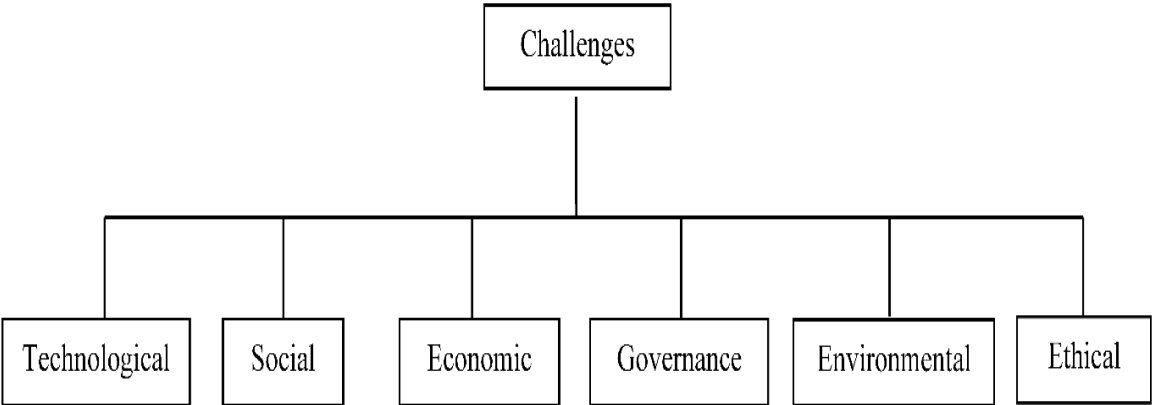


Fig 4. Smart City Challenges

1. Technological Challenges

- **Data Privacy & Security:** The collecting of large volumes of data from sensors, cameras and Internet of Things devices can lead to breaches of personal privacy and make cities vulnerable to cyber assaults.
- **Interoperability:** Integration is more difficult when different suppliers and legacy systems do not use defined protocols.
- **Scalability:** Smart infrastructure must scale up with growing cities. This can be costly and technically complex.
- **Data Overload:** Processing, storing and making sense of large volumes of real-time data is a huge challenge.

2. Social Challenges

- **Digital Divide:** Not all citizens have equal access to the benefits of digital technologies.
- **Resistance to Change:** Citizens and governments may be hesitant to adopt new technology due to lack of confidence or awareness.
- **Surveillance Concerns:** Continuous surveillance may provide the impression of being watched, which could violate civil liberties.

3. Economic Challenges

- **High Upfront Cost:** Smart infrastructure (sensors, networks, analytics platforms) requires significant upfront investments.
- **ROI (Return on Investment):** It is not always evident how quickly and how much economic rewards will be generated from smart city projects.
- **Funding and Budgeting:** Many towns lack the financial resources or methods for long term sustainability.

4. Governance Challenges

- **Policy Gaps:** Unclear policies around data use, sharing and ownership can delay or hamper smart city development.
- **Coordination Issues:** Smart cities necessitate the collaboration of multiple stakeholders, including government, private sector and people, which can be challenging to coordinate.
- **Corruption and Mismanagement:** Inefficient use of finances and lack of transparency can ruin projects.

5. Environmental Challenges

- **Generation of E-trash:** Smart gadgets and sensors, if not managed appropriately, might contribute to electronic trash.

- Energy Consumption – The deployment of data centers and IoT devices might lead to increased energy needs unless green technologies are implemented.

6. Ethical AI and Responsible Big Data Use

As smart cities become more dependent on AI-driven insights, ethical data practices are imperative. Building ethical AI is about transparency, accountability and fairness to citizens' rights. In smart cities, this means avoiding algorithmic bias, obtaining informed consent for the use of data and delivering explainable outcomes for automated decisions. Urban AI systems should be implemented responsibly according to frameworks such as:

- IEEE's Ethically Aligned Design
- EU's Guidelines on Trustworthy AI
- Principles of Transparency, Accountability and Fairness

Key considerations:

- Avoiding biased datasets in predictive policing or facial recognition.
- Providing opt out mechanisms and citizen awareness tools.
- Ensuring explainability in critical systems like healthcare triage or welfare allocation.

Suggestions

The following suggestions are highlighted towards focusing on future directions and research opportunities on the key areas in using big data technologies for smart cities:

Real-Time Data Analytics

- Goal: To enable immediate decision making for traffic control, emergency response, pollution monitoring, etc.
- Research Opportunity: Low-latency algorithms and edge computing architectures enabling faster processing near the data source.

AI & Machine Learning Integration

- Goal: Use predictive analytics to predict urban patterns (e.g., traffic flow, energy usage).
- Research Opportunity: Create city specific AI models that can learn from multimodal data (video, text, sensors) with minimal human supervision.

Interoperability & Standardization

- Goal: To enable diverse systems (transport, healthcare, utilities) to function together.
- Research Opportunity: Develop open data standards and semantic frameworks to allow system wide integration.

Privacy-Preserving Big Data Frameworks

- Goal: Preserve privacy for individuals in large scale data analysis.
- Research Opportunity: Explore techniques like homomorphic encryption, federated learning differential privacy.

Decentralized Data Architectures

- Goal: Move from centralized cloud systems to more resilient architectures.
- Research Opportunity: Develop blockchain-based data governance models that support traceability, transparency and citizen control over data.

Urban Digital Twins

- Goal: Create virtual models of cities for simulation and planning.
- Research Opportunity: Use big data to power real-time digital twins, enabling predictive modelling for urban planning, disaster management and infrastructure development.

Sustainability & Green Big Data

- Goal: Optimize resource use (energy, water, waste).
- Research Opportunity: Develop green algorithms and energy-aware data pipelines to reduce the carbon footprint of data analytics.

Citizen-Centric Data Ecosystems

- Goal: Empower citizens with data-driven services and participation tools.
- Research Opportunity: Create crowdsourced data platforms and interactive dashboards that involve citizens in co-creating smart services.

Data Quality & Missing Data Handling

- Goal: Ensure high-quality, reliable data for decision-making.
- Research Opportunity: Advance automated data cleaning, robust imputation techniques and context-aware preprocessing tailored to urban datasets.

Conclusion

The significance of big data for the creation and functioning of smart cities is highlighted in this study. A detailed examination of existing applications, challenges and emerging trends indicates that big data is critical for transforming urban infrastructure, enhancing service delivery and strengthening governance frameworks. It is to be noted that from real-time traffic control to predictive maintenance and from energy optimization to citizen interaction platforms, big data integration has significantly improved the efficacy and responsiveness of

urban infrastructure. Despite these developments, a number of obstacles still exist. Data privacy, interoperability, the digital divide and environmental concerns are some of the major obstacles to the sustainable use of big data technology. Therefore, to address these concerns, strong frameworks that strike a balance between technical innovation, ethical considerations, social equity and environmental stewardship are required. The effect of big data on smart city innovation is more than its capacity to collect and analyze enormous quantities of data. Instead, it is essentially based on its ability to support informed, inclusive and participatory urban planning. Realizing this potential necessitates a coordinated effort toward responsible implementation that ensures openness, protects privacy and encourages fair access to the advantages of data-driven innovation. Future research areas include privacy preserving data analytics, improvement of interoperability standards and the study of citizen inclusive data ecosystems. Smart cities will require holistic and collaborative approaches to be environmentally sustainable, inclusive and resilient metropolitan areas that meet the needs and aspirations of their inhabitants.

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A Conceptual View on Integrating Design Thinking, Project-Based Learning and Entrepreneurship Education for Future-Ready Graduates

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Abstract

After two decades of active research and practice connected with the intersection of marketing strategy, project management pedagogy and entrepreneurship ecosystem development, a professionally non-negotiable conclusion has emerged: the lack of employability and innovation that is being observed with Indian higher education graduates is not a knowledge issue and clearly a pedagogical architecture issue. The graduate competency contract has been completely transformed by the shift from Industry 4.0 to Industry 5.0. Employers are not just looking for technically competent candidates, but they are looking for professionals who can relate to who the stakeholders are and what their pain is and who can co-create solutions in an iterative fashion, both within and across functional disciplines with disciplined agility, who understands the commercial opportunity in social complexity and who will be able to execute entrepreneurial ventures with calibrated risk intelligence. This competency profile cannot be created through a traditional lecture-based instructional approach. This conceptual chapter presents the Integrated Future-Ready Graduate Framework (IFRGF) – a pedagogical framework with 8 stages that is firmly grounded and deliberately integrated Design Thinking (DT), Project-Based Learning (PBL) and Entrepreneurship Education (EE). Based on research publications in Scopus, WEF Reports 2020 & 2023, UNESCO Education 2030 and National Education Policy (NEP) 2020, the IFRGF is linked to Sustainable Development Goals (SDG 4 & SDG 8) imperatives and supported by institutional evidence from Stanford, MIT, Indian IITs and university incubation ecosystems in Gujarat. This research chapter offers practical suggestions for universities, faculty, policy makers and industrial partners to focus on integrating design thinking, project-based learning and entrepreneurship education thereby facilitating future-ready graduates.

Keywords: Design Thinking, Project-Based Learning, Entrepreneurship Education, Employability, Innovation, IFRGF.

Introduction

Traditionally, employability is primarily associated with domain knowledge and professional certification. The unstated premise that has been foremost in every curriculum is having a simple and a well-designed degree for workforce readiness. This assumption has been decisively discredited, not just on theoretical grounds, but by the body of empirical evidence, programme design and leadership experience gained over 20 years of incubation efforts that showed the outcomes of incubation in terms of entrepreneurship and employment and from employer feedback and outcomes data collected from diverse institutional settings across Gujarat and beyond.

Industry 4.0 to Industry 5.0 – A Paradigm Without a Matching Pedagogy

This section traces the evolution from Industry 4.0 to Industry 5.0 and examines the corresponding pedagogical implications for higher education. The shift from Industry 4.0, based on cyber-physical integration, automation and big data analysis, to Industry 5.0, which focused on human-machine interactions, societal resilience and sustainability imperatives. This shift not only transformed the nature of work, but also transformed the job descriptions as well (European Commission, 2021). Moreover, this has changed the psychological and cognitive relationship between education and employment. This transformation requires a corresponding transformation in the educational philosophy as well.

The half-life of certain technical skills is rapidly shrinking from decades to years and in some areas, it has been months (WEF, 2020 & 2023). In furtherance, what gains in value over this disruption cycle are meta-competencies—the ability to learn and relearn, deal with strategic ambiguity, synthesize across fields of study and translate insight into entrepreneurially valuable value. The Integrated Future-Ready Graduate Framework (IFRGF) proposed in this chapter is just such a solution—one that is not superficial curriculum changes, but radical redesign of curriculum, instruction, sequencing and assessment practices that will result in graduates who are truly equipped to succeed in a world that values entrepreneurial thinking, design sensibility and disciplined project execution.

Future-Ready Graduate: A Seven-Competency Portrait

Critical Thinking: The ability to break down complicated, vague problems; detect causal relationships; question assumptions; and make arguments based on evidence when under stress. Studies on the development of micro-thinking skills show that these sub-competencies can be developed and assessed from early educational stages (Desai et al., 2026a).

Creativity: The ability to generate ideas from outside of standard solution sets; cognitive process from the ideate stage of DT, is the source of entrepreneurial opportunity identification (Brown, 2008; Liedtka, 2018).

Communication: It is the ability to share ideas and concepts in a powerful, multi-layered manner to a variety of stakeholder audiences, from investor presentations to customer discovery calls, cross-functional teams to policy advocacy.

Collaboration: Ability to cooperate and cooperate well in interdisciplinary teams that struggle with genuine uncertainty, which is built over the course of extended engagement with real-world project challenges (Thomas, 2000; Han et al., 2015).

Conviction (Entrepreneurial Mindset): The psychological state of being has been convinced to see an opportunity in difficulty, to take intentional risks, to stay resilient in the face of failures and to remain committed to value creation, is a defining element of entrepreneurial behaviour that has been observed through field research in the higher education sector in Gujarat (Bird, 1988; Krueger et al., 2000).

Competence (Digital Readiness): Functional ability with digital tools, data analytics platforms, AI-assisted decision-making frameworks and digital marketing ecosystems – competencies that are essential for employment value and entrepreneurial competitive advantage (Desai et al., 2026b).

Command (Leadership): Being able to harness collective intelligence for collective purpose when uncertainty reigns - a competency that has grown out of the stakeholder management, project leadership and mentoring experiences in the latter stages of IFRGF.

Educational Challenge: Structural Misalignment at Scale

The chilling finding that previous empirical studies on higher education ecosystem in Gujarat, has consistently documented that the prevalent pedagogical model in higher education in this country is fundamentally at odds with the above competencies. Moreover, the essay, essay class and final examination form the backbone of many programmes, though there are occasional case studies and group assignments to break up the routine. Students build “knowledge chunks” and they do not often need to integrate across domains, to deal with real-world complexity across extended timeframes or to suffer the uncertainty of real-life entrepreneurial decision-making (Anjali et al., 2026).

Literature Review

Design Thinking: From Engineering Heuristic to Universal Innovation Pedagogy – Evolution & Theoretical Foundations

Design Thinking’s intellectual roots stem from Herbert Simon’s (1969) re-conceptualization of design as a human problem-solving process and Donald Schön’s (1983) characterization of

the reflective practitioner who learns by engaging in repetitive cycles of action and reflection; to Tim Brown and IDEO's five-stage, human-centered approach to design: Empathize, Define, Ideate, Prototype, Test (Simon, 1969; Schön, 1983; Brown, 2008; IDEO, 2015). The empathy stage is also architecturally relevant to a marketing scholarship point of view: it prioritizes the human experiential reality as the key data source for problem identification - this is the very tenet of customer-centric marketing theory, which has been advocated for decades (Kotler & Keller, 2016). The idea of iterative feedback is central to the agile project management methodology that has become vital to modern startup practice (Anjali et al., 2026) and it is embraced in Prototype and Test.

Applications & Documented Outcomes in Higher Education

These three outcome categories -- creative confidence, synthesis across disciplines and empathetic understanding of the complexity of real-world problems -- are all measurable and documented in the empirical literature on DT integration (Dym et al., 2005; Liedtka & Ogilvie, 2011). The systemic ability of DT to change the cognitive disposition of the practitioner, which creates a growth mindset according to the theory of Dweck (2006) and opportunity orientation, as defined by entrepreneurship scholars, is also a theoretical basis for the IFRGF's integration of DT and EE (Liedtka, 2018).

Project-Based Learning (PBL): Experiential Depth as the Engine of Competency Development

Theoretical Foundations and Constructivist Lineage

PBL's intellectual history is constructivist in nature, stemming from the work of Dewey (1938) who argued that true learning is linked to meaningful experiences. Vygotsky (1978) proposed that learning is a social process that takes place within a zone of proximal development and Kolb (1984) who posited that learning is an active process that cycles between concrete experiences, reflective observation, abstract conceptualization and active experimentation. In order to be considered genuine PBL, students must create a meaningful artefact as a genuine response to a real, complex challenge (Thomas, 2000; Krajcik & Shin, 2014). The stakes of artefact trigger metacognitive engagement and professional quality aspiration, which cannot be reproduced by hypothetical exercises.

Benefits, Limitations & Digital Extension

The meta-analyses outcomes of PBL always showed improvements in the areas of deep content mastery, motivation, transferable skill development and long-term retention (Han et al., 2015; Hmelo-Silver, 2004). Pre- and post-pandemic evidence from Indian universities indicated that the core elements of collaborative learning in PBL can be maintained online through Massive Open Online Course (MOOC)-based pedagogical adaptation, which provided the appropriate pedagogical design for facilitation of elements of collaborative learning. Moreover, assessment difficulties and high level of faculty facilitation need to be addressed accordingly.

Entrepreneurship Education: Cultivating the Disposition to Create Value from Complexity

Evolution from Vocational Training to Mindset Architecture

EE has grown from the business planning preparation focus to a more holistic pedagogical exercise that builds entrepreneurial cognitive and behavioural dispositions in all disciplines (Neck & Greene, 2011; Sarasvathy, 2001). The present chapter draws upon previously published longitudinal empirical research of authors, which has confirmed the statistically significant relationships between structured EE exposure and entrepreneurial intention among students of professional programmes in Middle Gujarat, developing an Indian context of Ajzen's (1991) theory of planned behaviour (TPB). Later research (Desai, 2017; Neck & Greene, 2011) confirmed that the quality of institutional infrastructure - incubation access, mentorship networks and seed funding - between the exposure in education and actual creation of a venture is a moderator, having direct implications for the IFRGF Stage 5–8 design.

Entrepreneurial Competencies, Risk Intelligence & Social Dimension

The entrepreneurial mindset literature (Bird, 1988; Krueger et al., 2000) describes a set of entrepreneurial traits that can be developed through proper educational experiences, such as opportunity recognition, risk tolerance, resilience, proactiveness and creative self-efficacy. Social entrepreneurship utilizes entrepreneurial approach to solve social problems. Also, it is a field of increasing importance to the development landscape of India. This combination of strategy, ESG analytics and machine learning into the entrepreneur's toolkit (Desai et al., 2026b; WEF, 2023) underlines the importance of technical, analytical, humanistic and ethical skills for the modern entrepreneur, supporting the rationale of IFRGF's cross-disciplinary integration.

Conceptual Convergence: Research Gaps in IFRGF

The systematic literature review brings a surprising picture to light: theoretical development of PBL and EE is predominantly parallel with very low levels of cross-citation and even less of cross-citation of empirical implementation. A casual reading of the three pedagogies reveals the clear structural complementarity that is required, but not always clearly stated for the three pedagogies: DT gives PBL project execution the empathetic problem-framing that the iterative process often lacks, PBL gives DT project execution a sustained collaborative infrastructure that the iterative process demands but rarely provides and EE gives PBL project execution a commercial or social validation that transforms its outputs from academically assessed artefacts to consequential real-world innovations. The IFRGF is a system of three architecturally compatible traditions that are amalgamated into a single sequentially coherent and mutually reinforcing instructional system, which can be found in the literature, but not in an operational model.

Need & Significance

Global Imperatives: A Workforce Whose Education Has Not Kept Pace

The findings of the World Economic Forum's Report (2023) on Future of Jobs should serve as a red flag for any and all higher education administrators: 44 percent of workers' core skills will be significantly disrupted by 2027. What they all have in common is that none of the top five competencies identified as critical are skills that can be passively acquired through content receiving. These are dispositional, procedural and experiential. In fact, they are exactly what Design Thinking, PBL and Entrepreneurship Education are designed to produce. UNESCO's (2022) Education 2030 framework reinforces this imperative, which is aligned with SDG 4 on Quality Education and SDG 8 on Decent Work and Economic Growth, the macro-policy architecture in which the IFRGF places its concrete base.

Relevance to Indian Higher Education Ecosystem

The higher education system in India admits more than 43 million students in the roughly 1,100 universities and 43,000 colleges (AISHE, 2022). The shift towards experiential learning, interdisciplinary integration, embedding in vocational education and support for entrepreneurship has been highlighted in this chapter and now explicitly called for in NEP 2020, at all institutional levels (Ministry of Education, Government of India, 2020). As a long-term interaction with the entrepreneurship education ecosystem in Gujarat, ranging from empirical research on entrepreneurial intention and development of entrepreneurship ecosystem at the university level and engagement with policymakers at CHARUSAT's CSIC, it has been consistently shown that when institutional infrastructure, pedagogical design and policy support are aligned, the outcomes become transformative (Neck & Greene, 2011; Ministry of Education, Government of India, 2020). The SSIP framework helped to incubate more than 90 startups in institutions such as CHARUSAT. This chapter projects a systemic question: how people get into this transformation becoming the norm? The need to build these capabilities in graduate education is further emphasized by the fast adoption of agile methodologies in Indian startups (Anjali et al., 2026), AI-driven analytics for business strategy and digital transformation and its impact on consumer behaviour (Desai et al., 2026b).

Significance for Stakeholders

Students: The IFRGF focuses on the development of 'meta-competencies' -empathetic problem-framing, creative ideation, project execution discipline, entrepreneurial resilience and digital fluency -that define long-term career trajectories and entrepreneurial potential (Desai et al., 2026a; WEF, 2023).

Universities: IFRGF aligned programmes help in NAAC and NIRF rankings on innovation and start-up parameters, get industry collaborations and become relevant to the university which ensure enrolment and funds (AISHE, 2022; Ministry of Education, Government of India, 2020).

Industry: IFRGF graduates are able to contribute from the start, with a cross-functional project management capability, design skills to solve customer problems and the ability to work in innovation pipelines (Desai et al., 2026b).

Policymakers: The IFRGF gives a practical, scalable framework for implementing the philosophical aspects of NEP 2020 into a curriculum that can be operationalized in a manner that has measurable outcomes for SDG alignment.

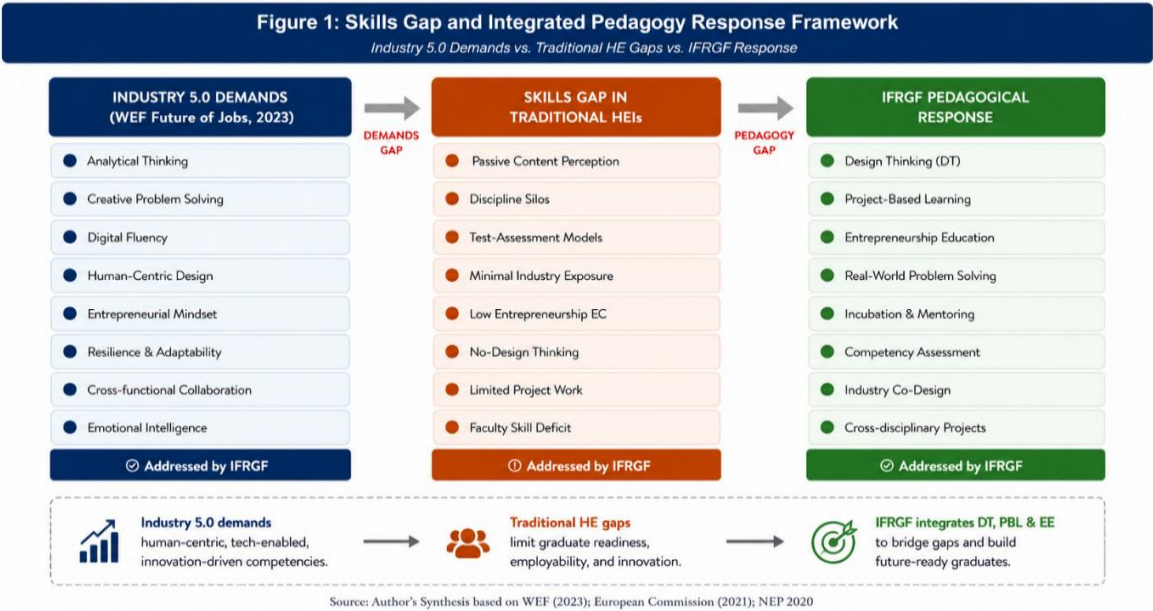


Fig 1. Skills Gap and Integrated Pedagogy Response Framework

Source: Compiled by the authors based on World Economic Forum (WEF) (2023); European Commission, 2021; Ministry of Education, Government of India, 2020.

Objectives

- To understand the pedagogical convergence of design thinking, project-based learning and entrepreneurship education for developing competencies of future-ready graduates
- To propose the conceptual integrated future-ready graduate framework (IFRGF) for implementation in higher education institutions

Methodology

The entire study is based on secondary data sources and adopted descriptive research method to explain and discuss the observations. The present study employed conceptual systematic review design, drawing upon peer-reviewed research publications, policy reports and empirical studies pertaining to Design Thinking (DT), Project-Based Learning (PBL) and Entrepreneurship Education (EE). Moreover, the secondary sources have been identified systematically across five categories: (1) Scopus- and Web of Science-indexed peer-reviewed

journals from 2000–2026 (2) WEF Future of Job Reports (2020 & 2023); UNESCO Education 2030 (2022); and European Commission Industry 5.0 Report (2021) (3) Ministry of Education, Government of India (NEP) 2020, AISHE 2022 Reports and SSIP documentation (4) institutional case documentation from Stanford d.school, MIT, IIT Bombay, CHARUSAT CSIC and Parul University and (5) previously published empirical studies conducted by the authors on entrepreneurship education, ecosystem development, digital transformation and cognitive skill development (Desai, 2017–2026). The research literature pertaining to aforesaid aspects has been thematically synthesized to identify key determinants, evaluate the pedagogical outcomes and develop a standardized integrated framework tailored to Indian higher education contexts.

Table 1: Research Methodology Summary

Parameter	Description
Research Design	Descriptive; Conceptual Systematic Secondary Literature Synthesis
Data Sources	Scopus, Web of Science, WEF (2020 & 2023), UNESCO (2022), NEP 2020, AISHE 2022, Author empirical research (2009–2026)
Period Covered	2000–2026 (seminal pre-2000 foundational works included)
Key Search Terms	Design Thinking, PBL, Entrepreneurship Education, Future Skills, Graduate Employability, Innovation Pedagogy, NEP 2020
Framework Method	Iterative conceptual synthesis; cross-domain convergence mapping; institutional case validation; practitioner experiential grounding
Quality Criteria	Theoretical coherence, internal logical consistency, empirical grounding, practical deployability, SDG alignment

Source: Compiled by the authors based on secondary data from Scopus/Web of Science-indexed journals (2000–2026); World Economic Forum (WEF) (2020 & 2023); UNESCO (2022); European Commission (2021); Ministry of Education, Government of India National Education Policy (NEP) (2020); AISHE (2022); SSIP Documentation; and previously published empirical studies.

Conceptual Framework: The Integrated Future-Ready Graduate Framework (IFRGF)

It is important to clarify that the Integrated Future-Ready Graduate Framework (IFRGF) presented in this chapter is a conceptual framework developed through systematic synthesis of peer-reviewed literature in Design Thinking (DT), Project-Based Learning (PBL) and Entrepreneurship Education (EE), as reviewed in the preceding sections and authors’ previously published conceptual and empirical studies on entrepreneurship education, ecosystem development and pedagogical innovation in Indian higher education (Desai, 2021). The IFRGF is not the product of a standalone primary empirical study conducted specifically for this research study; rather, it represents a theoretically grounded, evidence-informed conceptual contribution whose constituent elements are individually validated through the published literature cited herein. Institutions and researchers seeking to operationalize the IFRGF are encouraged to conduct context-specific empirical studies to validate its applicability in their settings.

A three-layered pedagogical architecture, including an Input Layer, a Process Layer and an Output Layer, is the theoretical core of this chapter, as it is the space, wherein DT, PBL and EE are all in play and mutually reinforcing. The framework is not a curriculum template, but rather a design philosophy for curriculum architecture that focuses on the structural principles that influence how components in the curriculum are sequenced, integrated and evaluated to achieve a desired profile of graduate competencies. Thus, through an Experiential Innovation Process, the three input streams merged into the Future-Ready Graduate whose competency profile is manifested in four societal & economic outputs viz. Employability, Innovation Capacity, Startup Creation and Social Impact, which are illustrated in Fig 1.

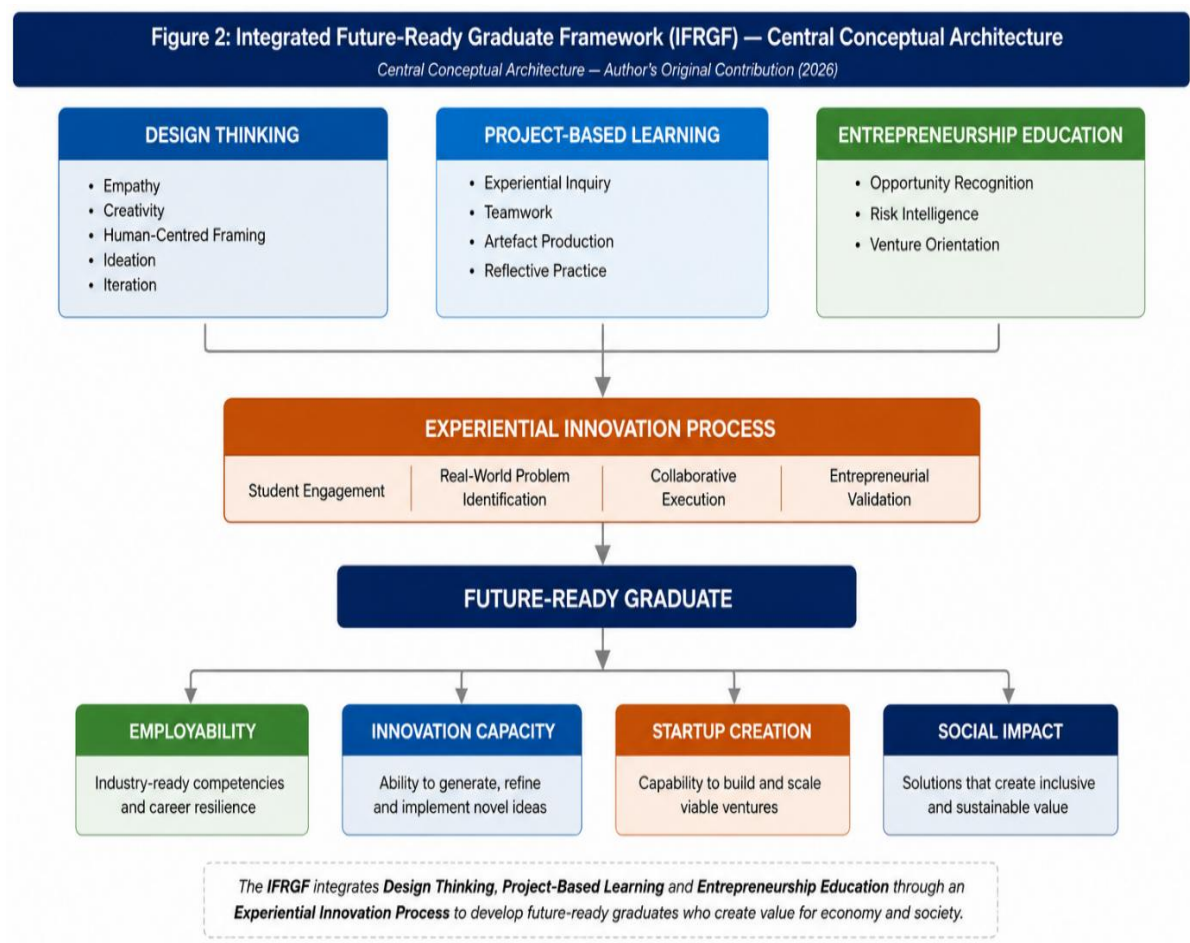


Fig 2. Integrated Future-Ready Graduate Framework (IFRGF) – Central Conceptual Architecture

Source: Compiled by the authors based on research studies by Brown, 2008; Thomas, 2000; Neck & Greene, 2011; Desai, 2021.

Input Layer: Three Streams – One Pedagogical Purpose

The Input Layer is deliberately and intentionally drawn from all three pedagogical traditions. Design Thinking brings empathetic stakeholder engagement, problem framing with human-centered focus, divergent creative ideation and rapid iterative prototyping. Project-Based Learning can foster prolonged real-world interaction, group inquiry, useful artifacts and reflective learning throughout a project’s life. Entrepreneurship Education provides opportunity recognition, risk calibration, market feasibility validation and value creation commitment -turning student projects into a vehicle for economic or social impact.

Process Layer: Experiential Innovation Engine

The Process Layer is the operationalization of the integration of three inputs into a pedagogical sequence that is repeated: Identification of a real-world problem, collaborative project execution, iterative innovation development, entrepreneurial market validation and social or commercial impact assessment. Student teams repeatedly go through the cycle of ideation, action and stakeholder feedback; the IFRGF makes sure that every problem solved is real, every solution is tested against actual stakeholder feedback and every project is assessed both academically and on its actual potential for viability and impact.

Output Layer: 7Cs Competency Profile

The 7Cs graduate competency profile is outlined in the Output Layer, which can be linked to specific instructional activities in the 8-step pedagogical model. Table 2 shows the pedagogical contribution in the three input streams of each IFRGF layer.

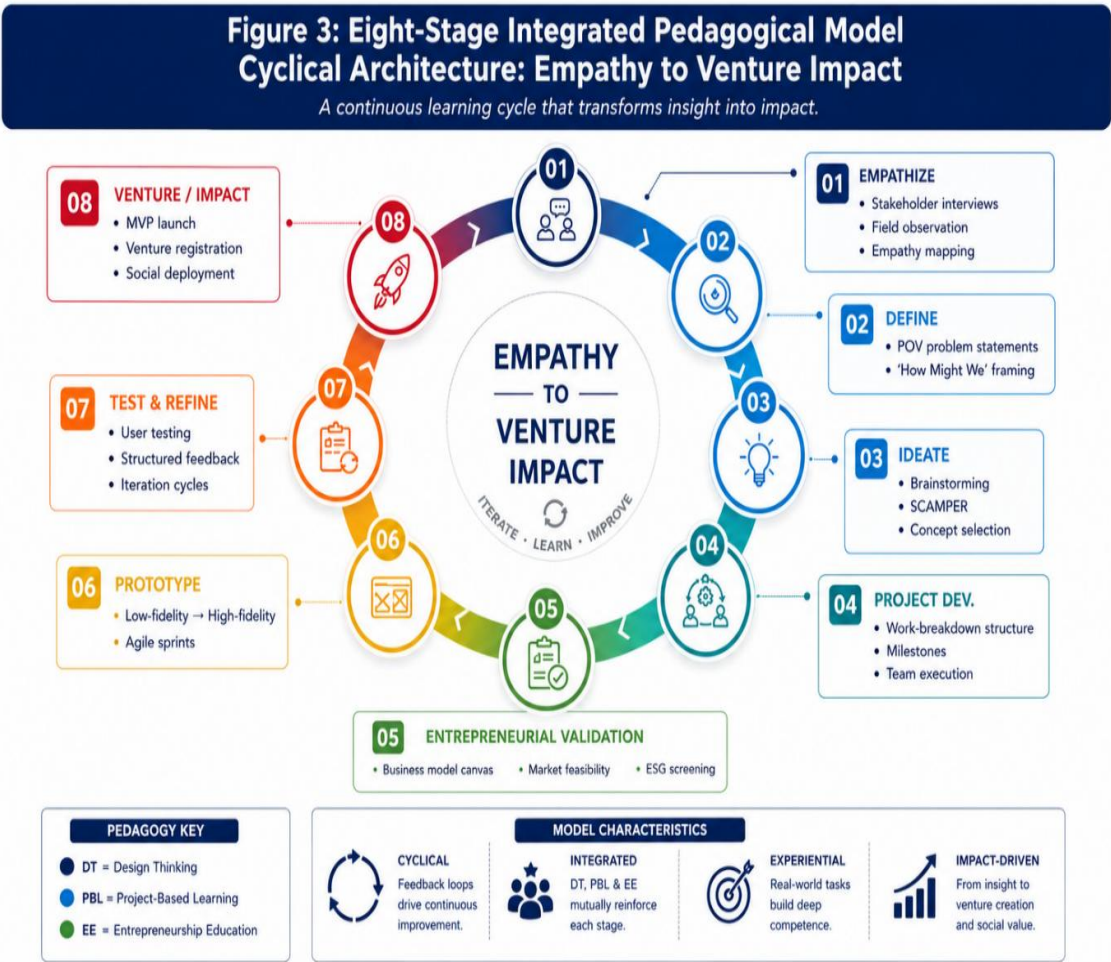
Table 2: IFRGF Layer-by-Layer Pedagogical Integration Map

Layer	Design Thinking	Project-Based Learning	Entrepreneurship Education
Input Layer	Empathy, Creative Ideation, Human-Centered Problem Framing	Experiential Inquiry, Team Collaboration, Artefact Production, Reflection	Opportunity Recognition, Risk Intelligence, Market Validation, Venture Orientation
Process Layer	User-Centered Problem Definition; Divergent Ideation; Rapid Prototyping	Sustained Project Execution; WBS Planning; Iterative Stakeholder Review	Market Feasibility; Business Model Development; Impact Assessment
Output Layer	Critical Thinking, Creativity, Communication	Collaboration, Digital Readiness, Leadership	Entrepreneurial Mindset / Conviction

Source: Compiled by the authors based on research studies of Brown (2008); Thomas (2000); Neck & Greene (2011); Liedtka (2018); Han et al. (2015); Sarasvathy (2001); and authors’ published research (Desai, 2021).

Proposed Integrated Pedagogical Model: Eight Stages from Empathy to Impact

The 8-stage Integrated Pedagogical Model translates the IFRGF into an unrolled version of an instructional design output for a full-semester course, for a year-long module, or for an institutional curriculum. A dominant instruction focus on the main source of pedagogical information and measurable student outcomes that characterizes each stage. The iterative, reinforcing process (user testing and market validation feedback loops back to refine the problem definitions and the quality of ideation) is illustrated in Fig 3. Sustained experience in designing and testing entrepreneurship training programmes and incubation curricula across the university system of Gujarat has led to the model’s strong emphasis on anchoring with real-world problems throughout all eight stages (Thomas, 2000; Krajeik & Shin, 2014). The IFRGF incorporates real-life complexity from Stage 1 (Empathize) through to Stage 8 (Venture Creation / Social Impact Deployment) to ensure that the cognitive involvement and exposure to genuine uncertainty are sustained not just at the end of the project deliverables, but enhanced throughout the learning journey.



Source: Author's Conceptual Development (2026)

Fig 3. Eight-Stage Integrated Pedagogical Model – Cyclical Architecture: Empathy to Venture Impact

Source: Compiled by the authors based on research studies of Brown (2008), Thomas (2000), Neck & Greene (2011), Desai (2021) and other literature reviewed in this chapter.

The model’s defining characteristic has been derived from sustained experience in designing and evaluating entrepreneurship training programmes and incubation curricula across Gujarat’s university ecosystem (Dewey, 1938; Neck & Greene, 2011) -is its insistence on real-world problem anchoring throughout all eight stages. The IFRGF embeds real-world complexity from Stage 1 (Empathize) through Stage 8 (Venture Creation / Social Impact Deployment), ensuring that cognitive engagement with genuine uncertainty is sustained and deepened across the entire learning arc rather than reserved for a terminal project deliverable.

Table 3: Eight-Stage Integrated Pedagogical Model Stage-by-Stage Description

S. No.	Phase	Instructional Focus & Student Activity	Pedagogy	Measurable Output
1	Empathize	Field-based stakeholder interviews, ethnographic observation and pain-point mapping across industry, community or social contexts	Design Thinking	Empathy Map; Stakeholder Journey
2	Define	Synthesis of empathy data into POV problem statements; “How Might We” question framing to bound the solution space	DT + PBL	Problem Statement Document
3	Ideate	Divergent ideation using brainstorming, SCAMPER, analogical reasoning; structured convergent concept selection	Design Thinking	Concept Portfolio; Solution Brief
4	Project Devt.	Structured execution through team project with work-breakdown structure, milestone reviews and role-assigned deliverables	PBL	Project Plan + WBS; Milestone Reports
5	E-Validation	Market feasibility analysis, competitive landscape mapping, Business Model Canvas development, ESG and social impact screening	Entrepreneurship Education	Business Model Canvas; Market Report
6	Prototype	Low-fidelity to high-fidelity prototype development through agile sprint methodology with iterative design review sessions	DT + PBL	Low-Fi + High-Fi Prototype

7	Test & Refine	Structured user testing with target stakeholders; quantitative and qualitative feedback collection; documented iterative refinement	DT + EE	User Test Report; Iteration Log
8	Venture / Impact	MVP launch; or formal venture registration with SSIP incubator; or social innovation deployment with structured impact measurement	Entrepreneurship Education	MVP / Venture Registration / Impact Report

Source: Compiled by the authors based on the studies of Brown (2008); Thomas (2000); Neck & Greene (2011); Krajcik & Shin (2014); Dewey (1938); Neck & Greene (2011); European Commission (2021); Ministry of Education, Government of India (2020).

The uniqueness of the model lies in the real-world problem anchoring on all eight stages of the model, with which it has been built after many years of designing and evaluating entrepreneurship training programmes and incubation curricula across the university system of Gujarat (Dewey, 1938; Neck & Greene, 2011). Sustaining and deepening cognitive engagement with genuine uncertainty is not limited to a terminal project deliverable; the IFRGF infuses real-world complexity through Stages 1 (Empathize) all the way through to Stage 8 (Venture Creation / Social Impact Deployment).

Observation & Discussion

Multiplier Effect: Why Integration Is Exponential, Not Additive?

From the literature synthesis and authors’ professional experience, the greatest learning to come from both is that the value of combining DT, PBL and EE together is not additive, but it is truly multiplicative. Documented improvements in competency have been found for each pedagogy individually. Each tradition complements the others, in the integrated, interdependent system of IFRGF: DT’s project empathy-driven problem framing improves the quality of problem framing in PBL teams, PBL’s institutional project infrastructure provides DT’s prototyping and testing phases with the form they need and EE’s market validation framework gives PBL outputs a consequential purpose, turning them from academically assessed artefacts into innovations that have the potential of a real deployment.

Academic & Cognitive Outcomes: Students’ content knowledge is increased, metacognitive self-regulation skills are improved and students’ transferable skill profiles are much stronger (Hmelo-Silver, 2004; Krajcik & Shin, 2014). Research on micro-thinking skill development (Desai et al., 2026a) presents some instruments for measuring these deeper level cognitive gains, which will provide empirical frameworks for institutions implementing IFRGF to assess the impact of their programmes.

Employability & Career Outcomes: IFRGF graduates consistently outperform other students on competencies that employers value, such as project management skills, cross-functional communication, client-facing empathy and agile problem-solving (WEF, 2023; Desai et al., 2026b). The research into digital transformation and consumer behaviour (Desai et al., 2026b) is a clear example of the analytically fluent graduate profile that employers are looking for, one which is designed to be human-centered.

Entrepreneurial & Ecosystem Outcomes: The most compelling evidence for IFRGF's entrepreneurial impact comes from Gujarat's SSIP-linked university incubation data. Institutions with structured EE embedded in experiential project contexts -including CHARUSAT and Parul University -have demonstrated venture creation rates significantly exceeding national averages (AISHE, 2022; Ministry of Education, Government of India, 2020). The progression through entrepreneurial education from intention to action, documented across Ajzen (1991), which precisely validated the IFRGF's Stage 5–8 architecture.

National Innovation System Outcomes: The programmes aligned to IFRGF shall contribute meaningfully to the National Innovation System. The entrepreneurial curriculum, with integration of ESG analytics, machine learning and AI-powered operations prepares the IFRGF graduates to thrive in an advanced innovation economy as India accelerates its data-driven development trajectory.

Challenges: An Unsentimental Institutional Audit

Faculty Transformation: IFRGF facilitation demands that educators have a new identity, as a DT facilitation specialist, PBL coaching practitioner, EE mentor and industry relationship manager, which is very different from being a lecture-hall content expert. It is a transition that demands ongoing investment of faculty in their competence and not professional enrichment workshops.

Assessment Architecture: The outputs of IFRGF - empathy maps, business model canvases, prototype iteration logs, venture registrations - are process-oriented, but the structure of conventional examination-based systems and processes is not. Process quality, rigour of innovation and entrepreneurial discipline have to be assessed using competency-based assessment rubrics which need to be developed, validated and institutionalized.

Functional Requirements for Stages 6–8: It includes resource requirements such as designing labs, rapid prototyping facilities, innovation spaces, SSIP registration and industry partnerships. Smaller institutions in rural and semi-urban areas need to solve these problems by means of SSIP, DST-NSTEDB, CED funding and by involving the alumni.

Regulatory Rigidity: Though NEP 2020 has introduced some flexibilities in the curriculum frameworks, UGC and AICTE continue to be significant constraints. The most viable pathway for legitimization involves proactive involvement with autonomy provisions, alongside documentation for NAAC and NIRF innovations.

Institutional Architecture for IFRGF Implementation

The Fig 4 illustrates the stakeholder ecosystem needed for implementation of IFRGF. It represents four main stakeholder areas (Universities, Faculty, Industry & Policymakers) with different enablers, converging on the common goal of supporting the student as primary beneficiary and IFRGF as the enabling philosophy of design. Institutions need to focus on the physical infrastructure, human infrastructure and organizational infrastructure like Innovation Labs, Design Studios, SSIP registered Incubation Centres, DT trained facilitators, industry mentors and entrepreneurship counsellors, industry MoUs, government funding pipeline and alumni entrepreneur network.

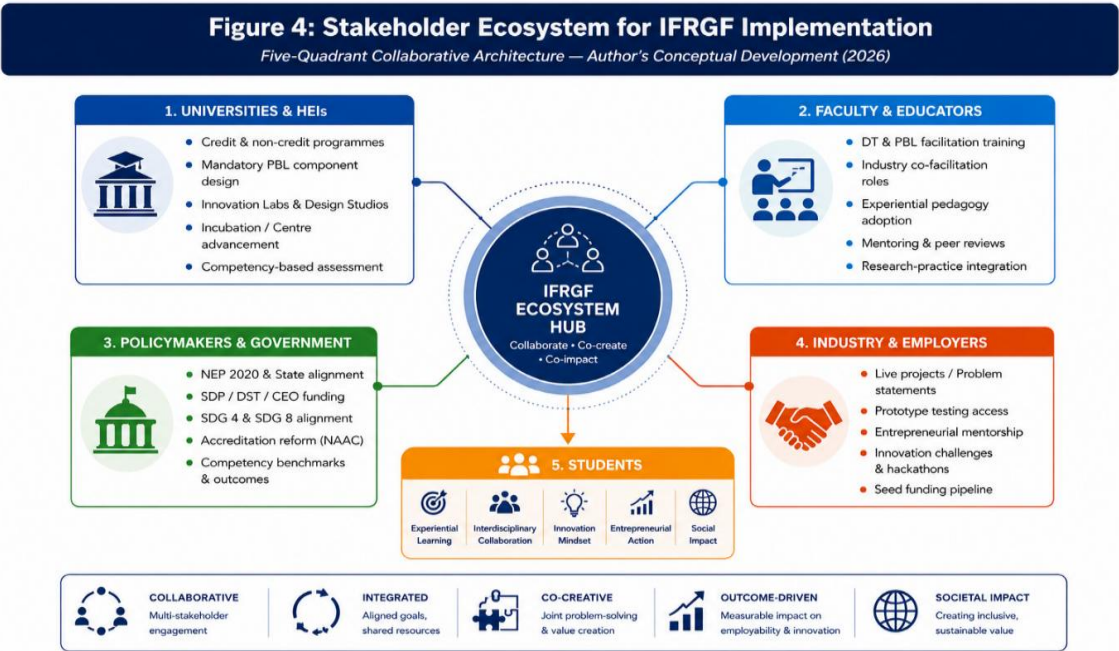


Fig 4: Stakeholder Ecosystem for IFRGF Implementation

Source: Compiled by the authors based on previous research studies conducted by Desai, 2021; Ministry of Education, Government of India, 2020.

Best Practices & Case Illustrations

Case 1: Stanford d.school – Global Template for Human-Centred Design Education

The most studied model of integrating DT at higher education is the Hasso Plattner Institute of Design at Stanford University. The IFRGF’s DT input stream has been successfully translated and scaled to hundreds of universities around the world, as it defining pedagogical innovation, namely the teams of students working on real human problems under conditions of facilitation focused on empathetic engagement and creative risk-taking, has been adopted. Documented outcomes – creative confidence, cross-disciplinary synthesis ability, growth mindset development – are exactly matching the 7Cs Output Layer of the IFRGF. This case highlights

the integration of education with venture infrastructure, specifically in the context of MIT's Entrepreneurship.

Case 2: MIT Entrepreneurship Ecosystem -Integrating Education with Venture Infrastructure

The key to MIT's model is deliberate co-location of educational programme design with venture support infrastructure – the Deshpande Center, Martin Trust Center and MIT delta v (Neck & Greene, 2011) work together to produce a seamless pathway from classroom learning to validation of the start-up to seed funding for the venture launch. The architecture directly supports the IFRGF's Stage 5–8 design logic - entrepreneurial validation, prototyping and venture creation is a constituent part of the educational experience, rather than activities which follow the end of education.

Case 3: Indian Institutes' Innovation Ecosystems – Scale & Contextual Adaptation

Embedding EE in the IIT system through institutionalized E-Cells, Technology Business Incubators (TBIs) and national programme partnerships with Wadhvani Foundation, NEN and other leading organizations into Entrepreneurship Development. Even in the context of a challenging academic curriculum, systematic on-campus DT workshops, PBL innovation challenges and EE programming create transformative entrepreneurial outcomes, as seen in the case of E-Cell at IIT Bombay. The takeaway: There is no single answer other than institutional commitment, as demonstrated by the allocation of resources and advocacy of leadership, to the pedagogical transformation at scale.

Case 4: Gujarat SSIP-Linked University Incubators – Evidence from Field Practice

It was during this period that CSIC of CHARUSAT has facilitated over 90 startups and 130 entrepreneurial ventures under 127 incubation programmes, securing over INR 1.27 crore in funding (AISHE, 2022) - which is the closest possible institutional analogue to IFRGF's Stage 8 in the Indian context. The operationalization of IFRGF principles in various programme contexts is taking place in a contemporary setting of the growing research and innovation ecosystem at Parul University, Gujarat.

Case 5: Longitudinal Evidence from Gujarat's Entrepreneurship Development Programmes

Across the programmes documented (Dewey, 1938; Neck & Greene, 2011), a fairly consistent empirical pattern emerged with respect to learning outcomes related to entrepreneurial intention, sophistication of business planning, risk tolerance and the probability of creating a business. As a result, the programmes that feature structured EE content in addition to live project experience, access to a mentorship programme and access to a peer entrepreneurial community that yield substantially better learning outcomes than mere content delivery programmes. These outcomes are further reinforced by the development of motivational and cognitive foundation that includes measurable instruments like Micro Thinking Skills Test

(Desai et al., 2026a) directly validating the Stage 5 and Stage 8 architectural decisions of IFRGF.

Suggestions & Recommendations

The following suggestions and recommendations are highlighted under four broad categories, viz., universities & higher education institutions, faculty & academic practitioners, policy makers & regulatory bodies and industry & corporate partners:

Universities & Higher Education Institutions

- Incorporate the IFRGF's three-stream integration principle in the curriculum policy with explicit credit allocation for DT, PBL and EE component, distinguishing between the latter and other peripheral courses.
- Provide Innovation Labs, Design Studios and Incubation Centres registered under SSIP with dedicated budgets and fulltime employees – in place of operational requirements of Stages 6-8, the physical and organizational infrastructure that facilitates the operation of a proper learning environment.
- Establish industry partnerships via MoUs, which include brief provision of live projects, student mentorship commitments, access to prototype testing and development of venture funding pipeline.
- Produce competency-based assessment rubrics for process fidelity, quality of innovation, impact of stakeholders and entrepreneurial rigour – a replacement for examination-based assessment that is not suited to the output profile of IFRGF.
- Seek opportunities to implement the provisions of UGC/AICTE academic autonomy proactively to allow for regulatory flexibility for designing and assessment of the curriculum, aligned with IFRGF.

Faculty & Academic Practitioners

- Commit to ongoing faculty development pathways development of DT facilitation, PBL course design and entrepreneurship mentoring competencies, with an understanding that IFRGF facilitation is a unique professional competence and needs to be intentionally and explicitly developed.
- Establish ongoing industry connections that offer live project briefs, mentorship networks, market intelligence and more -shifting the function of faculty member from content deliverer to innovation facilitator between the student teams and real-world challenge owners.
- Use digital pedagogical tools to create ways to expand delivery of IFRGFs in blended and online environments (MOOC content, simulation platforms and collaborative digital workspaces) (Makwana & Desai, 2023; Hmelo-Silver, 2004).

Policymakers & Regulatory Bodies

- Ensure pedagogical transformation through institutional incentives in NAAC and NBA accreditation processes for IFRGF aligned innovation and entrepreneurship programme components.
- Provide adequate funding for SSIP, DST-NSTEDB and CED and support for pedagogical innovation investment, faculty development support and infrastructure development under IFRGF for rural and semi-urban institutions.
- Create nationally recognized benchmarks of graduate competency aligned with IFRGF and WEF Future of Jobs projections and SDG 4/SDG 8 targets for programme design and measuring outcomes of programmes.

Industry & Corporate Partners

- Engage in strategic partnerships on live projects with university programmes alongside ongoing structured engagement, but with real organizational problems, real market data and access to the professional stakeholders, not as a CSR activity.
- Establish Entrepreneur-in-Residence and Mentor-in-Residence initiatives in university incubation ecosystems, bringing in networks, access to markets and entrepreneurial experience.
- Enable student teams to successfully navigate from Stage 7 to 8 by co-designing institution-based innovation challenges, design sprints and hackathons that provide the students with real organizational complexity and visible paths to venture funding.

Conclusion

The proposed Integrated Future-Ready Graduate Framework (IFRGF) in this chapter is grounded in a single argument: Design Thinking (DT), Project-Based Learning (PBL) and Entrepreneurship Education (EE). These are the three pedagogical traditions that are not three separate options among many but three traditions that are architecturally complementary; three traditions whose conscious combination brings together a competency profile of a graduate that none of them can produce independently and that conventional lecture-examination delivery cannot produce at all. However, this is not a doctrinal stance, but the result of two decades of programme design, institutional research and field observation in the changing landscape of higher education in India. The IFRGF's emphasis on experiential learning, interdisciplinary approach and entrepreneurship-based learning and its emphasis on sustained evidence-based research is shaped by the convergence of India's most ambitious articulation of educational transformation to date - NEP 2020 - with sustained evidence-based research. The various institutional evidences are discussed in accordance with the innovation ecosystem. The portion which has been a left over in this research study is the institutional will, investments in faculty development and commitment to industry to make the IFRGF from framework into a practicing curriculum. Furthermore, from a conceptual architecture into measurable, consequential and transformative outcomes for deserving students, employers and aspirations aiming towards sustainable development.

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A Diagnostic Assessment of Intervening Linkages with Brand Engagement and Sustainable Consumption Behaviour in the Context of Apparel E-Retailing Sector - A Framework for Antecedents-Consequences

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Abstract

Internet revolution and the growth of e-commerce platforms have led to major changes in shopping behaviour. Today, consumers prefer digital environments to search for information, compare and contrast product quality and prices. However, due to the absence of physical interaction with products and sellers, there is an increased risk and uncertainty, which makes trust a crucial factor that influences online purchase behaviour. In such contexts, brand trust becomes an important determinant of consumer decision-making and long-term brand relationships. The present study examines the antecedents and consequences of brand trust in the context of apparel e-retail. In addition, the present study sheds light on the intervening role of brand engagement and sustainable consumption behaviour in affecting the above linkages. The data has been collected through structured questionnaire from consumers who had bought apparel products online in the Delhi-NCR region. With the help of structural equation modelling and regression, a total of 839 valid responses is included and analyzed. The researchers have discussed the findings and provided appropriate recommendations for addressing the future requirements.

Keywords: Brand awareness, Brand Experience, Perceived Quality, Brand Engagement, Brand Trust, Sustainable Consumption Behaviour, Online Apparel Retail.

Introduction

Over the past decade, internet and information connectivity has revolutionized industries across the globe, shaping and transforming consumers' purchase behaviour and engagement

in e-commerce. As per the recent report by ITU (2025), around six billion people i.e. seventy-five percent of the world's population have consistent access to the internet, resulting in higher digital participation. The affordable mobile brand is one of the main reasons for wide internet connectivity of the internet in both developed and developing regions. With nearly 950 million active internet users (Ministry of Communications Press Release, 2024), the development of internet connectivity has shown remarkable progress in India. This number continues to grow due to rural coverage and widespread adoption of smartphones and digital services. Further, hassle-free digital transaction platforms have changed the landscape of online shopping and payments. However, despite the growing preference for online shopping, the absence of physical interaction with products and sellers poses an increased risk and uncertainty as consumers largely rely on product description, reviews and digital images. In this context, trust becomes a critical factor affecting consumer behaviour in online platforms.

Brand trust is pivotal in shaping consumers' perceptions of brands and their willingness to engage in online transactions. Studies suggest that the development and maintenance of brand trust is essential because consumers' belief in a brand can influence their confidence in the brand's products and services and help them meet their expectations. The level of brand trust varies among consumers because different individuals have different expectations, experiences and perceptions regarding brands. The role of brand trust becomes particularly important in the apparel sector. The apparel sector is highly experiential in nature as consumers usually want to assess the physical attributes such as fabric quality, colour, fit and comfort before buying, in online retail environments consumers are devoid of this experience, that's how brand trust affects the purchase decisions.

Literature Review

The most important combination of various branding components is indicated and explained as follows:

A) Brand Awareness & Brand Trust

Simply put, brand trust measures the degree of customers' confidence in different businesses and represent customers' view of a brand's staying true to its values, qualities and promises. The academic literature defines it as "the desire of consumers to rely on the brand's ability to show its value (Meulati et al., 2019). As branding helps to differentiate between products, brand awareness and familiarity becomes a crucial aspect of a company's marketing strategy, more so as brands that consumers are familiar with garner higher trust than the ones with which they are unfamiliar. Since online shopping is largely based on trust due to its limited characteristics in comparison to offline shopping, brand awareness plays a significant role in building that trust. Recent empirical studies have demonstrated that brand awareness increases consumer familiarity and reduces perceived risk, facilitating trust in brands when making purchase decisions (Uzir et al., 2025).

B) Brand Experience & Brand Trust

A significant strategy followed by retailers has been providing unique and memorable brand experiences. Brand experience is defined as customers' "feelings, sensations, cognitions and behavioral responses induced by brand-related stimuli that are part of the design, identity, packaging, communications and environments of a brand". Providing a positive brand experience has been widely acknowledged as an important aspect especially in the online shopping environment. Positive brand experiences are vital as a good online experience influences customers' online purchase behavior (Khan & Rahman, 2016). Several studies have highlighted that congenial brand experiences help in cultivating improved consumer trust in the brand (Mukhtar et al., 2024).

C) Perceived Quality & Brand Trust

Perceived quality, understood as consumers perception of overall quality or superiority of a product or service, holds a linkage with brand trust, particularly in the online setting. It has been posited as the main driver (Alhaddad, 2015) and a key indicator of brand trust as consumers' trust for a brand increase in case of high product / service quality (Fianto et al., 2014). As the online business environment is becoming increasingly complex, e-brands are concentrating on offering top-tier products and services to their customers in order to build trusting relations with them and create a niche in the e-retail market. The apparel industry, in particular, is often criticized with negative publicity in the media, therefore building trust among its customers through improving the quality of its products becomes indispensable for its performance. Hence, the perceived quality of an e-retail brand can be said to exert a direct impact on brand trust (Calvo-Porrà & Levy-Mangin, 2017).

D) Brand Trust & Brand Loyalty

Brand Loyalty, the ultimate objective of a brand, consists of a behavioral and attitudinal dimension that goes beyond repeated purchase and commitment is considered to be an essential feature. It depicts the motivation of a consumer to be loyal to a brand. Brand trust acts as a significant mediating factor on the behavior of a consumer before and after the product purchase. It results in sustained loyalty and helps in developing a robust relationship between the consumer and brand. Since trust has an important influence on the commitment of a consumer, it has a similar influence on loyalty too. However, it has been observed that consumers develop a trust for those brands that they feel are secure and reliable and work in the best interest of the consumers.

E) Brand Trust & Brand Equity

Brand equity is defined as "the differential effect of brand knowledge on consumer response to the marketing of the brand". An assessment of brand equity is done by a customer through its strength or the associations of brand and its value as compared to its costs. The research studies have suggested that brand equity is composed of brand awareness, brand image, brand associations and perceived quality (Ebrahim, 2020). Multiple brand trust models have been

developed that showed the influence of trust on brand loyalty, brand equity as well as purchase intention. It has been noted that when higher levels of trust are perceived by a consumer towards a certain brand, their commitment and loyalty towards that brand increases. It promotes the purchase intention of individuals and apart from that, the attributes of brand further promote brand trust, which enhances trustworthiness and integrity thereby promoting brand equity (Liao, 2015).

F) Brand Trust & Brand Value

Brand value refers to the consumer's perception on benefits or utility received in comparison to its cost. The perceived costs of a brand will be impacted by the experience gained from consuming its benefits. If the customers consider that the experience gained from the brand's product provides them with good value, then the brand can be expected to be judged positively by the customers and thus result in the development of a positive attitude towards the said brand (Rammile, 2015). Studies suggested that perceived brand value to be positively related to the consumer's willingness to continue a relationship with the brand. A study by Vazquez (2021) found that consumers are more likely to move towards brand having high value to them, due to similarities between interpersonal attachment and brand attachment formed as a result of trust.

G) Brand Engagement & Sustainable Consumption Behaviour

In addition to antecedents, brand engagement has emerged as an essential element in establishing sustained relationships between brands and their customers (Martinez-Lopez et al., 2021). It refers to the emotional involvement and interaction that consumers develop with brands through digital platforms (Hollebeek et al., 2014). Higher engagement strengthens consumer-brand relationships and enhances trust formation. Brand engagement plays an important role as a mediating variable between brand awareness, brand experience and brand trust. In the online environment, consumers interact with brands through different digital platforms such as social media, websites and other communication channels. This engagement increases their involvement and familiarity, which ultimately leads to higher trust in the brand. Therefore, brand engagement acts as a mechanism through which brand awareness and brand experience influence brand trust (Nandita & Setyawan, 2025).

Consumers who prioritize sustainability tend to form stronger attachments to brands that align with their environmental values. When such consumers trust a brand, their loyalty and positive perceptions are further reinforced. Therefore, sustainability orientation plays an important role in shaping consumer responses in online retail contexts. Simultaneously, growing environmental concerns have led to increased emphasis on sustainable consumption (Swarup & Ganesan, 2025). Moreover, consumers differ in their level of concern toward environmental issues and sustainable practices. For consumers who give higher importance to sustainability, trust in a brand that aligns with their values leads to stronger outcomes such as higher loyalty, better brand equity and greater perceived value. However, for consumers who are less concerned about sustainability, the impact of brand trust on these outcomes may be comparatively weaker.

Need & Relevance

Online retailers offer various digital marketing strategies to generate trust among consumers such as websites, social media platforms, blogs and emails to offer product information and consumer interaction. Through these channels retailers get a chance to engage directly with consumers, address their concerns and respond to feedback. Such communication generates brand trust and encourages consumers to use digital platforms for purchasing apparel products (Jeon & Jeong, 2017). Empirically, brand awareness, experience and perceived quality capture distinct cognitive, affective and evaluative mechanisms that jointly contribute to consumers' trust formation (Uzir et al., 2025; Mukhtar et al., 2024). In furtherance, including these aforesaid antecedents, it provides a comprehensive basis for explaining trust development in apparel retail. In addition to the brand trust, consumer engagement with brands has become an important factor influencing online consumer behaviour. Moreover, contemporary researches have posited the importance of sustainability in influencing consumer attitudes and purchasing behaviour. Although consumer attitudes toward sustainability have been widely examined across demographic and psychographic variables, wherein researchers observed that inconsistencies in explaining differences in sustainable consumption behaviour. These inconsistencies highlighted the need and relevance for further research examining the interaction between sustainability orientation and other aspects of consumer behaviour.

Objectives

- To examine the antecedents and consequences of brand trust in the context of apparel e-retail
- To assess the intervening role of brand engagement and sustainable consumption behaviour in affecting the above linkages
- To propose the brand sustainability framework through various branding components and validate it in the perspective of consumption behaviour

Alternative Hypotheses

H₁: Brand awareness directly and positively influences brand trust.

H₂: Brand experience directly and positively influences brand trust.

H₃: Perceived quality of e-retail brand exerts a direct and positive impact on brand trust.

H₄: Brand trust directly and positively influences brand loyalty.

H₅: Brand trust directly and positively influences brand equity.

H₆: Brand trust directly and positively influences brand value.

H₇: Brand engagement plays a mediating role between brand awareness and online brand trust.

H₈: Brand engagement plays a mediating role between brand experience and online brand trust.

H_{9a}: Sustainable consumption behaviour plays a moderating role between brand trust and brand loyalty.

H_{9b}: Sustainable consumption behaviour plays a moderating role between brand trust and brand equity.

H_{9c}: Sustainable consumption behaviour plays a moderating role between brand trust and brand value.

The aforementioned alternative hypotheses have been formulated for achieving the objectives and validating the proposed brand sustainability framework presented in Fig 1.

Brand Sustainability Framework

The brand sustainability framework has been proposed based on the branding components viz. brand awareness, brand experience, brand value, perceived quality, brand trust, brand equity, brand loyalty, brand engagement and sustainable consumption behaviour.

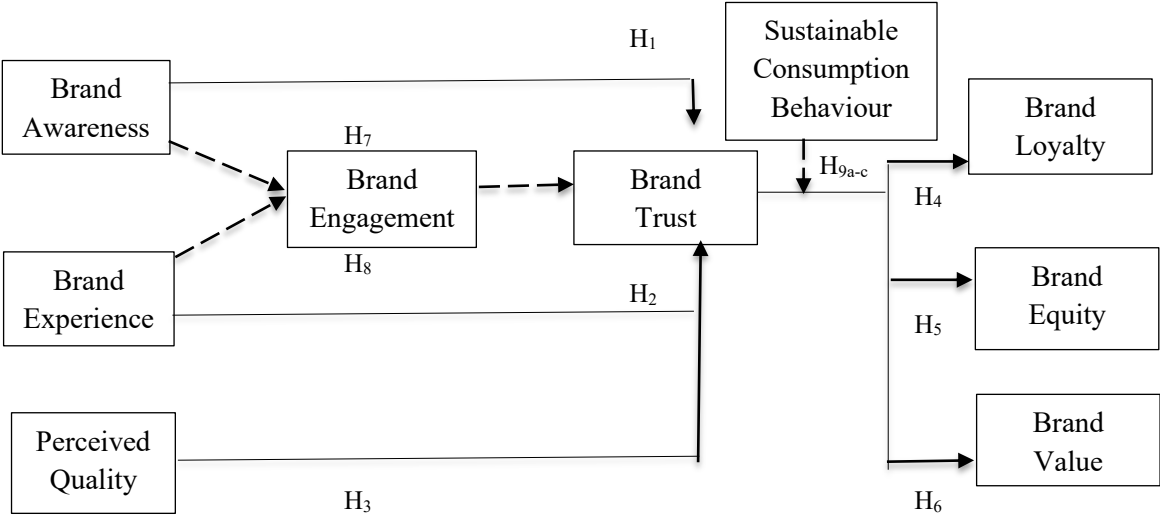


Fig 1. Brand Sustainability Framework

Methodology

The present study administered mixed-method design in accordance with the conjunction of objectives. Primary data has been collected by distributing questionnaires among 1000 consumers in the Delhi-NCR region who purchase apparels online and secondary data gathered mainly from journals, web sources and books.

The questionnaire is categorically divided into three parts. The first part consisted of questions pertaining to demographics i.e., age, gender, whereas the second part contained statements relating to antecedents of brand trust. The third part comprised of aspects related to the outcomes of brand trust, engagement and sustainable consumption behaviour.

The scale items for these constructs and their sub-dimensions have been largely adapted from previous studies (Refer Table 1). However, these research studies are conducted in accordance with more developed western countries, some of the statements have been modified to make them more suitable for apparel sector in the context of emerging economies such as India. All the statements have been quantified using a seven-point Likert scale ranging from strongly disagree (1) to strongly agree (7), whereas after removing the outliers, the effective sample comprised of 839 respondents.

Table 1: Constructs Used in the Study

S. No.	Construct	No. of Items	Source
1.	Brand Trust	14	Lee & Turban (2014); Horppu et al. (2008); Khan & Rahman, 2016).
2.	Brand Awareness	5	Mukherjee & Nath (2007); Aaker (1991); Yoo & Donthu (2001)
3.	Brand Experience	5	Morgan-Thomas & Veloutsou (2013); Schimtt (1999)
4.	Perceived Quality	4	Pappu & Quester (2006); Ho & Lee (2007)
5.	Brand Loyalty	8	Aaker (1996); Horppu et al. (2008); Chaudhari & Holbrook (2001)
6.	Brand Equity	4	Netemeyer et al. (2004); Yoo & Donthu (2001); Sasmita & Suki (2015)
7.	Brand Value	10	Yoo & Donthu (2001)
8.	Brand Engagement	7	Hollebeek et al. (2014); Brodie et al. (2011)
9.	Sustainable Consumption Behaviour	10	Dolnicar & Leisch (2008)

Analysis & Results

First, Harman’s single-factor test (Harman, 1976) and the confirmatory factor analysis (CFA) single-factor model has been used to detect bias in the dataset. The results revealed a single factor accounting for 41 per cent of the variance explained. As this is less than the threshold value of 50 percent, there is an absence of common method variance (Podsakoff et al., 2003).

The CFA single-factor model has been employed. Overall, the results indicated a good fit (Chi-square= 4826.116, df=1804, CMIN/df=2.675, CFI-0.788, RMSEA= 0.045, NFI= 0.701) of the measurement model. As the next step, reliability and validity have been examined. All values of Cronbach alpha above 0.70 indicated reliability of measures used in the study. The discriminant validity indicated by correlation matrix found that all constructs having a

correlation coefficient of less than 0.85. The convergent validity, assessed by checking the loading of each observed indicator on their underlying latent construct, confirm validity of the model.

a) Results of Direct Effect

To test the Brand Sustainability Framework presented in Fig 1, structural equation modelling (SEM) has been carried out using AMOS software (26 version). Results presented in Table 2 revealed that the direct relationship between online brand trust and its antecedents and consequences are statistically significant, leading to the acceptance of hypotheses H₁ to H₆.

Table 2: Assessment of Direct Effect

Direct Effects	Hypothesis	β value	p value	Result
Brand Awareness- Brand Trust	H ₁	.025	< 0.05	Accepted
Brand Experience- Brand Trust	H ₂	.027	< 0.05	Accepted
Perceived Quality- Brand Trust	H ₃	.031	< 0.05	Accepted
Brand Trust-Brand Loyalty	H ₄	.058	< 0.05	Accepted
Brand Trust-Brand Equity	H ₅	.013	< 0.05	Accepted
Brand Trust- Brand Value	H ₆	.016	< 0.05	Accepted

The results indicated positive and significant effect of brand awareness, brand experience and perceived quality on brand trust. Thus, it can be inferred that consumers who are familiar with a brand have positive experiences with it and perceive its products to be of high quality are more likely to develop trust in the brand. The analysis also indicated that brand trust has significant positive effects on brand loyalty, brand equity and brand value. This suggests that when consumers trust a brand, they are more likely to remain loyal, develop positive brand perceptions and perceive greater value associated with the brand.

b) Results of Indirect Effect: Mediation & Moderation Analysis

Following Baron and Kenny’s (1986) methodology, the study performed mediation and moderation analysis. The results of mediation with brand engagement showed the relationship between brand awareness and brand trust (SRW = 0.31, p < 0.01) to be significant.

In addition to this result, impact of brand awareness on brand engagement has been found to be significant (SRW = 0.48, p < 0.01). The relationship between brand engagement and brand trust are found to be significant (SRW = 0.39, p < 0.01).

Hence, the first three conditions of mediation analysis given by Baron and Kenny (1986) are fully satisfied. Finally, in the fourth step, brand engagement is introduced into the relationship between brand awareness and brand trust in an unconstrained model.

Table 3: Assessment of Indirect Effect

Direct Effects	Hypothesis	p value	Result
Brand Awareness-Brand Engagement-Brand Trust	H ₇	< 0.01	Accepted
Brand Experience-Brand Engagement-Brand Trust	H ₈	< 0.01	Accepted
Brand Trust-Sustainable Consumption Behaviour-Brand Loyalty	H _{9a}	< 0.01	Accepted
Brand Trust-Sustainable Consumption Behaviour-Brand Equity	H _{9b}	< 0.01	Accepted
Brand Trust-Sustainable Consumption Behaviour-Brand Value	H _{9c}	< 0.01	Accepted

The results revealed an insignificant relationship between brand awareness and brand trust (SRW= 0.19, $p > 0.01$), thus satisfying the conditions of full mediation effect. Hence, the results supported complete mediation of brand engagement in affecting the relationship between brand awareness and brand trust. Accordingly, the hypothesis H₇ stands accepted. Furthermore, a similar procedure has been adopted to examine the mediating role of brand engagement in affecting the relationship between brand experience and brand trust. Once again, the results indicated that brand engagement fully mediates the relationship between brand experience and brand trust, thereby lending support to the acceptance of H₈.

The study also investigated the moderating role of sustainable consumption behaviour in affecting the relationship between brand trust and its outcomes namely brand loyalty, brand equity and brand value. The moderation analysis has been conducted within the structural equation modelling framework by examining whether the intensity of the relationship between online brand trust and the outcome variables varied across different levels of sustainable consumption behaviour. The results indicated that sustainable consumption behaviour influences the strength of relationships between online brand trust and its outcomes. Consumers who exhibited stronger sustainable consumption values demonstrated stronger positive responses toward trusted brands when compared with consumers who exhibit lower sustainability orientation. In particular, the effect of online brand trust on brand loyalty, brand equity and brand value becomes stronger for consumers who display higher levels of sustainable consumption behaviour, therefore supporting the acceptance of H_{9a-c}.

Discussion

Brand trust has proved to be an important aspect when customers intend to buy online, especially for the product category in apparels, where customers still like to visit online stores for window shopping, or for price comparisons and their actual buying is dependent on various other factors. Moreover, over a period of time, customers have started relying on various e-commerce platforms for their actual buying. It is in the context of this change, the present study outlines relevance of brand trust as an important ingredient required to sell fashion merchandise online. In the light of the insights drawn in the present study, online retailers should pay considerable attention towards the factors that are important for building trust while designing their websites. Moreover, the notion that brand trust directly influences e-retail brand

value and can be considered (Rammile, 2015). Since this is a growing area of interest, only a little empirical evidence has emerged in the context of an emerging economy such as India. The study makes an attempt to unveil the factors that managers should consider while building e-retail brand trust.

The present study found a positive and significant influence of three antecedents on brand trust. This signifies that brands should focus on activities that influence awareness, experience and quality of their brands, which in turn will enhance trust in their brands. For instance, industry practitioners should adopt effective promotional strategies to communicate about their brand and have a wider reach so that larger section of consumer develop awareness of the brand. Consumers use branding as a tool to assess a product's quality and do not perform further search if trust in the brand exists. Therefore, it has been observed that brand awareness directly influences brand trust (Mudzakkir & Nurfarida, 2015). Simple and goal centric promotional strategies will help retailers in not only retaining existing customers but also aids in bringing new and potential customers for the brand. Moreover, new advertising strategies can prove to be extremely helpful in the presentation of the brand on online platforms.

This study exhibited a strong and positive impact of brand trust on loyalty, equity and value. This can help retailers to have a good customer base and long-term profitability to survive in a competitive environment. In this regard, retailers should continuously make an effort to reduce risk and uncertainty associated with online transactions so that trust and loyalty is maintained.

The results have lent support to mediating role of brand engagement between brand experience, brand awareness and online brand trust. On the basis of this outcome, it is advised that brands should make efforts to positively appeal to their consumers. This will aid in engaging and creating positive brand experiences which will in turn result in increasing brand trust. Also, consumers repurchase in the situation of having positive experience with the brand, in turn resulting in brand loyalty and effective commitment to the brand. Furthermore, memorable brand experiences enhance consumer trust (Jung et al., 2014). Moreover, managers need to concentrate on customers preferring non-brands too because if they are engaged and aware, these customers may also develop a desire to acquire trendy apparel brands over a period of time.

Sustainability-oriented consumers play a greater importance on trust when evaluating brands. It is to be noted that sustainable consumption behaviour acts as an intervening variable in the linkage between brand trust and its outcomes (Arif et al., 2025). In furtherance, when such consumers trust a brand, they are more likely to develop stronger loyalty toward the brand and perceive greater value associated with it. The moderating role of sustainable consumption behaviour highlights the importance of aligning brand strategies with sustainability expectations of consumers.

Implications & Suggestions

The results of present have study provided managers of chosen sector with the following implications and suggestions:

- ❖ A combination of both visual and audible methods can be used to attract a large number of customers. Also, providing the customers with better brand experiences consistently through innovative ways like customization of products, easy navigation access may give them superior experiences and would improve overall efficiency of the organization and may serve as a competitive advantage over others.
- ❖ The study also suggested that an increase in consumers' trust towards the brand can enhance their general evaluation of benefits of the products purchased from the brand, thereby indicating a greater value for the brand. The due focus on customer relationship, customer profile and responsiveness will help in enhancing equity of the brand.
- ❖ A good customer-marketer relationship is indispensable in the online retail market space. Hence, building connections is recommended with existing as well as potential customers as it can support the brand by bringing in customer loyalty in the long run.
- ❖ The emotional aspects like satisfaction and retention may also lead to increased brand engagement. The online sharing of experiences by customers with others on social networking sites will further enhance the awareness of other customers about the brand. Furthermore, it is seen that an increase in brand engagement among existing customers leads to an increase in their trust in the brand and subsequent advocacy. As a result, they connect with other consumers and interact with them.
- ❖ Incorporating sustainable consumption behaviour into the study of brand trust provides a deeper insight into how environmentally conscious consumers respond to brands. Consumers who prioritize sustainability may exhibit stronger loyalty and value perceptions toward brands that they trust and perceive as environmentally responsible. Therefore, sustainable consumption behaviour may influence the nature as well as the intensity of linkages between brand trust and its outcomes.

Limitations & Future Research Directions

Despite making efforts, the study has some limitations that can be addressed by future researchers. The manner in which the consumers of only some well-known websites like Amazon, Myntra and Ajio in the Delhi-NCR region of India have been taken into consideration, which might have caused specificity of the results thereby revealing only such facts that may be true for some consumers and websites and not for others. Therefore, future researchers have to avoid such mistakes by taking into consideration various regions and incorporating multiple websites, both popular and less popular, to make the findings more generalized in nature. Moreover, the present study is limited to the examination of brand trust, that too for online apparel sector only. With time, several brands have adopted e-commerce platforms to expand their reach to their customers. For instance, through its educational

content, Nykaa has created strong brand awareness and brand value. Also, they engage customers through their marketing efforts to maintain a long-lasting trust-based customer relationship. Hence, comparative studies with different sectors, products and settings and inclusion of other constructs like brand personality and brand satisfaction can be done to make the model more robust and comprehensive. Also, while the core constructs selected are foundational, emerging predictors such as brand communication transparency, data privacy assurances ethical and sustainability messaging warrant further exploration in the apparel retail context. In furtherance, always there exists a possibility of improving the reliability and validity of scales used in the present work.

Conclusion

India has been experiencing a technological transformation. The internet penetration has empowered people and brought them closer to the global community through the creation of a network. E-commerce is a result of such technological transformation. With the popularization of e-commerce and social media, there has been an emergence of “social shopping”, which not only involves the sharing of information but also the sharing of personal experiences by existing customers of a brand, thereby facilitating the potential customers to put their trust in that brand. Recognizing the need of marketers to develop brand trust, the present study has been undertaken with a focus on analyzing customers’ perspectives on the antecedents and consequences of brand trust. The study provides a detailed analysis of antecedents (brand awareness, brand experience and perceived brand quality) and consequences (in the form of brand loyalty, brand equity and brand value). Moreover, the mediating of brand engagement and moderation of sustainable consumption behaviour has been studied, wherein the interventions exhibited the relationships. Overall, the study helps in gaining a better understanding of purchase behaviour of consumers and branding sustainability for apparel sector.

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A Study on Jal Jeevan Mission in Transforming Rural Water Supply within Mizoram

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Abstract

The Government of India launched the Jal Jeevan Mission (JJM) throughout the nation with a motto ‘Har Ghar Nal Se Jal’ with the vision to ensure access to safe & clean drinking water to all the rural citizens by providing Functional Household Tap Connection (FHTC) by 2025-26. The study specifically focuses on Mizoram with the objective of critical analysis of JJM implementation in Mizoram, its impact & successes in terms of enhancement of coverage of rural water supply and improvement in the quality of life & health of the rural population. The secondary data have been collected from government reports, publication of Ministry of Jal Shakti, journals & research articles published in this area. The study indicated that 100 percent household tap water coverage will be achieved in all the 11 districts of Mizoram benefiting 132,060 rural households by 2025-26. The study established that JJM has enhanced access to safe & clean drinking water and brought down dependence on traditional sources of drinking water. It has improved rural well-being and health and brought down the human hours spent in fetching water particularly by women and children. The present study highlights the role of institutions, community involvement and adoption of sustainable approaches for water management for the successful implementation of JJM. This research has concluded that Jal Jeevan Mission is a path breaking program, which shall support rural development and ensure water security of Mizoram in long run.

Keywords: Jal Jeevan Mission, Functional Household Tap Connections (FHTC), Rural Water Supply, Ministry of Jal Shakti, Mizoram, Water Security, Rural Development.

Introduction

A basic human need is easy access to freshwater. Therefore, sufficient supplies of safe drinking water are important for people’s well-being and for planning and managing development sustainably. The households in rural India have depended on a variety of sources for water and have experienced seasonal supply and water quality challenges. Hence, to address access

issues, Government of India has launched the Jal Jeevan Mission (JJM) in 2019 with the promise of ‘Har Ghar Nal Se Jal’ or ‘every home will have water’, providing Functional Household Tap Connections (FHTCs) for all rural households. Also, in support of objectives of JJM, the Government of India sought to provide an assured supply of safe drinking water to residents at the rate of 55 liters per person per day. The introduction of JJM has transformed the water supply infrastructure and service delivery in the State of Mizoram within India. It has brought safe drinking water to rural communities, reduced the burden of water collection and improved the communities’ standard of living.

Table 1: Institutional Mechanism Under JJM

1	National level	National Jal Jeevan Mission
2	State level	State Water & Sanitation Mission (SWSM)
3	District level	District Water & Sanitation Mission (DWSM)
4.	Gram Panchayat level	Paani Samiti/ Village Water & Sanitation Committee (VWSC)/User group

Source: Ministry of Jal Shakti, Government of India, 2026

Literature Review

Access to safe drinking water is widely recognized as a fundamental requirement for public health, human dignity and sustainable development. Crow and Sultana (2002) found that gender and socio-economic inequalities significantly influence access to water with women and poorer households facing greater challenges in obtaining reliable water supplies. Likewise, Keefer & Bousalis (2015) argued that inadequate access to safe water disproportionately affects the women and girls by increasing their time and labour burden thereby limiting educational and economic opportunities. Adopting a rights-based perspective, Spijkers (2020) emphasized that access to safe drinking water is a fundamental human right reflected in Sustainable Development Goal 6 (SDG 6), which calls for universal and equitable access to safe and affordable drinking water through sustainable governance and policy interventions. In the Indian context, Ministry of Jal Shakti (2026a; 2026b) reported that substantial progress under the Jal Jeevan Mission (JJM), particularly, through the expansion of Functional Household Tap Connections (FHTCs), which strengthened water quality monitoring and improved community participation. Shah (2023) also described JJM as a transformative initiative that has improved public health outcomes and shifted rural water supply from source-based schemes to household-level service delivery. Similarly, Radhika (2025) observed that the Mission has contributed to improved health, reduced drudgery for women, enhanced school attendance and broader rural development. Also, through providing an empirical evidence, Singh & Naik (2024) have concluded that the early implementation of JJM has generated positive societal outcomes, including improved sanitation practices, reduced time spent collecting water and enhanced household welfare. Collectively, these studies have indicated that Jal Jeevan Mission is a significant policy intervention for achieving universal rural drinking water access while promoting gender equity, public health and sustainable rural development. However, limited research has specifically examined the implementation and impact of Mission in Mizoram, thereby justifying the need for carrying out this research study.

Need & Relevance

Safe and adequate supply of drinking water is vital for the development of sustainable rural communities and wellbeing of the community and public health. The Jal Jeevan Mission (JJM) aims to reduce the dependence on traditional water sources and provides Functional Household Tap Connections (FHTCs) to every family living in rural areas. In Mizoram, many residents are heavily reliant on spring water, well water and rainwater harvesting systems. Therefore, it is important to study the effect of JJM in this state. This study investigates on how access to piped water improves the quality of life by reducing the water collection burden, especially for women & children and how this access improves health. This study also analyzes the partnership of the community and government in providing universal access to water and the role of government and community in providing universal access to water. It further provides constructive insights for the improvement of rural development policies with a focus on sustainability and water security in the state of Mizoram.

Objectives

- To examine the implementation and achievements of Jal Jeevan Mission (JJM) with special reference to the provision of Functional Household Tap Connections (FHTCs) in rural areas
- To assess the impact of Jal Jeevan Mission on rural communities in terms of access to safe drinking water, public health and improvement in people's quality of life

Methodology

This study adopts mixed-method research design for examining the implementation, progress and challenges of 'Jal Jeevan Mission' in Mizoram. The quantitative component relies on secondary data gathered from Jal Jeevan Mission (JJM) official publications, Ministry of Jal Shakti reports, journals, books and other relevant documents. The quantitative data relating to JJM implementation, Functional Household Tap Connections (FHTCs), funding trends, institutional mechanisms and rural water supply coverage have been analyzed using tabular analysis and percentage comparison across other States of India. Moreover, qualitative component involves content analysis of JJM policy documents, governance initiatives and government regulations associated with the Jal Jeevan Mission (JJM).

Financial Implication & Funding Pattern of JJM

In order to provide tap water to every rural household in India, the Jal Jeevan Mission (JJM) to give tap water to every rural home in India, wherein it will cost ₹3.60 lakh crore. The mission has a shared its funding plan, which is between the federal and concerned state governments to make sure it works well. The funding ratio for North-Eastern and Himalayan states, like Mizoram, is 90:10. This means the state pays 10 percent and central government pays 90 percent. Moreover, for Union Territories, the central government pays 100 percent of the costs. It is to be noted that for remaining states other than the aforesaid categories, the funding ration is 50:50 between the center and state. This funding plan helps with money for water supply

projects and also takes into account different areas’ needs. The focal point of this scheme is to make an easy drinking water sources, with proper distribution system and a treatment process.

Fund Allocation Criteria in JJM

To promote a more equitable and need-based allocation of financial resources, the funding criteria of Jal Jeevan Mission (JJM) has been revised. Unlike the previous funding model, JJM now assigns a 20 percent weight to the number of households lacking access to tap water. This approach enables states with a higher number of uncovered rural households to receive increased funding for the development of water supply infrastructure. Furthermore, 10 percent of weightage is allocated to rural residents residing in areas with poor water quality, characterized by the presence of heavy metals, chemical pollutants or other hazardous water conditions.

The revised funding formula ensures that states facing significant drinking water issues receive increased financial support to effectively tackle these challenges. In furtherance, by directing resources to marginalized and vulnerable communities, it also promotes equitable regional growth. In regions where water quality is compromised, states are encouraged to prioritize the initiatives such as constructing secure water sources, establishing treatment plants and strengthening distribution systems. This funding approach reduces health risks linked to polluted water and enhances access to clean and potable water.

JJM promotes efficient resource utilization and accelerates the creation of universal Functional Household Tap Connections (FHTCs) by aligning fund distribution with actual requirements and service deficiencies. The revised standards not only support infrastructure development but also advance social equity, public health and sustainable rural progress across the country. Overall, the funding strategy reflects the mission’s commitment to ensuring that all rural households have access to safe drinking water.

Table 2: Comparison of Fund Allocation Criteria and Weightage under the National Rural Drinking Water Programme (NRDWP) and Jal Jeevan Mission (JJM)

Criteria	As per NRDWP (%)	As per JJM (%)
Rural Population (as per last Census)	40	30
Rural SC and ST population (as per last Census)	10	10
States under DDP, DPAP, HADP and special category Hill States in terms of rural areas	40	30
Population (as per IMIS) residing in habitations affected by chemical contaminants including heavy metals (as on 31 st March of preceding financial year)	10	10
Weightage for balance individual household connections to be provided	Nil	20

Source: Ministry of Jal Shakti, Government of India, 2026

Jal Jeevan Mission (JJM) – An Overview

The Jal Jeevan Mission (JJM) was launched by Prime Minister of India on 15th August, 2019, with the ambitious goal of providing tap water supply to every rural household by 2024. At the time of its inception, only 3.23 crore (17 percent) of rural households had tap water connections. The mission aims to bridge this gap by providing nearly 16 crore additional households with tap water by 2024, ensuring the functionality of existing water supply systems and directly benefiting over 19 crore rural families. This initiative is intended to reduce the rural-urban divide and enhance public health.

The main objective of this scheme is to provide a Functional Household Tap Connection (FHTC) to every rural household. Priority has been given to a quality-affected areas, drought-prone regions, desert areas and Sansad Adarsh Gram Yojana (SAGY) villages. Moreover, JJM mission will ensure a functional tap connection in Schools, Anganwadi Centers, Gram Panchayat Buildings, Health and Wellness Centers and Community Buildings. It will also empower and develop a human resource in the water sector, covering construction, plumbing, electrical work, water quality management, water treatment, catchment protection and create a raising awareness about the significance of safe drinking water and involving stakeholders to make water everyone’s responsibility.

Table 3: Status of Tap Water Supply Across India as on 3rd March 2026

S. No.	State / UT	Total Rural HHs (in lakh)	Rural HHs with Tap Water (in lakh)	With Tap Water (%)	Rural HHs without Tap Water (in lakh)	Without Tap Water (%)
1	Andaman & Nicobar Islands	0.62	0.62	100.00	-	-
2	Andhra Pradesh	95.53	71.71	75.06	23.82	24.94
3	Arunachal Pradesh	2.29	2.29	100.00	-	-
4	Assam	72.24	59.03	81.71	13.22	18.29
5	Bihar	167.55	160.36	95.71	7.19	4.29
6	Chhattisgarh	49.97	41.20	82.44	8.77	17.56
7	DNH & DD	0.85	0.85	100.00	-	-
8	Goa	2.64	2.64	100.00	-	-
9	Gujarat	91.18	91.18	100.00	-	-
10	Haryana	30.41	30.41	100.00	-	-
11	Himachal Pradesh	17.09	17.09	100.00	-	-
12	Jammu & Kashmir	19.26	15.64	81.23	3.61	18.77
13	Jharkhand	62.53	34.51	55.18	28.03	44.82
14	Karnataka	101.31	87.83	86.70	13.48	13.30

15	Kerala	70.77	38.84	54.88	31.93	45.12
16	Ladakh	0.41	0.40	97.97	0.01	2.03
17	Madhya Pradesh	0.13	0.12	91.45	0.01	8.55
18	Maharashtra	111.29	82.27	73.92	29.02	26.08
19	Manipur	146.78	132.75	90.44	14.02	9.56
20	Meghalaya	4.52	3.59	79.60	0.92	20.40
21	Mizoram	6.51	5.43	83.47	1.08	16.53
22	Nagaland	1.33	1.33	100.00	-	-
23	Odisha	3.64	3.44	94.47	0.20	5.53
24	Puducherry	88.64	68.48	77.25	20.17	22.75
25	Punjab	1.15	1.15	100.00	-	-
26	Rajasthan	34.27	34.27	100.00	-	-
27	Sikkim	107.69	63.00	58.50	44.69	41.50
28	Tamil Nadu	1.33	1.22	92.09	0.11	7.91
29	Telangana	125.26	112.20	89.57	13.06	10.43
30	Tripura	53.98	53.98	100.00	-	-
31	Uttar Pradesh	7.51	6.48	86.33	1.03	13.67
32	Uttarakhand	267.20	243.72	91.21	23.48	8.79
33	West Bengal	14.48	14.19	97.97	0.29	2.03
Total		1935.87	1581.70	81.71	354.17	18.29

Source: Ministry of Jal Shakti, Government of India, 2026

The Jal Jeevan Mission has made great strides throughout India, as seen in the table above. 1,581.70 lakh (81.71 percent) of the 1,935.87 lakh rural households have access to tap water, while 354.17 lakh (18.29 percent) have not yet. A number of states and union territories have reached 100 percent rural tap water coverage, including the Andaman & Nicobar Islands, Arunachal Pradesh, Gujarat, Haryana, Himachal Pradesh, Nagaland, Punjab, Rajasthan and Tripura. West Bengal (97.97 percent), Odisha (94.47 percent), Ladakh (97.97 percent) and Bihar (95.71 percent) have also reported extremely high coverage levels. Kerala (54.88 percent), Jharkhand (55.18 percent) and Sikkim (58.50 percent), on the other hand, exhibit relatively lower coverage and still have a significant percentage of households without tap water connections. Assam and Meghalaya have recorded 81.71 percent and 79.60 percent, respectively, while Mizoram has attained 83.47 percent coverage among the Northeastern States. The Jal Jeevan Mission has made significant progress overall, according to data, though some states still need to make efforts to ensure that every household has access to tap water.

Jal Jeevan Mission in Mizoram

Mizoram State officials used video conference to update the National Jal Jeevan Mission on the state's planning and execution of the mission as part of Jal Shakti Ministry's mid-term review of the progress of Union Government's flagship program (JJM) in all States and UTs. The Ministry of Jal Shakti has been collaborating with the States and UTs to carry out the Union Government's flagship Jal Jeevan Mission program, which aims to lessen the drudgery of rural residents, particularly women and girls. The Government of India provides funds based

on the number of functional household tap connections and use of the central and matching states that are available. According to JJM 2.0, all rural households in Mizoram will have 100 percent tap water connections by 2025–2026, wherein approximately there are 1.35 lakh rural households in the state out of which 1.02 lakh lacked a household tap. The State intended to provide tap water connections to 33,796 households in 2020–21. The mid-term review made clear the necessity of examining the Piped Water Supply (PWS) programs currently in place in villages where not a single connection has been made. The Mizoram State Government has been urged to concentrate on providing universal coverage in aspirational districts, villages under the Sansad Adarsh Gram Yojana (SAGY) and villages dominated by SC/ST.

The supply of drinking water in Mizoram's rural areas used to be outside the government's purview. The primary traditional sources of drinking water in rural areas have frequently been private wells, individual rainwater harvesting systems and community-managed Improved Village Spring Source (IVSS / Tuikhur). The first government-installed rural water supply programs have been put into place in the 1950s as part of the government's strategy to give rural residents access to basic drinking water supplies. Since then, the government's involvement in the rural water supply sector has grown while communities' role has decreased. With the introduction of Accelerated Rural Water Supply Programme (ARWSP) in 1972–1973, the Indian government began its involvement in the rural drinking water supply sector by helping the states supply potable water to rural populace. Providing sufficient drinking water was Rural Water Supply's (RWS) primary goal from 1972 to 1986. The Rajiv Gandhi National Drinking Water Mission (RGNDWM) (1991–1992) replaced the Technology Mission (1986–1987), which was the first of two generations of programs. The idea behind third-generation Sector Reform Project, which was started in 1999–2000 was to include the community in the development, execution and administration of RWS programs. This project was later expanded as Swajaldhara in 2002. Thus, in order to give every rural household a Functional Household Tap Connection (FHTC), the Indian government reorganized and merged the National Rural Drinking Water Program (NRDWP) into Jal Jeevan Mission (JJM) with a promise 'Har Ghar Nal Se Jal (HGNSJ)' by the year 2024. Under JJM, the following types of projects and plans are suggested:

- In-village water supply Public Water Supply (PWS) infrastructure for tap water connection to every household.
- Reliable drinking water source development / augmentation of existing sources.
- Transfer of water through multi-village scheme; where quantity & quality issues are there in the local water sources.
- Technological intervention for treatment to make water potable, wherein water quality is an issue, but quantity is sufficient.
- Retro fitting of completed and ongoing piped water supply schemes to provide FHTC and raise the service level.
- Grey water management.
- Capacity building of various stakeholders and support activities to facilitate the implementation.

Table 4: Status of Households with Tap Water Connection in Mizoram as on 1st June 2026

S. No.	District	Total Households	Households with Tap Water Supply	Households with Tap Water Supply (%)
1	Aizawl	17,254	17,254	100
2	Lunglei	17,312	17,312	100
3	Siaha	7,966	7,966	100
4	Champhai	9,317	9,317	100
5	Kolasib	9,038	9,038	100
6	Serchhip	7,147	7,147	100
7	Lawngtlai	27,158	27,158	100
8	Mamit	18,184	18,184	100
9	Saitual	9,433	9,433	100
10	Khawzawl	4,910	4,910	100
11	Hnahthial	5,341	5,341	100

Source: Ministry of Jal Shakti, Government of India, 2026

According to the data, all the 11 districts of Mizoram have achieved 100 percent household tap water coverage, a milestone for public service delivery and rural water supply. Total Tap Water Infrastructure Saturation There are a total of 132,060 Functional Household Tap Connections (FHTCs) installed in the state. Lawngtlai has the highest number of households connected to tap water (27,158) followed by Mamit (18,184), Lunglei (17,312) and Aizawl (17,254). It is to be noted that in all districts 100 percent coverage has been achieved in spite of differences in number of households and size of population, which is a testimony to equitable implementation of water supply schemes by the state.

Findings & Discussion

The findings indicated that Jal Jeevan Mission (JJM) has substantially transformed rural drinking water supply in Mizoram through the expansion of Functional Household Tap Connections (FHTCs). As of June 2026, all eleven districts of the state have achieved 100 percent household tap water coverage, benefiting a total of 132,060 rural households. This demonstrated the effective implementation of the Mission despite the state’s difficult terrain and dispersed settlements. The institutional framework comprising the National Jal Jeevan Mission, State Water and Sanitation Mission (SWSM), District Water and Sanitation Mission (DWSM) and Village Water and Sanitation Committees (VWSCs) have contributed significantly to efficient planning, coordination and monitoring. These findings supported the observations of Shah (2023), who described JJM as a transformative initiative that shifted rural water supply from source-based systems to reliable household tap connections, thereby strengthening public service delivery.

The study further revealed that JJM has significantly improved access to safe and clean drinking water, reducing dependence on traditional water sources such as springs, private wells and rainwater harvesting systems that were previously common in rural Mizoram. The

provision of piped water has enhanced public health by minimizing the risk of water-borne diseases and ensuring a more reliable supply of potable water. These findings are consistent with the reports of Ministry of Jal Shakti (2026a; 2026b), which highlighted the improvements in water quality monitoring and rural drinking water infrastructure under JJM. Similarly, Spijkers (2020) emphasized that universal access to safe drinking water is essential for achieving Sustainable Development Goal 6 and protecting the human right to water, a goal that Mizoram has effectively advanced through successful implementation of the Mission.

Another significant finding is the positive socio-economic impact of Jal Jeevan Mission on rural communities. The availability of household tap water has considerably reduced the time and physical effort previously spent collecting water, particularly among women and children. The time saved can now be utilized for education, livelihood activities and household welfare, thereby improving overall quality of life. This finding supported the research works by Crow and Sultana (2002) and Keefer and Bousalis (2015), who have argued that inadequate water access disproportionately affects women and marginalized households by increasing labour burdens and limiting social and economic opportunities. Likewise, Radhika (2025) and Singh and Naik (2024) concluded that JJM has contributed to improved health, sanitation, school attendance and rural development, findings that closely align with the present study.

Finally, the study highlighted that the success of Jal Jeevan Mission in Mizoram is attributable not only to financial assistance under the 90:10 Centre–State funding pattern for North-Eastern states but also to strong institutional coordination and community participation. The active involvement of Village Water and Sanitation Committees (VWSCs) and local communities has strengthened the sustainability of rural water supply systems. However, the long-term success of JJM will depend on continuous water source conservation, regular water quality monitoring, maintenance of infrastructure and efficient water management practices. These findings reinforced the literature emphasizing on sustainable rural water governance, which requires not only infrastructure creation but also community ownership and effective institutional management (Ministry of Jal Shakti, 2026a; Spijkers, 2020). Therefore, while Mizoram has achieved universal household tap water coverage, sustained policy attention is essential to ensure long-term water security and continued improvements in rural well-being.

Suggestions

Ensuring Availability of Water Sources for Longer-Term Use: Government needs to work harder to conserve water sources such as rain water harvesting, groundwater recharge, watershed etc. for a sustainable supply of safe drinking water in rural communities.

Enhance Involvement of Community: Offer training and capacity building programs for Village Water and Sanitation Committees (VWSCs) organizations such as Young Mizo Association (YMA) and local residents to improve the operation and upkeeping of water supply systems.

Strengthen Monitoring of Water Quality: Regularly test and monitor the quality of drinking water to prevent contamination and ensure the provision of safe drinking water to all households.

Promote Efficient Water Usage & Conservation: Conduct awareness campaigns on effective water utilization, management of household wastewater and conservation methods to prevent future water shortages.

Ongoing Assessment & Review: To secure lasting benefits for rural communities, maintain operational efficiency and tackle emerging obstacles, the government should periodically assess JJM infrastructure and service provision.

Conclusion

The Jal Jeevan Mission (JJM) has significantly transformed the rural drinking water supply in Mizoram, leading to a notable impact. A recent study revealed that all eleven districts have accomplished full coverage of household tap water, ensuring that rural families have equal access to safe drinking water. The implementation of Functional Household Tap Connections (FHTCs) has not only enhanced living standards but also reduced dependence on traditional water sources, particularly benefiting women and children. Furthermore, JJM has positively influenced public health, community engagement and rural progress. The effective functioning of institutional structures, adequate financial backing and the active involvement of local residents are credited for its success. JJM also marked a crucial milestone in attaining water security and promoting sustainable rural growth in Mizoram.

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Morphological, Biochemical and Physiological Response in Rice (*Oryza sativa* L.) under Iron Stress (FeCl_3) in Hydroponic Culture – An Analytical Approach

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Abstract

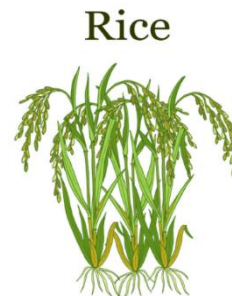
Rice (*Oryza sativa* L.) is an aquatic plant with a characteristic of forming an iron plaque on its root surfaces. It is considered to be the most Fe-tolerant species among cereal crops. The primary objective of conducting this study is to determine the effects of iron stress (FeCl_3) in rice (*Oryza sativa* L.) on the basis of morpho-physiological and biochemical analysis in hydroponic culture. Seeds *Oryza sativa* L. variety Jogesh has been used in this study and grown hydroponically in a growth chamber with different concentrations of iron (FeCl_3). Different morphological parameters such as seed germination percentage, shoot & root length and fresh weight & dry weight have been taken into consideration to screen tolerance of the genotype with regards to iron concentration. The selected high tolerant and susceptible concentrations have been taken for further experiment at lower concentration of iron (0, 10, 20, 40, 60, 80, 100, 200, 400, 600, 800, 1000 ppm) to study the physiological and biochemical analysis. The experimental plant showed adaptive responses to prolonged iron stress treatment with no negative effects on germination at 10-80 ppm on comparison with control however, as the stress increased all the growth parameters decreased, suggesting an inhibitory effect of iron stress. Total chlorophyll, phaeophytin, carotenoid, total carbohydrate, total amino acid, total protein, total DNA & RNA content, total phenol and proline content showed variation in different concentration of iron (FeCl_3). The oxidative enzymes also showed variation among different concentration of iron stressed rice plant. The chosen rice plant has been classified as tolerant, medium tolerant and susceptible to iron stress on the basis of root and shoot growth and biochemical analysis. Based on observations, it has been concluded that seed germination is not affected at lower concentration of iron ($\leq 80\text{ppm}$) whereas, at higher concentration the germination ($\geq 100\text{ppm}$) rate declined against selected iron concentration.

Keywords: *Oryza sativa* L., Ferric Chloride (FeCl_3), Hydroponic Culture, Germination Kinetics, Oxidative Stress, Antioxidant Enzymes.

Introduction

Rice (*Oryza sativa* L.) is a premier member of the Monocotyledons, globally recognized as a foundational pillar of human civilization and food security. Taxonomically, it is classified as follows:

- Kingdom: Plantae
- Sub-kingdom: Tracheobionta (Vascular plants)
- Division: Spermatophyta (Seed plants)
- Sub-division: Magnoliophyta (Flowering plants)
- Class: Liliopsida (Monocotyledons)
- Sub-class: Commelinidae
- Order: Cyperales
- Family: Poaceae (Gramineae)
- Genus: *Oryza*
- Species: *Oryza sativa* L.



Rice (*Oryza sativa* L.) is one of the major cereal crops that serve as staple food for more than 50 percent of the world population (Muthayya et al., 2014). In India, rice is the basic food crop & being a tropical plant it flourishes comfortably in hot and humid climate. Rice is mainly grown in rain fed areas that receive heavy annual rainfall and called as kharif crop in India. In Odisha, Rice as the main staple food of almost entire population covers about 69 percent of the cultivated area and covers about 63 percent of the total area under food grains. Jeypore tract in South Odisha has been identified as a putative secondary center of origin of cultivated rice (Ramiah & Rao, 1953). The regions comprising Western Odisha, Jharkhand and Chhattisgarh are recognized as the centre of origin of ecotype of rice (Sharma et al., 2000).

Plants generally acquire their mineral elements from the soil solution. In addition to oxygen, carbon dioxide and water, plants require at least 14 mineral elements for adequate nutrition (Marschner, 1995). The essential micronutrients are very much required for normal growth and development of the plants in minute quantities (low concentration or perhaps in ppm or in trace amounts and referred to as trace elements or trace metals. They are critically involved in the functional activities of large numbers of proteins involved in sustaining growth and development. Moreover, heavy metals such as Fe, Mo, Mn, Zn, Co, Ni, and Cu are quite essential micronutrients whose uptake in excess to the plant requirements leads to toxic effects (Elless et al., 2000). Exposure of plants to toxic levels of heavy metals triggers a wide range of physiological and metabolic alterations that can cause damage to plants (Dubey, 2010). In deficiency and excess quantities of these metals effect on normal metabolic function, disorders, or even death of the plant. One of the major consequences of heavy metal stress is the enhanced production of reactive oxygen species (ROS), which usually damage the cellular components; such as membranes, nucleic acids and chloroplast pigments.

Iron toxicity is a main concern in rice cultivation. Typically, iron toxicity symptoms are manifested as tiny brown spots starting from the tips and spreading towards the base of lower leaves. With progress of iron toxicity, the brown spot is on the inter-veins of the leaves. The roots are also affected by iron toxicity and it became short, coarse and blunted and dark brown in colour. Other nutrients may play an important role not only in reducing the effect of iron toxicity but also in the expression of iron tolerance by different rice varieties (Sahrawat et al., 1996; Sahrawat, 2000).

Iron deficiency in rice starts at the seedling stage exhibiting iron Chlorosis in younger leaves, which in severe deficiency leads to death of seedlings. The species and varieties differed largely in terms of tolerance to iron toxicity. The search for genotypes, which are more adapted to irrigated rice system is therefore an efficient alternative to circumvent this problem. Plant cells can limit the damaging effects caused by this metallic ion by storing the excess iron in iron-protein complexes called phytoferritin (Arosio & Levi, 2002). Also, by the aerenchyma in the rice plant the atmosphere oxygen can be diffused effectively to the rhizosphere, where the ferrous ions can be excluded by oxidation, since Fe^{2+} reaching the root surface can be precipitated and are not absorbed by the plant. The iron toxicity is caused by excessive iron concentration in a plant body (Sahrawat, 2000). Moreover, Fe concentrations in soils that can affect lowland-rice yields ranged from 10 to more than 2,000 ppm and Fe-induced yield reduction is frequently associated with a poor nutrient status of the soil (Becker & Asch, 2005). Protection strategies against Fe toxicity within the plant may involve enzymatic mechanisms that includes the actions of antioxidant enzymes, such as superoxide dismutase, catalase, peroxidase and ascorbate peroxidase and glutathione reductase (Apel & Hirt, 2004). Furthermore, the iron stress causes the typical leaf-bronzing symptoms and affects rice growth. The reduction in height and dry matter has a related with rice production and ultimately affect the rice yield. Iron predominates as ferric ion (Fe^{3+}) in the soil. The Fe^{2+} is insoluble and hence, largely unavailable to be absorbed. The soil lower pH results the reduction of Fe^{3+} to Fe^{2+} , wherein Fe^{2+} is soluble and able to get absorbed by the rice plant (Becker & Asch, 2005). Plants show iron toxicity when absorb high Fe^{2+} by root and transported to leaves via xylem flow. In furtherance, excessive uptake of Fe^{2+} cause the production of radicals and lead to an accumulation of oxidized polyphenols, which can cause the irreversible cell damage, DNA and plants proteins (De Dorlodot et al., 2005). Therefore, exploiting the varietal tolerance to iron toxicity is accepted as the most cost-effective and practical means for increasing rice production under iron toxic soils (Shimizu, 2009).

Hydroponics is the method of growing plants in different types of substrates (chemically inert), such as sand, gravel, liquid (water) in which nutrients are added, but no soil is used (Douglas, 1975). It is an efficient technique to investigate the biotic and abiotic factors with higher accuracy, lower costs and in less time. This is useful when the results obtained in controlled conditions are highly correlated with those from field experiments. Based on the above information, the purpose of this study is to evaluate the performance of irrigated rice genotypes in response to iron toxicity in hydroponic culture. Also, this study intends to assess the viability of this technique as an auxiliary tool in rice breeding programs for Fe^{2+} stress tolerance.

Literature Review

Rice is the principal source of calorie intake for about half of world's population. Iron (Fe) and zinc (Zn) deficiencies are the widest spread human micronutrient deficiencies and are particularly prevalent in resource-poor countries where there is a heavy dietary reliance on staple crops. Iron toxicity is one of the most important abiotic stresses limiting rice production in lowland systems. It is to be noted that in India, 11.7 million hectares of land is affected by iron toxicity. Iron toxicity interferes a range of nutrient disorders and deficiencies particularly potassium, phosphorus, calcium, magnesium and zinc in plant metabolism (Mehraban et al., 2008). These elements have been reported to have play major roles in manifesting toxicity symptoms in paddy. Iron toxicity of wetland rice is associated with a high concentration of ferrous iron in soil condition (Ponnamperuma et al., 1955). Traditional rice production, however, consumes more water than any other crop. Thus, to reduce usage of water in environments with water shortages, agronomists have developed an aerobic rice production system in which aerobic rice cultivars are grown without flooding (Kreye et al., 2009). Aerobic rice is grown as a dry field crop in irrigated but non-flooded and non-puddled fertile soils. However, its excess and deficiency can have harmful effects on plants. Excess free iron is found in the low pH and high oxygen tension can affect the cell because of its high affinity to bind with oxygen leading to the generation of cytotoxic hydroxyl radicals via Fenton reaction (Connolly & Guerinot, 2002; Becker & Asch, 2005; Grotz & Guerinot, 2006). Excessive amounts of Fe^{2+} due to Fe reduction under anaerobic conditions at low pH have been reported to result in significant yield reduction ranging from 12 to 100 percent, depending on the intensity of Fe toxicity and tolerance of the rice genotype (Sahrawat, 1996). Also, on subcellular level, the vacuole constitutes an important compartment for tissue tolerance at leaf through the storage of excess Fe^{2+} ions.

Another mechanism of leaf tissue tolerance could be the scavenging of ROS through plant's antioxidant network, thus avoiding the formation of oxidative stress. However, plants do not possess effective scavengers of hydroxyl radical, the product of Fenton reaction (Apel & Hirt, 2004). Therefore, antioxidants would have to remove the precursors of hydroxyl radical such as hydrogen peroxide, which is reduced to water by antioxidant enzymes such as catalases and peroxidases (Blokhina et al., 2003). However, iron tolerance is a complex and multigenic trait, whereas breeding programs must look beyond isolated leaf scores; developing resilient cultivars. This requires a comprehensive understanding of genetic variability, which emphasize on how key morphological, physiological and biochemical traits coordinate under stress.

Need & Relevance

Oryza sativa L. is a major cultivated cereal crop plant belongs to family **Poaceae**, wherein its grains are an important source of human dietary carbohydrate. Moreover, it gains relevance by being a common dietary crop plant and economically important. Hence, the eco-physiological studies can serve as an indicator of phytotoxicity caused by iron stress. The objective of this study is to evaluate the morphological, biochemical and physiological response in rice plant (*Oryza sativa* L.) under different concentration of iron stress (FeCl_3) in hydroponic culture and

help in determining lethal concentration 50 (LC50). The present study is much needed to address the aforesaid aspects and it will be useful to the breeders so that this can be exploited to develop cereal lines with improved rice variety with iron stress tolerance. Also, it provides an understanding about level of tolerance of upland and lowland rice genotypes at the early stage to reduce iron toxicity.

Objectives

- To identify the improved rice variety through effective concentration of iron stress
- To analyse various parameters of rice like germination, morphological, biochemical and physiological respectively

Methodology

The present study adopted analytical method to perform the experiments and observations are discussed accordingly. Certified seeds of *Oryza sativa* L. (Jogesh variety, family Poaceae) have been procured from the Pulse Research Institute (CPRI), Berhampur and hand-sorted for uniformity in size, shape and weight. This short-duration Kharif (monsoon) crop matures in 90–95 days from sowing (June) to harvesting (October–November) and is widely cultivated in Odisha's rainfed uplands and lowlands. The anhydrous ferric chloride (FeCl₃; GR grade, HIMEDIA Laboratories, India) served as the test chemical for the experiment. Variable stock concentrations prepared using a modified Hoagland nutrient medium (Hoagland & Arnon, 1950) to establish a soil-free hydroponic system. This basal growth solution has been formulated by dissolving essential macro, micro and trace elements in double-distilled water to supply all nutrients necessary for optimal plant development.

Table 1: Hoagland’s Nutrient Solution

Macronutrient	Stock/Lit	Solution/100 mL	Main Stock/200 mL	Full Strength of Stock (mL/L)
1.KH ₂ PO ₄ (1M)	136.09g	13.60g	27.20g	1mL
2.KNO ₃ (1M)	101.10g	10.11g	20.22g	5mL
3.Ca (NO ₃) ₂ .4H ₂ O(1M)	236.15g	23.61g	47.22g	5mL
4.MgSO ₄ .7H ₂ O(1M)	246.48g	24.64g	49.28g	2mL
5. Micro Nutrient Solution	Table 2A			
6. Trace Compound	Table 2B			

Table 2A

Micronutrient	Stock /lit	Solution/10 0mL	Main stock /200mL	Full strength of stock (mL/L)
(a) H ₃ BO ₃	2.86g	0.286g	0.572g	1mL
(b)MnCl ₂	1.81g	0.181g	0.362g	
(c)ZnSO ₄	0.22g	0.022g	0.044g	

(d)CuSO ₄ .3H ₂ O	0.08g	0.008g	0.016g	
(e)H ₂ MoO ₄ +H ₂ O	0.028g	0.0028g	0.056g	

Table 2B

Trace Compound	Solution/100mL	Main stock /20mL	Full Strength of Stock (mL/L)
(a) FeSO ₄ (0.5 percent)	0.5g	0.1g	0.3mL
(b) Tartaric acid (C ₄ H ₆ O ₆)	0.4g	0.08g	0.3mL

A primary stock solution of 1000 ppm has been prepared by dissolving 1 g of anhydrous FeCl₃ in 1 L of Hoagland nutrient medium. A gradient of experimental treatment concentrations- specifically 0 (control), 10 ppm, 20 ppm, 40 ppm, 60 ppm, 80 ppm, 100 ppm, 200 ppm, 400 ppm, 600 ppm, 800 ppm and 1000 ppm (Table 1, Tables 2A & 2B) have been subsequently established through proportional serial dilutions using the Hoagland solution as diluent.

Oryza sativa L. can serve as an indicator of phytotoxicity caused by ferrous stress. Also, used to identify the differences in responses of different concentrations of Iron (FeCl₃) stress and help in determining lethal concentration 50 (LC50).

Cleaned, surface-sterilized 200 mL polystyrene cups are labelled by treatment concentration and fitted with a sterilized, net-stitched ring framework positioned just below the rim. Each container is filled with its respective FeCl₃-supplemented Hoagland solution, ensuring the fluid level consistently remained above the mesh surface without leaking to facilitate hydroponic seed placement. Following a 10-minute surface sterilization in 0.1 percent HgCl₂ and then sterilized seeds are rinsed with distilled water 3-4 times and seeds are imbibed for 24 hours before transferring 10 uniform individuals onto the hydroponic mesh surface. The culture on a sterilized rack maintained under controlled room temperature with an 8-hour photoperiod (400 lux). Solution levels are monitored daily and topped up with the respective test concentrations to prevent drying or flooding; healthy, uniform 10-day-old seedlings are then harvested for experimental analysis.

Based on pilot study, the results showed dual promoting and retarding effects, 10 concentrations of FeCl₃ (10 ppm, 20 ppm, 40 ppm, 60 ppm, 80 ppm, 100 ppm, 200 ppm, 400 ppm, 600 ppm, 800 ppm and 1000 ppm) and a control have been selected for plant germination and seedling growth screening.

On the 10th day, seedling shoot and root lengths are measured using a 30 cm scale. The replicated organs are separated, blotted dry and weighed on an electronic balance for fresh weight. Samples are then oven-dried at 70°C for 30 minutes to record dry weight.

Biochemical analyses are conducted on 10-day-old control and stress-treated seedlings grown across ten concentrations. Separated root and shoot tissues are weighed and 100 mg of fresh shoot material is homogenized in 80 percent acetone and centrifuged twice (20 min at 2000 rpm) to collect a 10 mL supernatant for pigment profiling, reserving the pellet for protein

estimation. Spectrophotometric analysis has been used to quantify pigments based on standard formulas: chlorophyll a, b and total chlorophyll via absorbance at 645 nm and 663 nm (Arnon, 1949); carotenoids at 470 nm (Davies, 19767; and pheophytin at 610 nm and 700 nm (Vernon, 1960).

Protein content has been estimated via the Lowry et al. (1951) method by homogenizing 100 mg of fresh 10-day-old tissue in 80 percent acetone and centrifuging twice (20 min, 2000 rpm) to isolate the residue. This pellet is digested overnight in 2N NaOH, boiled for 20 min and centrifuged. A 0.5 mL aliquot of the supernatant has been treated with alkaline and Folin phenol reagents and absorbance is measured at 620 nm. Protein concentration (mg/g fresh weight) is quantified against a BSA standard curve using the formula: $x = (y - 0.04) / 0.0016$, where y is the absorbance at 620 nm.

Amino acid content has been determined using the Ninhydrin method (Moore & Stein, 1948). Fresh 100 mg samples were extracted twice in 70 percent ethanol (20 min, 2000 rpm) and the pooled supernatants are evaporated to half volume and re-diluted to 10 mL. A 1 mL aliquot is boiled with 3 mL of 0.3 percent ninhydrin for 20 minutes and the absorbance is measured at 620 nm against an ethanol blank. The content (mg/g fresh weight) is quantified against a glycine standard using the formula: $x = (y - 0.05) / 0.0076$, where y is the absorbance at 620 nm.

Sugar content is determined through Anthrone method (Yoshida et al., 1976). The fresh 100 mg samples are extracted twice in 70 percent ethanol (20 min, 2000 rpm) and the pooled supernatants are evaporated to 0.5 mL and diluted to 10 mL with distilled water. A 0.5 mL aliquot is boiled with 2.5 mL of anthrone reagent for 10 minutes, cooled and absorbance has been measured at 620 nm against a reagent blank. Sugar concentration (mg/g fresh weight) is quantified against a D-glucose standard using the formula: $x = (y - 0.015) / 0.063$, where y is the absorbance at 620 nm.

Nucleic acids are extracted by homogenizing 100 mg of fresh tissue in 70 percent ethanol and centrifuging for 10 minutes. The residue is washed with ethanol, centrifuged and incubated overnight in 1 mL of 5 percent TCA at 4°C. It is after centrifuging and discarding the supernatant, the pellet is boiled in 5 mL of 10 percent TCA for 20 minutes, cooled and centrifuged to collect the nucleic-acid-containing supernatant.

For DNA estimation (Schneider, 1957), 1 mL of this supernatant is boiled with 3–4 mL of diphenylamine reagent for 20 minutes, cooled and the absorbance is measured at 620 nm against a distilled water blank. The DNA concentration (mg/g fresh weight) has been quantified against a calf thymus DNA standard curve using the formula: $x = (y - 0.017) / 0.0018$, where y is the absorbance at 620 nm.

For RNA estimation (Schneider, 1957), 1 mL of the previously obtained nucleic acid supernatant is boiled with 3 mL of orcinol reagent for 20 minutes and cooled. The absorbance is measured at 620 nm against a distilled water blank. The RNA concentration (mg/g fresh

weight) has been quantified against a commercial RNA standard curve using the formula: $x = (y - 0.072) / 0.0073$, where y is the absorbance at 620 nm.

Proline content is quantified using the Bates et al. (1973) method. The fresh tissue (100 mg) is homogenized in 5 mL of 3 percent aqueous sulfosalicylic acid and centrifuged at $12,000\times g$ for 10 minutes. A 2 mL aliquot of the supernatant is reacted with 2 mL each of acid-ninhydrin and glacial acetic acid at 100°C for 1 hour and then cooled in an ice bath. The mixture is extracted with 4 mL of toluene and the absorbance of upper toluene phase has been measured at 520 nm against a toluene blank. Proline concentration (μ -mol/g fresh weight) is determined using a D-proline standard curve.

Enzyme extraction and catalase (CAT) assaying followed a modified method of Kar & Mishra (1976). The fresh plant tissue (100–500 mg) is homogenized in cold 0.1M sodium phosphate buffer (pH 7.0) and centrifuged (1500 rpm for 20 min or $1000\times g$ for 10 min at 4°C). The supernatant is collected and diluted to 10 mL with buffer to serve as the crude enzyme extract. For the CAT assay, 1 mL of supernatant is mixed with 3 mL of phosphate buffer and 1 mL of H_2O . It is after incubation for 1 minute, the reaction is stopped by adding 10 mL of H_2SO_4 . The residual H_2O_2 is quantified either by measuring absorbance at 420 nm or via titration against 0.01M KMnO_4 . Enzyme activity has been expressed as μ -mol H_2O_2 destroyed/min/mg protein with protein content quantified using the Bradford (1976) assay against a BSA standard.

Polyphenol oxidase (PPO) activity has been assayed according to Kar & Mishra (1976) method. The reaction mixture consisted of 1 mL of crude enzyme extract, 2 mL of phosphate buffer and 1 mL of 0.01M pyrogallol with the absorbance monitored at 420 nm using a spectrophotometer.

Results

Morphological Study & Biomass Allocation Under Fe-Stress

Exposing *O. sativa* seedlings to progressive iron concentrations induced distinct, dose-dependent phenotypic and morpho-physiological variations in hydroponic culture (Photo 1). Percentage of germination is calculated after 4 days of culture.

Percentage of Germination = Total Number of Germinated Seeds / Total Number of Seeds Inoculated $\times$ 100

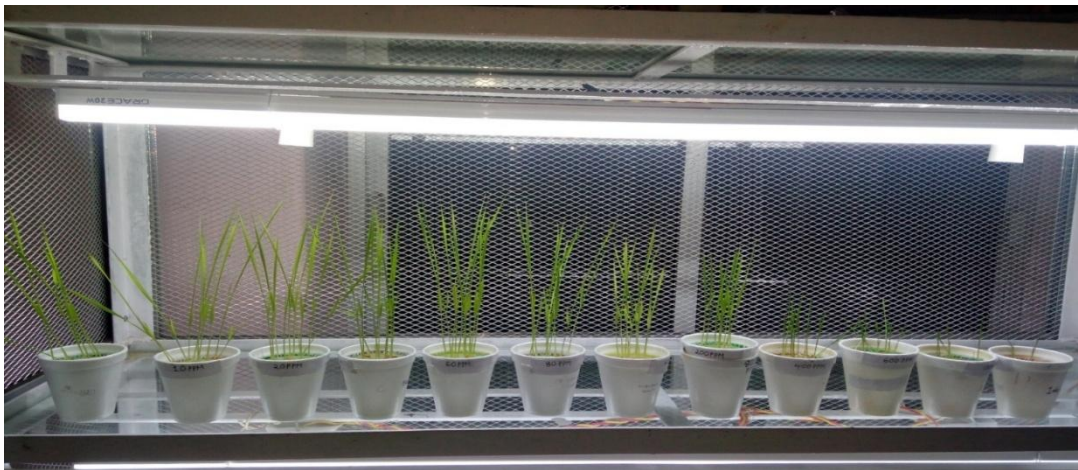


Photo 1: Germination of *Oryza sativa* L. Seeds After 10 days Treatment FeCl₃ Stress under Laboratory Conditions



Photo 2: Effect of Different Concentrations of FeCl₃ on the Growth of Seedling of *Oryza sativa* L.

Germination & Leaf Emergence: Seed germination and primary leaf emergence exhibited a biphasic response. Lower iron concentrations (10 to 80 ppm) did not significantly impair initial growth, with optimal development observed alongside a transient promotional effect. However, severe toxicity manifested at treatments exceeding 100 ppm. The germination rate systematically declined from 100 percent in the control to its lowest threshold of 40 percent at 1000 ppm FeCl₃. Concurrently, leaf emergence fell sharply, reaching a critical low of 9 percent at 1000 ppm (Fig 1). Based on these phenotypic survival gradients, the median lethal tolerance threshold (LC₅₀) for Jogesh cultivar is established between 100 ppm and 400 ppm.

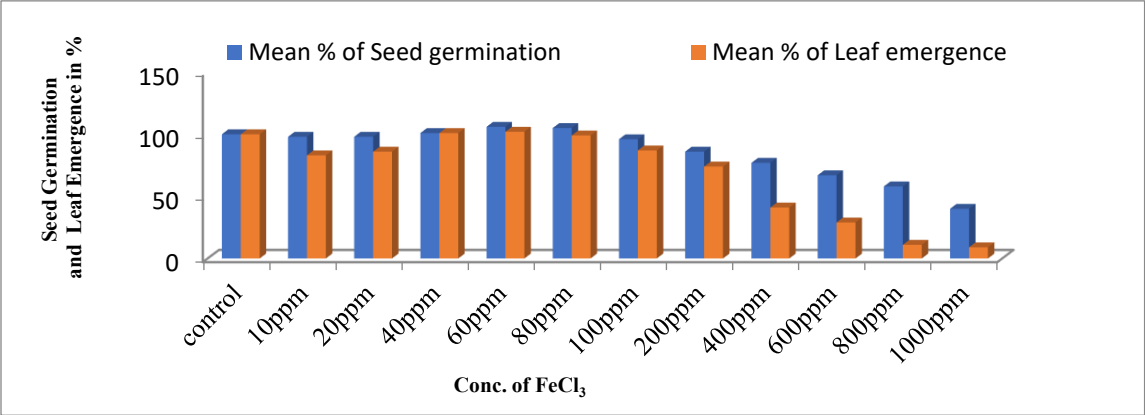


Fig 1. Effect of Different Concentrations of FeCl₃ on the Percentage of Seed Germination and Leaf Emergence of *Oryza sativa* L.

Seedling Elongation: Shoot and root elongation displayed an inverse relationship with FeCl₃ concentration above 80 ppm (Fig 2). Hormetic growth stimulation occurred at low doses, wherein maximum shoot length reached 18.26 cm (60 ppm) and maximum root length reached 10.38 cm (10 ppm) compared to control values (14.8 cm and 9.44 cm, respectively). It has been observed that beyond 100 ppm the growth is collapsed. At 1000 ppm, root growth is virtually arrested (0.12 cm) and shoot height is severely stunted (3.02 cm). The RL/SL ratio contracted progressively from 0.63 (control) to 0.039 (1000 ppm), underscoring that the root system is highly sensitive to direct iron phytotoxicity (Photo 2).

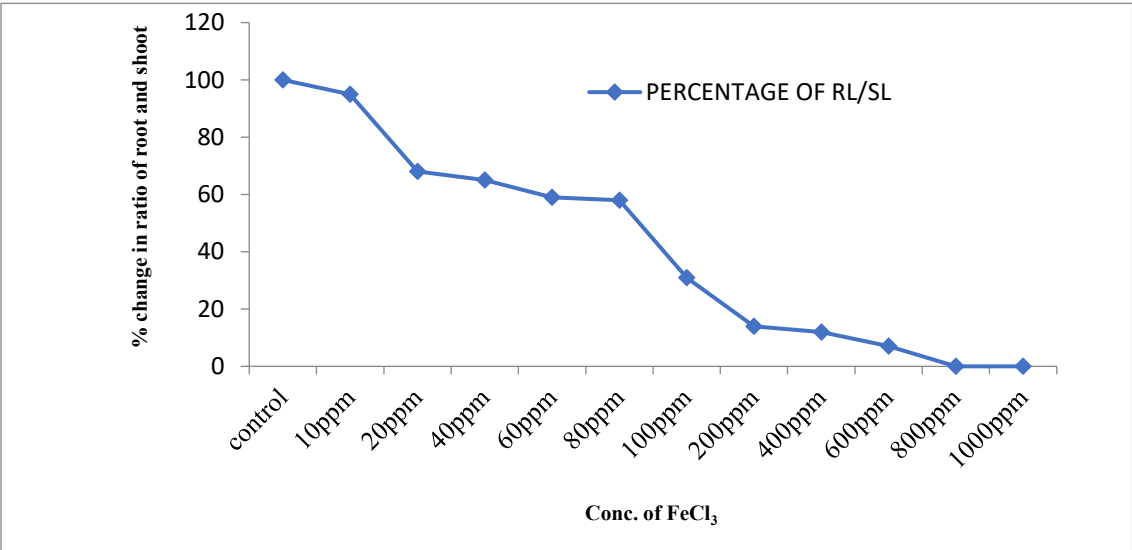


Fig 2: Effect of Different Concentrations of FeCl₃ on the Root & Shoot Length Ratio of 10 Days Old Seedlings of *Oryza sativa* L.

Biomass Accumulation: Biomass allocations mirrored the elongation trends (Fig 3 & 4). Shoot and Root fresh/dry masses peaked between 20 ppm and 40 ppm. At higher exposure

levels (≥ 400 ppm), severe visual symptoms emerged, including the complete inhibition of lateral root development, root tip necrosis, leaf interveinal chlorosis, patchy brown bronzing spots and premature senescence. At the maximum stress level (1000 ppm), shoot and root dry weights are suppressed by 70 percent and 82 percent respectively relative to the controls.

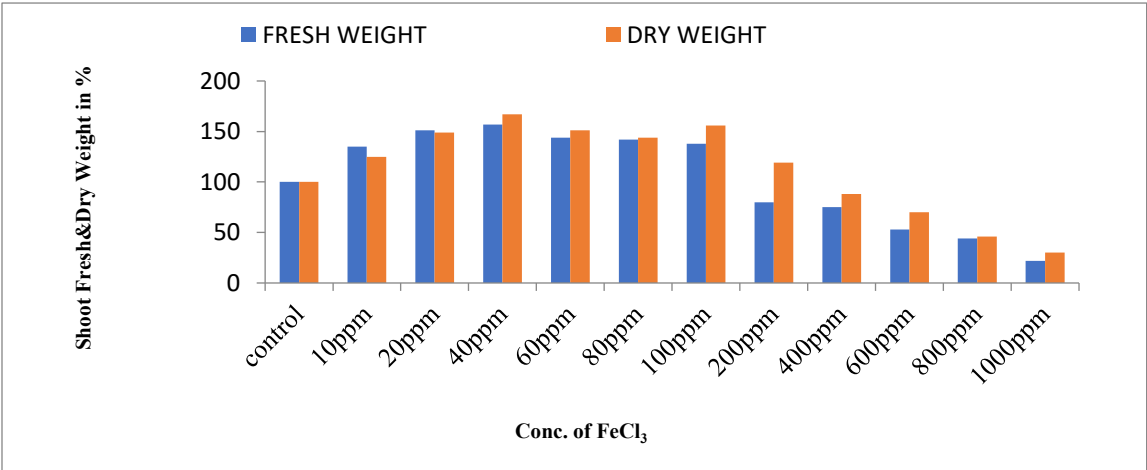


Fig 3. Effect of Different Concentrations of FeCl₃ on the Fresh & Dry Weight of Shoot of 10 Days Old Seedlings of *Oryza sativa* L.

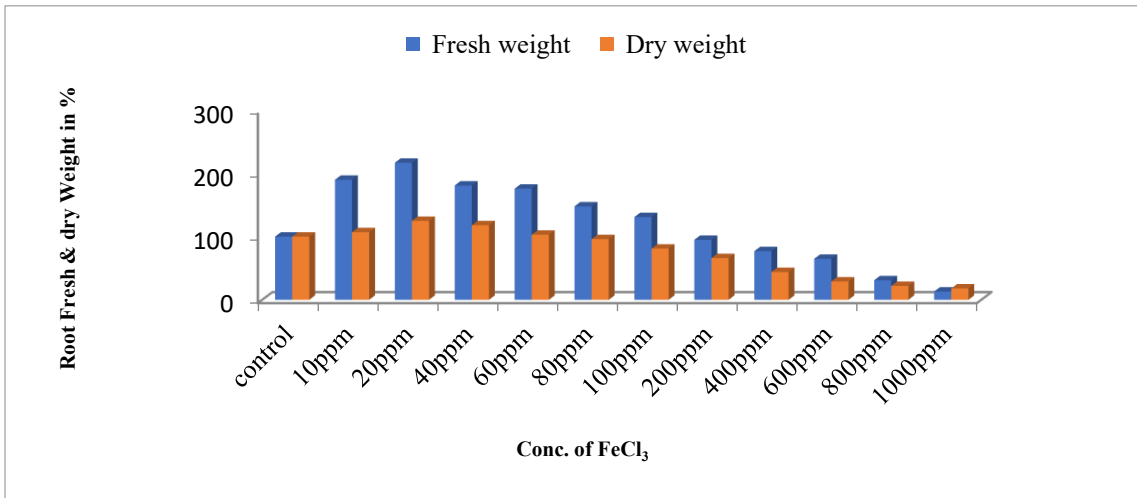


Fig 4. Effect of Different Concentrations of FeCl₃ on the Fresh & Dry Weight of Root of 10 Days Old Seedlings of *Oryza sativa* L.

Estimation of Photosynthetic Pigments: Iron stress drastically altered the chloroplast pigment composition (Fig 5 & 6). Chlorophyll *a*, *b*, total chlorophyll, phaeophytin and carotenoids scaled upward dramatically with low-dose iron supplements, peaking at 80 ppm, wherein total chlorophyll content surged to nearly 10 times that of the control. Conversely, concentrations exceeding 100 ppm initiated severe pigment degradation. At 1000 ppm, total chlorophyll fell to a mere 15 percent of the control baseline, aligning with visible macro-

chlorosis and necrotic lesions observed on the leaves in different concentration of FeCl_3 of 10 days old seedling of *Oryza sativa* L.

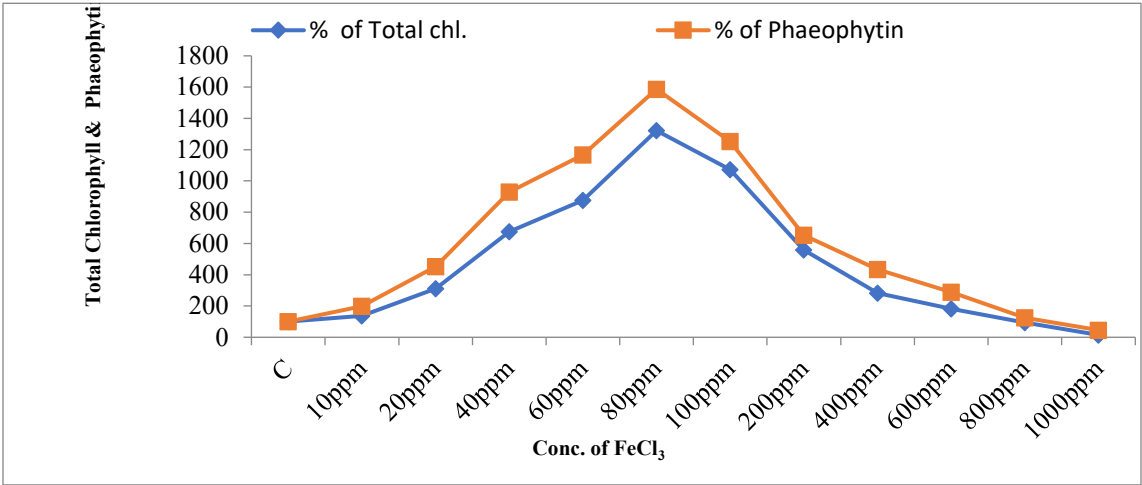


Fig 5. Effect of Different Concentrations of FeCl_3 on Percentage of Total Chlorophyll and Pheophytin Contents of 10 Days Old Seedling of *Oryza sativa* L.

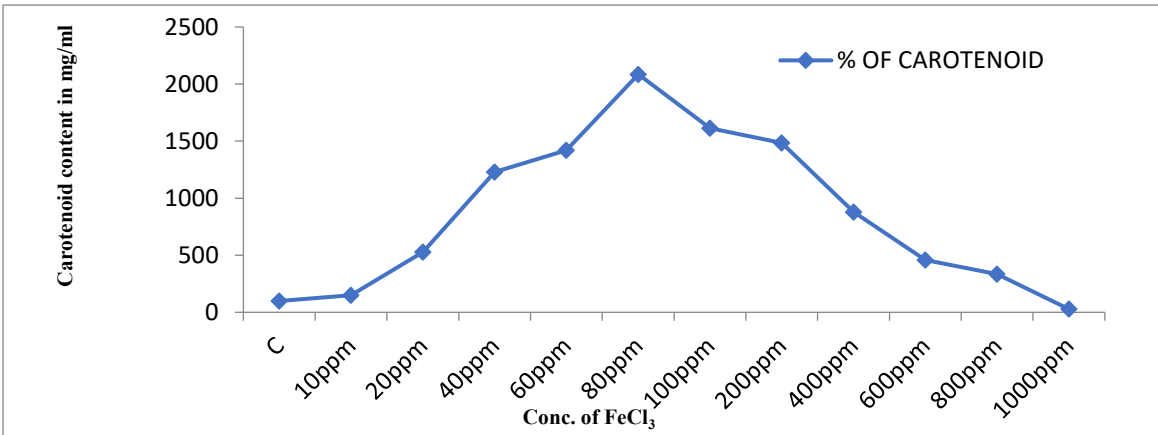


Fig 6. Effect of Different Concentrations of FeCl_3 on the Percentage of Carotenoid Contents of 10 Days Old Seedling of *Oryza sativa* L.

Estimation of Carbohydrates: Soluble sugar concentrations in shoots accumulated steadily up to 80 ppm (reaching 389 percent of control values) before declining under excessive stress (Fig 7). In roots, soluble sugars dropped sharply above 80 ppm, plummeting to 11 percent of control levels at 1000 ppm, signifying a severe disruption in source-to-sink carbohydrate translocation.

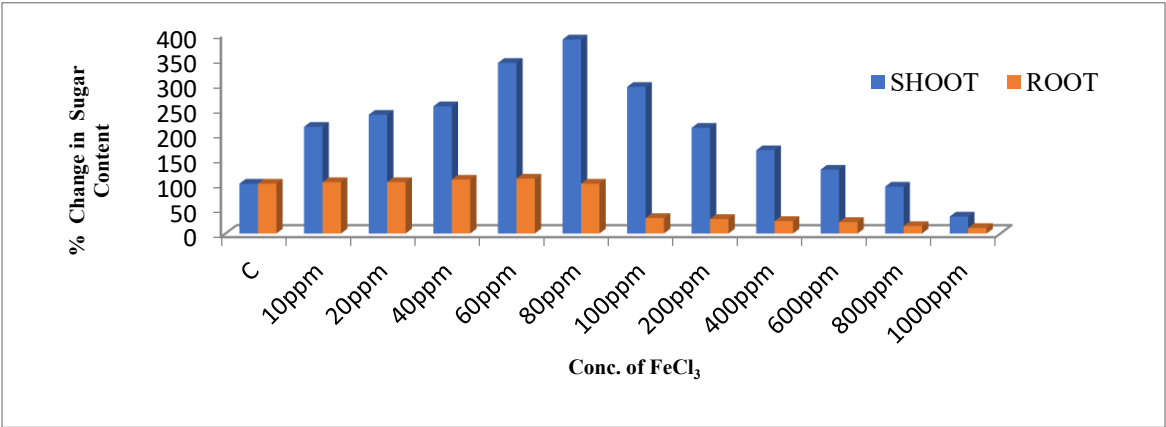


Fig 7. Effect of Different Concentrations of FeCl_3 on the Carbohydrate Content of 10 Days Old Seedling of *Oryza sativa* L.

Estimation of Amino Acids and Proteins: Free amino acids accumulated linearly across both organs as stress levels escalated, showing a four-fold increase in shoots (439 percent) and a two-fold increase in roots (224 percent) at 1000 ppm (Fig 8). Soluble protein content followed a U-shaped metabolic curve; protein concentrations initially decreased under mild stress (dropping to 49 percent in shoots at 80 ppm), but surged under severe stress (≥ 200 ppm), ultimately doubling at 1000 ppm (Fig 9). This response indicated the active synthesis of stress-protective or shock-related proteins.

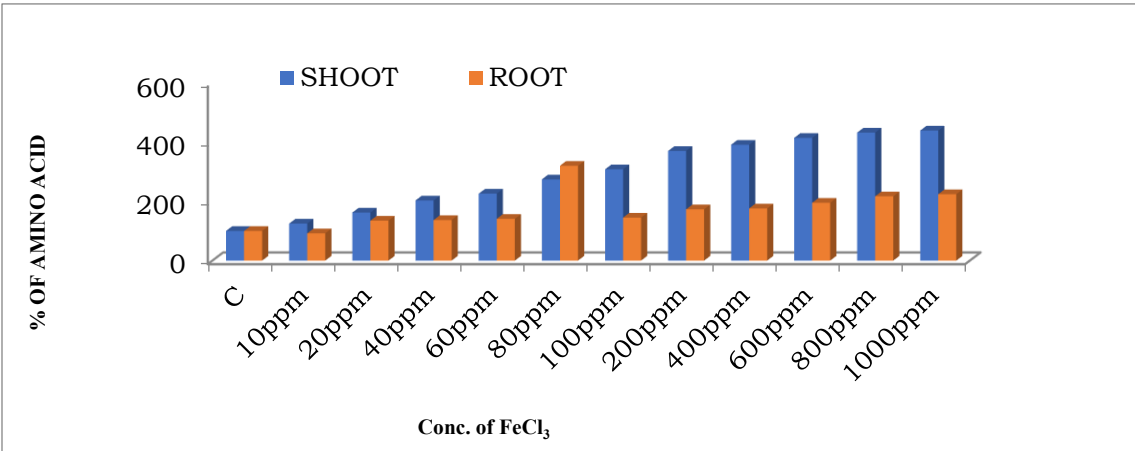


Fig 8. Effect of Different Concentrations of FeCl_3 on the Amino Acid Content of 10 Days Old Seedling of *Oryza sativa* L.

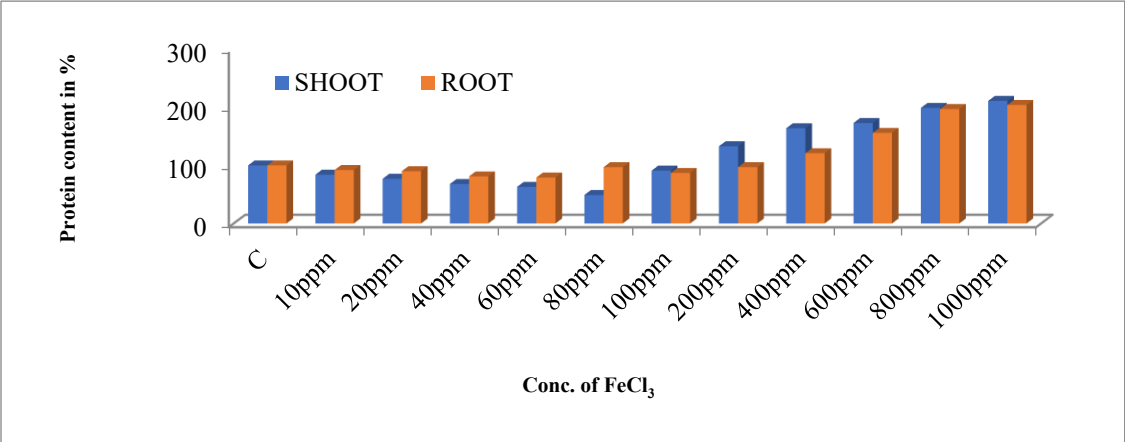


Fig 9. Effect of Different Concentrations of FeCl₃ on the Protein Content of 10 Days Old Seedling of *Oryza sativa* L.

Estimation of DNA and RNA Content: Nucleic acid expressions varied widely between the root and shoot systems (Fig 10 & 11). Shoot DNA levels peaked heavily under moderate treatments (reaching 1250 percent of the control at 80 ppm) before declining back to baseline levels at higher concentrations. Conversely, root DNA was severely depleted by excess iron, dropping to just 23 percent of the control value at 1000 ppm. RNA content showed an inverse trajectory. It decreased moderately under low iron inputs (≤ 60 ppm in shoots; ≤ 80 ppm in roots), but accumulated significantly under extreme toxicity, rising to 158 percent (shoots) and 126 percent (roots) at 1000 ppm.

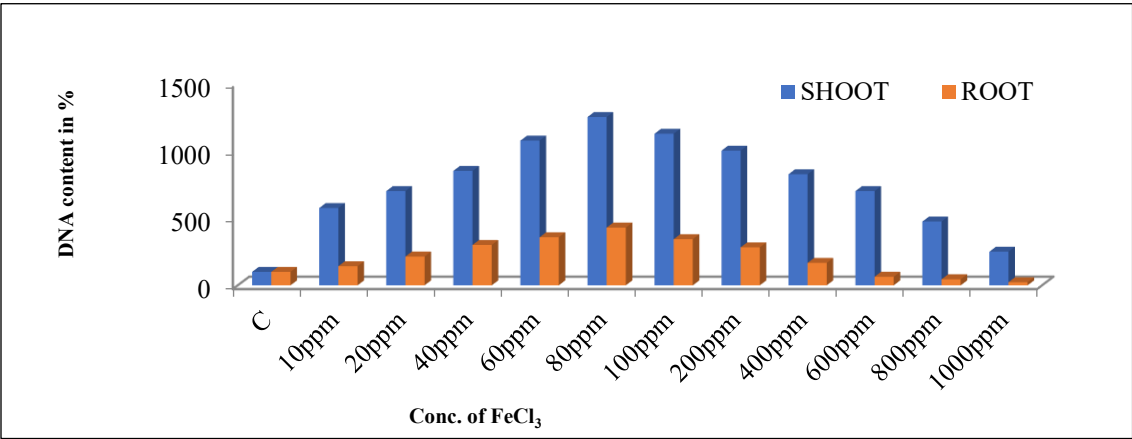


Fig 10. Effect of Different Concentrations of FeCl₃ on the DNA Content of 10 Days Old Seedling of *Oryza sativa* L.

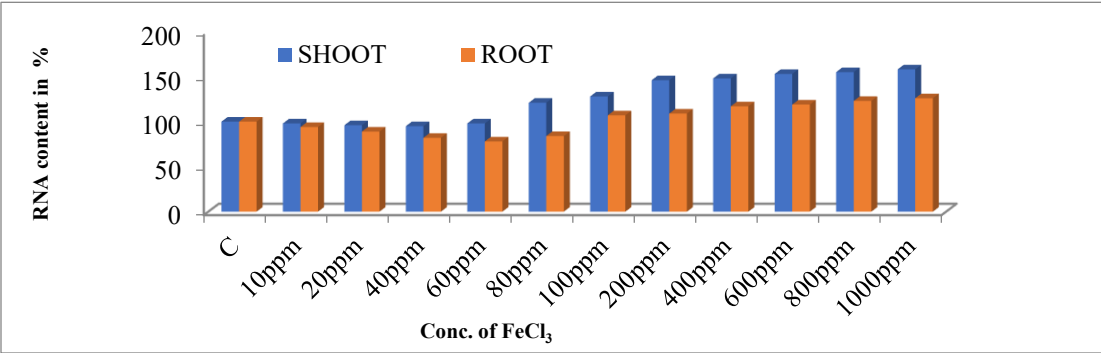


Fig 11. Effect of Different Concentrations of FeCl_3 on the RNA Content of 10 Days Old Seedling of *Oryza sativa* L.

Estimation of Proline: Proline functioned as a key osmo-protective biomarker under iron stress (Fig 12). Tissues maintained baseline proline levels up to 80 ppm. Beyond this threshold, severe stress triggered an exponential surge in proline accumulation. This response is most prominent in the shoots, peaking at an extraordinary 6314 percent of the control value at 1000 ppm, confirming its role in managing iron-induced osmotic and oxidative stress.

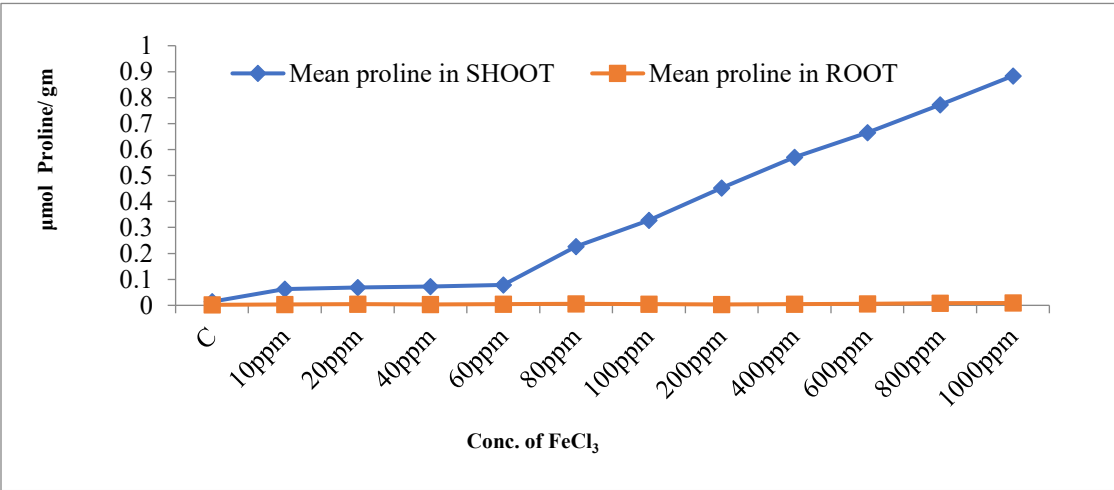


Fig 12. Effect of Different Concentrations of FeCl_3 on the Proline Content of 10 Days Old Seedling of *Oryza sativa* L.

Estimation of Antioxidant Enzymes: The activity oxidative enzymes confirmed that excessive iron triggers metabolic shifts to manage oxidative stress.

Estimation of Catalase (CAT): CAT activity responded unpredictably. It has been suppressed under initial iron exposures up to 80 ppm, recovered sharply to peak at 600 ppm (118 percent in shoots; 138 percent in roots) and ultimately deactivated at 1000 ppm due to severe cellular toxicity (Fig 13).

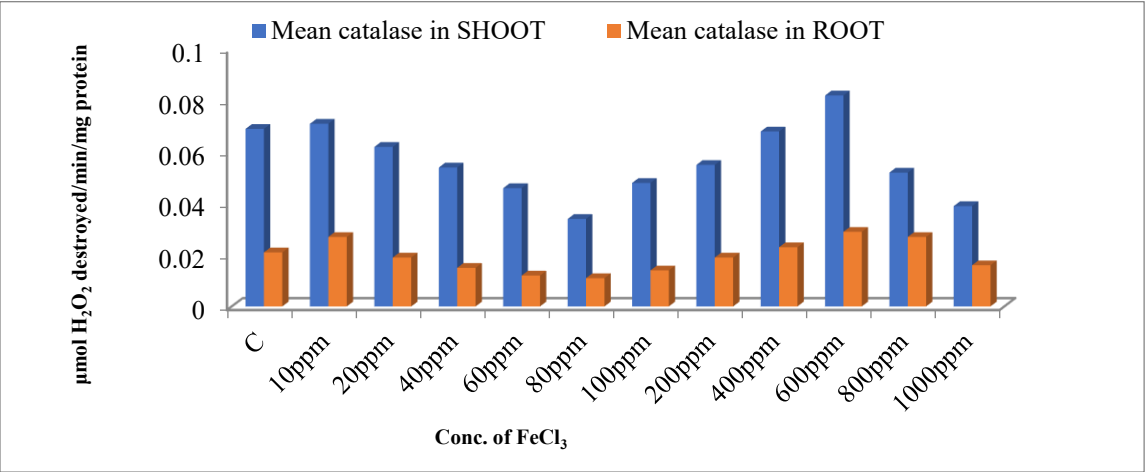


Fig 13: Effect of Different Concentrations of FeCl₃ on the Catalase Activity of 10 Days Old Seedling of *Oryza sativa* L.

Estimation of Peroxidase (POX): POX activity acted as a highly responsive indicator of heavy metal stress. It climbed steadily as iron concentrations increased, peaking at 100 ppm in shoots (193 percent of control) and 80 ppm in roots (138 percent of control) (Fig 14). This increase highlighted an active hydrogen peroxide (H₂O₂) scavenging mechanism before enzymatic denaturation occurred at higher concentrations.

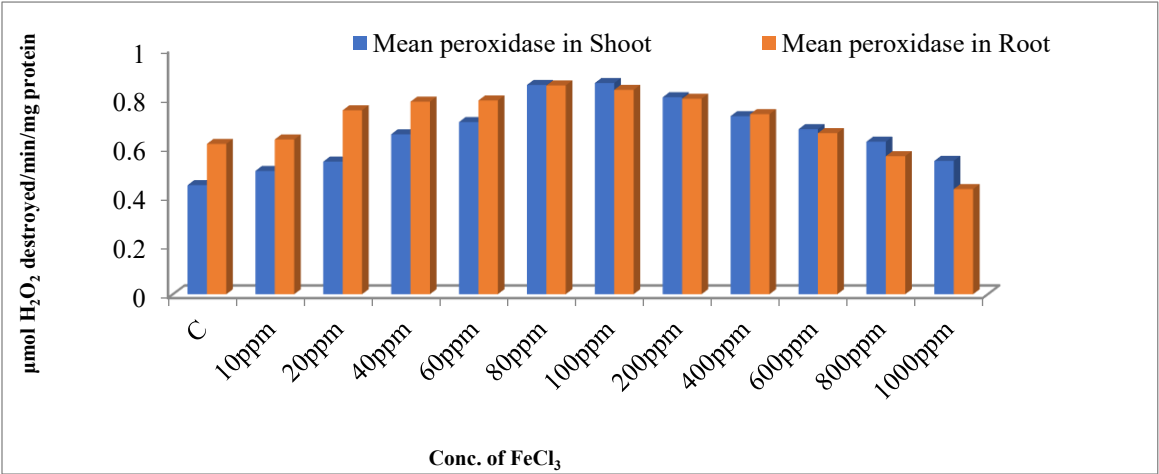


Fig 14: Effect of Different Concentrations of FeCl₃ on Peroxidase Activity of 10 Days Old Seedling of *Oryza sativa* L.

Estimation of Polyphenol Oxidase (PPO): PPO activity dropped initially up to 80 ppm, but experienced a strong turnaround at higher concentrations. From 100 ppm to 1000 ppm, PPO activity rose significantly, reaching 139 percent in shoots and 106 percent in roots at the highest

treatment level (Fig 15). This late-stage increase matches the accumulation of phenolic compounds, likely driven by severe iron-mediated oxidative stress.

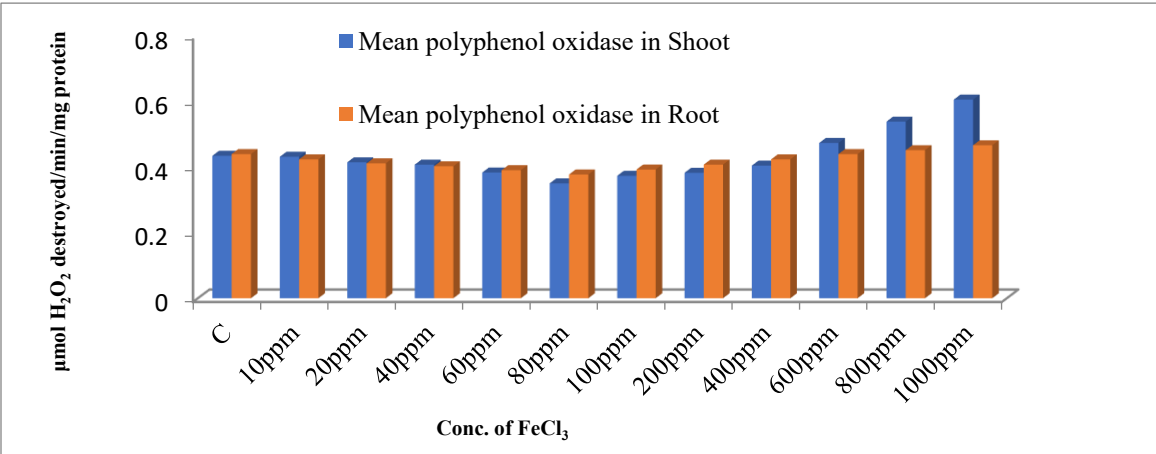


Fig 15: Effect of Different Concentrations of Fecl₃ on Polyphenol Oxidase Activity of 10 Days Old Seedling of *Oryza sativa* L.

Discussion

The findings of present study have showed that seed germination is not affected at lower concentration of iron (0-80ppm) whereas, at higher concentration (100ppm-1000ppm) germination rate are declined against selected iron concentration. On the basis of LC50, the chosen rice variety (*Oryza sativa* L.) is quite tolerant to iron at the level of 80 ppm and middle tolerance at level of 400 ppm while above concentrations i.e., 600 ppm, 800 ppm, 1000 ppm irons have showed less tolerance. The experimental plants are susceptible against the highest level of irons viz., 1000 ppm. Leaf emergence has been found 40 percent found in concentrations at 400 ppm of iron stress (Sharma et al., 2000). There has been a significant variation between in root tolerant and shoot tolerant in different rice varieties with respect to 80 ppm of Fe concentration. The root and shoot length and its ratio also decreased with the increase in iron concentration. The percentile of mean fresh weight and dry weight of shoot increased up to 80 ppm as compared to control (100 percent), which showed a positive effect. However, an increase in concentration showed negative effect. Likewise, root also showed same effect up to 100 ppm of FeCl₃ and sharp decrease has been found with increase of concentration. The maximum growth has occurred in chosen rice plant at iron concentration of 80 ppm (FeCl₃). Moreover, a significant increase and then decrease in the pigments has been observed with increase of FeCl₃ concentration. The percentile of chl-*a*, chl-*b*, Total Chlorophyll, Pheophytin, Carotenoids of seedlings, which has highest in 80 ppm as compared to control (100 percent) and lowest 1000 ppm. Chlorosis has been found from 400 ppm of iron concentration onwards (Ahmad, 2007).

The amounts of sugar content showed significant decline with increase in FeCl₃ concentration from 80 ppm onwards in root. However, in shoot a steady increase has been found up to 600 ppm and then shows a decrease as compared to control. The contents of amino acid increase with increase in concentration of iron in both root and shoot of *Oryza sativa* L. as compared to control. The protein content is differing between different concentrations of iron stress. The content of

protein suddenly decreases after control; a steep increase has been observed and after that with a gradual increase in FeCl_3 concentration. Leaf soluble protein is decreased with increase of Fe concentration from 10 ppm to 200 ppm in root. In shoot, percentile of DNA content is maximum in 80 ppm as compared to control, whereas in root it is raised with increase of FeCl_3 concentration. Moreover, RNA content in root tissue indicated a decrease up to 80 ppm of FeCl_3 concentration, whereas it showed an increase with increase in iron concentration. Proline content is increased with increase of iron stress in shoot and root of *Oryza sativa* L. In *Oryza sativa* L. root has lower catalase activity than shoot. Also, the catalase activity has been maximum at 400 ppm and 600 ppm iron treated plant as compared to control, whereas others showed reduction. As compared to percentile of control value peroxidase activity has increased with increase of FeCl_3 concentration in *Oryza sativa* L. plant. The polyphenol oxidase has showed a very low activity in decreasing order with the increase in iron stress up to 80 ppm. However, 100 ppm onwards it caused increasing activity in shoot up to 39 percent and in root it is only 6 percent as compared to the percentile of control. Phenolic content also increased at high concentration of iron probably due to the production of H_2O_2 .

Suggestions

Iron toxicity can be minimized by using iron tolerant varieties and by applying other nutrients whose presence is negatively affected by a high concentration of iron in soil. Moreover, to minimize the iron toxicity effects in iron-rich soils, soil management techniques are recommended by combining with lime application, soil drainage, later beginning of flooding irrigation, drainage during the cultivation period and anticipation of phosphate and potassium fertilization. This findings of this study can also be employed for quick screening of rice varieties for Fe tolerance for breeding programme. However, it is also only a temporary solution to the problem. Further experiments are necessary to know the hidden facts on the mechanisms of Fe tolerance in starch rich plant. Also, hydroponics can be used to study the root and liquid interactions, symptoms of nutrient deficiencies in rice plant without interference of limiting factors in the soil, enzymatic activities of the roots, effects of toxic elements on roots and root architecture efficiently.

Conclusion

Hydroponics is a specific technique for plant biology researches, which provides proper conditions to determine the individual effects of nutrient elements on quality and quantity of crop yields. Many researchers reported that uptake the heavy metals by plants and any subsequent phytotoxic reaction should be analyzed under controlled conditions and suggested hydroponics as a suitable way to screen and identify the heavy metal tolerant and remediative plants before field studies. Also, hydroponics is a suitable technique for measuring the root growth under Fe stress conditions. On the basis of the growth parameters and growth pattern in different concentrations of iron exposure, the chosen genotype *Oryza sativa* L. categorized with regard to iron tolerance as tolerant, medium tolerant and non-tolerant respectively. Also, the aforementioned chosen variety has showed some disorders such as chlorosis, dark brown speckles, leaf yellowish green and inner venial spots on the leaves due to Fe toxicity.

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Understanding the Importance of Occupational Therapists in Providing Post Discharge Aid to Elderly Patients Using Smart Homes and Assistive Technologies - A Conceptual Overview

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Abstract

Independent living of the elderly citizens arises when their heirs eventually settle at a geographically distant land owing to several social, cultural and logistical reasons contemplating upon migration, job, marriage and also foregoing generational differences as a stated rationale for the same. Moreover, expected to be validating individualistic living, the elderly parents capitulate under health reasons, which needs either manual assistance or technological aids. Manual support facilitates the basic activities of daily living and in specific situations the aid in bathing, dressing, self-care and meal preparation is extended for a comfortable sustenance. The present chapter insists on possible usage of digital assistance to replace the manual support for elderly patients living independently as suggested by the Occupational Therapists (OTs). Also, it aims at decreasing the response time at the time of emergency for independent elderly population. This perspective is analysed from an OTs service to substantiate the elderly through appropriate suggestive measures. In furtherance, elderly patients to be provided with the required comfort at home space with maximizing the use of appliances in homes like light, fan, speaker, music system, room heater, etc. under voice-controlled features. These features will enable the foreground through possible digital assistance that could make the post discharge from hospitalization of elderly patients' life quite comfortable and more sustainable.

Keywords: Elderly, Occupational Therapists (OTs), Digital Assistance, Discharge, Patients, Equipment, Smart Home, Caregiver.

Introduction

Elderly population, the ubiquitous developmental phenomenon of any nation, stands as a witness to nation's pride to series of achievements, challenges and progress. The National Research Council (1988) reported that the elderly population of a nation holds a prime position in the musing of policy makers in relative executive and legislative branches of government on quality of health service and cost. The consolidated idea of elderly population might sound ideologically fruitful; where the typical cultural ideal of South Asian family rests on togetherness, harmonious blending and collective bonding in a happy joint family. Such idealized representations might theoretically prove fulfilling; however, the pragmatic scenario appears to be not so rosy. The emotional, physical and resource needs make them dependable on kith and kins. The family members are expected to be the caregivers. This requires the constant attention embarking on a journey of interdependence and the fulfilment of filial duty. As a result, the elderly population at home lose their autonomy in decision making. On the other hand, Global North experiences nuclear family structures with independent and focused cultures, wherein living separately of the older adults is a socially accepted practice. Living with elderly parents is not so common and the need of caregiving is fulfilled by professional help like elderly care homes or trained nurses. Combating loneliness to fuel up the emotional need becomes one of the important battles in the entire process. The situation becomes critical when the loneliness of independent living of the elderly population meets with failing health, subsequently making them immobile and stationary to carry out their needs. Such health problems may accompany a compression of disability such as critical care and nursing care. Moreover, nursing care could be mobilized at home with professional assistance, wherein the acute care needs immediate effect of hospitalization.

Literature Review

During discharge of the older adults an Occupational therapists work together to unite with other forces of the healthcare team like physiotherapist, social workers, nurses and doctors to advance towards a very tailored needs, plans and goals (Alawad et al., 2023). The elderly patients who walked with aids during hospitalization and did not have to undergo any surgery had lower chances of attaining higher CAS level during discharge as compared to patients who had undergone surgery (Sidoli et al., 2024). The methodology of treatment of an Occupational therapist is to motivate the elderly patients on participation in leisurely activities, nurturing their hobbies, outcome-based activities, recollection of past, accompanied by the conducive physical and social environment with the help of well-trained staffs to help the elderly patients with dementia to improve their quality of life (Uceda-Portillo et al., 2024). There are specific occupational therapy programmes that help in reducing stress, anxiety, longer stay and readmission rate in hospital and finally proves worth for an improved quality of life (Cuevas-Lara et al., 2019). The functionality of an occupational therapist is vital in the rehabilitative team for both patients admitted in the hospital as well as those not admitted in the hospital (Thompson & Goldstein, 1976). Although technological developments have been beneficial for the elderly people, yet qualitative research-based discussion is required for pondering upon the subjective perspective of elderly for a fruitful outcome through a collaborative effort by the aged patients and occupational therapists in theory and practice because there is still limited

availability of knowledge concerning their everyday lives and doings in daily life (Larsson et al., 2008). The importance of community participation in the elderly patients with depression could be treated with client-centred occupational therapy, wherein it would help in improving the ADL and mental wellbeing through community participation (Jeong & Kim, 2025). Moreover, telemedicine aims to reduce the constraint of time and space by combining with occupational therapy to prove medical efficiency and clinical effectiveness (Ding et al., 2023).

The social and mental functionality of an occupational therapist during limited resources in the setting of a day hospital is a task apart from their usual task of assessing a patient's upper extremity function and ADL performance, wherein they also participate to work in cooperation with physiotherapist, speech therapist, psychologist and social worker (Szekais, 1984). An occupational therapist assesses a fall, which is based on extrinsic factors like home modifications, assistive technologies and educational interventions and intrinsic factors through exercise (Miranda-Duro et al., 2021). Also, the systems surrounding the provision of assistive technology for patients with diseases like dementia needs to be revised by including person-centred care (Curnow et al., 2024). Occupational Therapists role is not only confirming and assessing the mobility disorders patients with muscular dystrophy, Parkinson's disease, polio myelitis, spinal cord injury, stroke, spina bifida and multiple sclerosis result but also providing support to overcome the disorders that affect musculoskeletal and neurological systems such as ankylosing spondylitis, osteogenesis imperfecta, osteoporosis, Paget's disease and cerebral vascular accident, Guillain-Barre syndrome and Huntington's chorea (Akyurek et al., 2017). The necessity of assistive technology is due to the fact that there is a growing trend in disease and functional limitations towards a different direction, which demands a parallel resource in medical care, rehabilitation and compensatory interventions (Parker & Thorslund, 2007).

Significance

The common health problems that arise in independent living includes dysentery, vomiting, sudden fall, heart attacks, severe injury and Chronic Obstructive Pulmonary Disorder (COPD). The elderly who are living alone usually have chronic conditions, cognitive/motor deficit and higher risk of social isolation (de Paiva Santos et al., 2019). The cases like dysentery and vomiting could be treated at home with medicine and saline water, whereas the latter ailments require immediate admission to emergency ward in hospital. It is very common of the fall occurring due to frailty and growing age as the elderly population tend to lose balance. Cluttered environment inside the house, suffering from Parkinsons Disease could lead to stumble and falter, sudden postural drops arising from the sleeping position to walking, fall in BP and drop in blood sugar level are some of stated major reasons for the fall. Parkinson Disease is an independent predictor of hospitalization (Paul et al., 2017). The Cerebrovascular Accident (CVA), spinal cord injury and hand injury that requires hospitalization with immediate effect. The long-lasting effect of covid-vaccine, smoking, exposure to pollution, pneumonia could lead to Chronic Obstructive pulmonary Disorder (COPD). Also, respiratory impairment is strongly related to increased risk of hospitalization (Van Frago et al., 2012). When the things get worsen due to cold climate, inhaler and nebulizer do not work at home and serious breathlessness occur, which leads to immediate hospitalization. The sudden rise in

blood pressure level, stress, sedentary and poor life style lead to CVA. Once after their fall, if they are conscious, they drag, crawling and gather themselves up near to phone and then they dial the emergency numbers and if not conscious, they remain in that position until any caregiver comes and discovers. The smart assistive equipment is suggested to raise an alarm to their kith to kin and to take immediate action without delay amongst senior citizens living alone.

Objectives

- To understand the role of occupational therapists as caregivers in handling elderly patients during hospitalization
- To highlight the importance of occupational therapists in facilitating elderly population towards adopting to smart homes and technologies

Methodology

The gap identified through literature review raises the pertinent research question on how the efficiency of assistive aids could be improved to reduce the response time during emergency of the independent elderly population. This chapter aims to answer the distinctive research question through the usage of digital assistive aids that could be suggested by Occupational Therapist during the discharge of elderly patient for free mobilization in their homes. As per the literature review, it has been observed that if an elderly patient is admitted to hospital under emergency, the possible assistance that an occupational therapist can provide in the post discharge scenario is through assistive aids. However, the recent development in digital technology could also be incorporated by the OTs in their discharge summary to make independent living safe and avoiding further hospitalisation. The study administered descriptive research design under which observation method has been adopted to understand the practical investigation. The key findings are elaborated in undersection, which wraps up the effectivity of suggestive digital aids after elderly patients gets discharged from the hospital, wherein they are ensured for resting with safety through progress on usage of those digital aids.

Observations & Findings

Scott (1999) described that elderly patients admitted in the hospital with respective psychiatric, medical and social challenges such as psycho-social disadvantages, psychiatric illness, cognitive impairment, functional impairment and other multiple chronic medical illnesses face longer stay in hospital with high-cost expenses along with a risk of iatrogenic events and complications. The concerned medical team comprising of the doctors and nurses start their primary investigations to determine the cause of admission and treating the individual so that he/she can be discharged soon safely. Everyday morning multidisciplinary team (MDT) meeting takes place where the medical condition of each and every patient is discussed. If a patient needs to be taken care by the Occupational therapist, it is discussed in the meeting. After a day or two stay in hospital, if the patient is mobile all by themselves and is locomoting or in his/her pre-admission level in terms of Activities of Daily Living (ADL) then the

intervention of Occupational therapist could be ignored. However, if the patient has issues with locomotion or in ADLs then the role of occupational therapist is initiated.

The Occupational Therapist visits and assess the patient and if the patient is not at his/her pre-admission level, therapeutic intervention is provided so that the patient rehabilitates back to his/her pre-admission level or a new baseline is initiated with the help of support systems like different assistive devices or with the help of care providers. For provision of these assistive aids or equipment, the home situation needs to be verified by Occupational therapist after speaking to next of kin or by making home visit of the respective patient. An occupational therapist generally caters to and rehabilitates patients with neurological conditions like Cerebrovascular Accident (CVA), Spinal Cord injury, Parkinsons Disease, neuropathic conditions, respiratory illness patients like Chronic Obstructive pulmonary Disorder (COPD), asthma, pneumonia and various respiratory infections, orthopaedic conditions like fracture, or any other postoperative conditions, gastrointestinal conditions occurring and hampering their mobility or ADLs due to prolonged period of hospitalizations.

Discussions

Understanding Occupational Therapist

An individual who uses self-care work and participatively conducts activities to provide therapeutic intervention to increase functional independence, enhanced development and prevent disability among patients could be identified as Occupational Therapists. Also, he /she may adopt task or environment to achieve maximum independence and amplify quality of life. The patient treated under an Occupational Therapist range from paediatrics to geriatrics and thereby working to rehabilitate the individual to come back to meaningful physical activities. The prime role of an OT is to help the individual in performing his daily activities independently with/without the assistive aid. They deal with variety of condition like paediatrics involvement include autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), Cerebral Palsy (CP), Muscular Dystrophy (MD) and other neurological conditions not only among children but also adults such as Cerebrovascular accident (CVA), spinal cord injury (SCI), motor neuron disease (MND), brachial plexus injury, post operative rehabilitation like knee replacement, hip replacement, hand reconstruction using plastic surgery. Geriatrics conditions like Parkinsons, frequent fall, restrictive daily activities and difficulty in locomotion.

Royal College of Occupational Therapist (RCOT), UK defines Occupational therapists as professionals who see beyond diagnoses and limitations to hopes and aspirations. They look at relationships between the activities you do every day – your occupations – alongside the challenges you face and your environment. They then create a plan of goals and adjustments targeted at achieving a specific set of activities. The plan is practical, realistic and personal to you as an individual; to help you achieve the breakthroughs, you need to elevate your everyday life.

All India Occupational Therapists Association (AIOTA) in India defines an occupational Therapist as one who imparts a holistic evidence-based client- centred first contact and/or referral profession of modern health care system, based on science of occupation, with primary focus on purposeful goal-oriented activity/occupations, enhanced with the use of latest technological systems for evaluation, diagnosis, education and treatment of the patients (clients) of any age group, whose function(s) is (are) impaired by physical, psychosocial and cognitive impairments, development disorders or the ageing process affecting their quality of life, with the aim to prevent disability, promote health & well-being and return to optimum occupational roles.

Role of Occupational Therapist During Discharge of the Elderly Patient

At the time of discharge, OT assess the patient and decides if he/she is at their preadmission level then they are discharged without any aids. If not at preadmission level, OT assess the current physical condition of patient and then decides what aids and care package can be provided to ease their hardships after discharge. This is done after consulting the patient and their family members. If care package is arranged, OT decides the carers timing after speaking to the patient and with what roles they are going to help the patient like meal preparation, washing, dressing, toileting, shopping, etc. They also partake the responsibility to advice some exercises that the patient might continue after they go back home. If patient needs to be assessed in his/her own environment after discharge, an OT in hospital arranges for a community OT visit to assess patient and design home plan according to the situation.

Handling Elderly Patients – Suggestive Measures

The need for digital assistance arose much during the Covid-19 pandemic era. The practitioners capitalized their skills and upgraded the treatment to provide the desired treatment at the comfort of home. The occupational therapists may take the support of various digital technologies in the intervention of their treatment. As Akyyurek (2017) proposed that it includes the evaluation of needs, the selection of appropriate device, buying the device, lending support to the user and other interested person during the process and also training the staffs. The CCTV cameras are obvious boon for vigilance where digital aids would complement the movements of patient. There could be relevant assistive digital aids that provides a safe ambience for the elderly patients at home. Miranda-Duro et al. (2021) brings in some of the important assistive technology that could be used to prevent falls in older adults like video-monitoring, electric sensors, health monitoring and fall detectors. He also emphasises upon extensive range of technologies like virtual realities and wearables that could be suggested by the occupational therapists. Thus, taking these discussions ahead, the study proposes some of the digital aids that elderly patients, which could be suggested by OTs during their discharge.

Digital Cognitive Behavioural Therapy – The CBT programme called COMPASS is one of the major digital supports that elderly patients are suggested by the expert OTs. Upon investigating the results of multiple randomized controlled trials, it has been found that CBT was effective for mental problems such as hypochondriasis, anxiety disorder, attention deficit hypersensitivity disorder, bulimia nervosa, depression and in certain physical conditions such

as breast cancer, chronic fatigue syndrome, bulimia nervosa, attention deficit hypersensitivity disorder, irritable bowel syndrome and even in behavioural problems such as drug abuse, smoking, obesity, antisocial behaviour at least in the short term; more follow-up observations are needed to assess the long-term effects of CBT (Nakao et al., 2021). Digital cognitive behaviour therapy reduces the distress in 89 percent of participants living with long term physical conditions if treated under proper guidance by the therapists. The researchers at Institute of Psychiatry, Psychology & Neuroscience (IoPPN) at Kings College London have found that the therapist guided digital programme COMPASS showed a significant reduction in psychological distress (a combined score of anxiety and depression) among people living with long-term conditions (Picariello, 2024) and they are called 12-weeks after the commencement of study. Moreover, 194 patients have been recruited via long-term condition charities, which included Crohn's & Colitis UK, Kidney Care UK, MS Society, Shift.ms and Psoriasis Association in the UK out of which half of the participants received the COMPASS programme and other half did not. However, both groups continued to access their usual charity support. Overall, 89 percent of participants who have received COMPASS showed a clinically significant improvement in distress when compared to 45 percent of those who did not have access to the programme. Alongside improvements in anxiety and depression, COMPASS also associated with improved ability to undertake daily activities, reduction in illness-specific distress and better quality of life (Picariello, 2024).

Virtual therapeutic groups form one of the important resources for occupational Therapist. These platforms provide a supportive environment for the older population to connect with others, share and learn coping strategies. Also, organizations like Age UK and Talking Therapies provided by the National Health Science through virtual groups are effective in older adults.

Fall Savers Chair Mat – A digital aid exclusively for the older adults or elderly to reduce fall that is used throughout United Kingdom providing flexibility, wherein the wireless monitor is capable of monitoring two pads simultaneously and works with a variety of new and existing fall prevention solutions. This digital aid works, when it is placed below chair cushion and needs to be plugged in. The machine gets activated when someone gets off the chair and immediately alerts the care giver. It gets reset automatically, if weight is back on chair or carer comes and resets it. A sensor is involved that detects the change in movement and pressure, which is connected to the alarm system. This system alerts the caregivers when the elderly patient takes any movement or there is sudden fall.

Pendant alarms – The accelerometers and gyroscopes are implanted within the pendant that detects angle change or an indication that there might be a fall. It is mainly worn by the elderly patients as pendant. Sometimes the alarms are sent automatically through cellular networks or else if there is a fall then the victim is instructed to press the alarm button, which would send an SOS message to the caregiver or kin.

Floor mats – The sensors are placed below the floor mats so that when the foot falls on the floor mats, the caregiver gets alert or alarmed.

Smart Exercise Bikes or Pedal Trainers – This smart motorized bicycle can help Parkinson Disease patient to reduce the symptoms. The study conducted by Mohammadi-Abdar et al. (2016) have confirmed that there are two controlled algorithm for this bike, one implements the inertia load (static mode) when the bike works as a regular exercise bike with programmable resistance load which helps to record and capture the heart rate, power and cadence and other algorithm implements speed reference (dynamic load) where the bike operates according to user selected speed with programmable variability in speed to achieve the desired motor performance benefits for post discharge patients. In addition to this, the flexible and extensible design of the bike permits readily changing the control algorithm and incorporating additional I/O as needed to provide a wide range of riding experiences.

Lifeware Spoons – The smart technology that is suggested for elderly patients suffering from Parkinson Diseases is designed in way to stabilize the tremor and shaky hands.

Ring of Support – A voice tool used by the elderly patients at home, which does the daily wellness check with them. Also, reminds them to take their medication, events that are happening in their community. The conversations and alerts that are happening are monitored by the expert team. It is after looking into the map, the staff is dispatched at the location to take care of the situation.

Smart Home Assistants – Home automation devices like Amazon Alexa helps elderly people listen to songs, turn on lights and voice control instead of getting up and need to do everything manually. Hence, smart lights and voice assistants not only make life easy but also prevents fall since the work is done without movement. Health wearables like smart watches helps in remote therapy. Also, smart pill boxes manage the medication process by connecting to a potential mobile app and by the usage of sensors and data logging to track adherence and identify if missed out on a pill, helps in remote monitoring.

Proposed Suggestion on Usage of Digital Assistance: Additionally, the possible digital assistance could be suggested to keep vigilance on the patient at home and restricting further fall. Introducing the digital cognitive behavioural therapy to the patient will help to overcome anxiety and improve problem solving and virtual therapeutic groups can be used to provide timely therapeutic intervention in more frequent intervals. Since the patient is diagnosed with Parkinson Disease, the lifeware spoons will benefit as the tremors caused due to Parkinson will be detected by sensors and shift the spoon in opposite direction to minimize shaking. The patient can be advised to enrol themselves into the services of ring of support group, so that he/she can be always under periodic checks and be engaged into various activities with other members of the group throughout the day. OT can also advise the patient to install smart home assistants so that he/she can have access to many controls inside his/her home by using voice commands. Besides all these patients will benefit from using pendant alarm, sensed floor mat and falls savers chair mat.

Comparative Aspects - Occupational Therapists in India & UK

Nagga et al. (2012) in their study confirms that healthcare service utilization and health behaviour get hit by the factors such as education, environmental status, knowledge, attitudes, values, age and gender where the understanding of service utilization is based on contextual and individual determinants. A country like India, with rising population and challenging resources, appointing occupational therapists is a luxury for the common lot. Moreover, majority of the mass lack awareness of existence of this profession. The scenario worsens when the professional is appointed at a meagre salary in reputed hospitals with over 600 beds. The number of patients attended by an occupational therapist during per day working hours is way more than the count in UK, ranging from an average of 10-12 patients in India to 2-3 in UK respectively. It is to be noted that the availability of service of an Occupational therapist in rural India is almost nil, whereas the urban India lacks in training in digital technologies. The upskilling available is through workshops and NGOs. In contrast, the professional training through Continued Professional Development (CPD) is provided to the Occupational Therapist in UK. The wide availability of technology is already integrated with the training of occupational therapist and in the given socio-economic potential, the introduction of digital assistive technologies aids fall detectors, smart home systems, telehealth and cognitive aids, which can bridge the gap between the patient and hospital. In India, the urban middle class has access to basic devices such as fall alarms and teleconsultation tools. However, that is limited to very specific demographic group who are monetarily capable of affording the expense. The government body like National Health System (NHS) is the major health care support system in UK supporting the use of assistive technologies and also providing the funding for elderly patients. Furthermore, the schemes under Government of India provides a limited coverage. The treatments for government run free and low-cost leads to underfunding and overcrowding, making the accessibility to the facilities a far reach for the elderly patients whose mobility is restricted. The high expense of private care could be a preferred choice for infrastructure, whereas the liminality of monetary resources among the elderly population makes it not much an option for treatment. The funding gaps, inequality and elderly outreach still make India at the journey of striving to attain the top position in health care.

Suggestions

- ❖ OT led discharge module should include mandatory training sessions for the independent living patients and their caregivers on operating and troubleshooting the smart devices.
- ❖ Introducing assistive technologies incrementally than all at once during post discharge, starting with the least intrusive device and gradually moving towards the complex system.
- ❖ A well-coordinated follow-up system involving occupational therapists and telehealth providers to monitor whether the assistive measures are being used correctly and still relevant to the patient's evolving condition.
- ❖ Future implementation frameworks account for regional affordability and digital literacy gaps, particularly in middle- and low-income contexts by providing devices at reasonable rates and not being expensive.

Conclusion

Experiencing today's healthcare system, the team of scientists and technological experts are looking to future health of elderly by continuously working on shaping and transforming the healthcare system. There is a huge demand among the aging population to remain at home and expecting all things carried out in institutions and healthcare provided at home setting. The terminology like 'homispital' emerges out of such need and technologically equipped companies and resource rich countries are working towards it. When so much is the process to prevent aging then it is quite inevitable and the easier way is to get embraced, wherein the journey of elderly becomes smooth. The question on how to support the aging is answered through focusing on aspects, viz., wellness, prevention, assessment, treatment, care delivery and monitoring, which are also the six crucial stages of executing the plan. Hence, to respect the independent living of elderly, the use of suggestive digital aids is useful at providing individualistic care. Moreover, analysing from the sustainable point of action, the use of optimal product at optimal time also helps in reducing the carbon footprints thereby has the potential of sustainability. Thus, they help in the preservation of wellness with a degree of cocreation. The need for elderly assistive digital tech is rising -from wearables to immersive experiences- the elderly could connect to their closer ones and hospital officials. While the pandemic era of Covid 19 has taught to extend caregiving without physical touch, the need for these digital aids has arisen even more. Also, it aims to fill the gap that arises with the untrained caregivers. As independent elderly living at home, wellness is very important, there has been a growing prime concern of all the digital aids is to humanize the aid imparted towards the elderly as they require human love, touch and companionship alongside trust, dignity and comfort. There has been reimagining of how human touch could be provided with the digital aid at home. However, the human touch and care can help to combat perceptions such as loneliness, depression and isolation. Also, it instils the emotion of compassion, empathy and bonding, which no artificial intelligence and robotics can even replace. Moreover, this can happen only when the home is filled with kith and kins. Although, there is no possibility of staying together, the frequent visit to elderly parents can brim their lives with happiness and mental wellbeing. One must not forget that aging is a consequential process and the present sequences any individual create for his/her parents is the future that they receive from their children. Hence, one has to be compassionate and supportive with elderly and provide the care through proper OTs to make their life comfortable.

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Interplay of Employment Status, Self-Esteem and Financial Self-Efficacy among Women - A Comparative Study

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Abstract

The stability of employees in an organization or company depends upon various aspects. Moreover, the job sequences like employment status, self-esteem and financial self-efficacy plays a crucial role in workforce sustainability of any company / organization, particularly with regard to gender. Keeping this in view, the present study examined the relationships among financial self-efficacy, self-esteem and psychological well-being among employed and unemployed women to have a better understanding. A quantitative approach using cross-sectional design has been adopted on an equally distributed sample size of 102 women from Odisha, i.e., samples comprise of employed and unemployed women who are equally distributed. Standardized measures of financial self-efficacy, self-esteem and psychological well-being are collected through both online and offline modes of data collection. Pearson product-moment correlation, multiple regression and one-way multivariate analysis of variance (MANOVA) are performed on the samples. The findings indicated that self-esteem and financial self-efficacy contributed both positively and significantly related to psychological well-being, with self-esteem emerging as the stronger predictor. In furtherance, these two variables accounted for approximately 35.6 percent of variance in well-being scores. Employment status, when examined on its own as a grouping variable, did not produce statistically meaningful differences between employed and non-employed women on any of the three outcome variables. The results suggest that a woman's internal psychological resources particularly her sense of self-worth and financial confidence matter more for her overall functioning than whether or not she holds a job.

Keywords: Employment Status, Financial Self-Efficacy, Self-Esteem, Psychological Well-Being, Job, Employed, Unemployed.

Introduction

Women in the Broader Social Context

To understand how women think about themselves and how they feel about their lives one has to look at the world they live in. For a time, women have been treated as secondary to men with regard to gender inequality perspective. This is does not always mean or hurtful, but it has been the way things are perceived over years. Women are often viewed as wives, mothers and daughters, wherein the society defined their relationships with men not by who they are as individuals. This is not a small part of society it was a big part of how everything worked. Sociologists have noticed that powerful systems stay in place not just because people are forced to follow them. The reason being they become normal and seem natural over time. Women who grew up in these systems heard messages that they are not important as men. They started to believe these messages and in spite so many rapid global and societal changes these beliefs did not just disappear hitherto.

Traditional Gender Roles & Psychological Consequences

There are four things that traditional gender roles did to women's lives. First and foremost, aspect is that women have been expected to take care of the home and family, wherein a man's work is hard and important. It is seen as the only thing women should be doing. The problem is that women are not paid for this work and recognized for their skills. Second, women did not have their money so they have to rely on men for everything. This meant that women did not have the chance to learn how to manage money and make decisions about finances. The world women live in has an impact on how they feel about themselves and their lives. Women have been treated as secondary to men for a time and this has affected how they think about themselves. It is not about how women are treated; it is about how they are seen and how they see themselves. Women have been defined by their relationships with men, which has limited their opportunities and experiences.

Traditional gender roles have had an impact on women's lives. Women are expected to take care of the home and family, which has been seen as their only role. This has meant that women have not had the chance to develop their skills and interests. Also, they have not had the chance to learn how to manage money and make good decisions about finances. All of these aforesaid aspects have affected how women feel about themselves and their lives. Women's lives and experiences have been shaped by the world they live in, which has a big impact on them.

Social Transformation & Modern Landscape

The changing timelines, especially during 20th century many social, legal & cultural changes shaped women's lives or we can say that it changed their lives both positively and negatively. One of such change is the awareness and spread of gaining formal education. Nowadays, women are getting access to education, which further leads to gaining knowledge, thinking independently and become more confident in making their own decisions. Several legal reforms also supported women's progress like right to vote, right to own property and legal

protection at workplaces. Urbanization and industrialization also played an important role in women's growth, wherein cities developed through participation of women. Also, women availed the opportunity to work outside home and gain independent status and confidence. It further leads to build own or different lives outside the home, where they did not feel completely dependent on their families. In present India, more women are getting educated and able to work in different profession apart from industries and becoming financially independent. Although all women are not equally benefited from it, but the momentum caused their economic progression. Despite the positive changes it comes with new challenges, one such challenge is called 'second shift' (Hochschild & Machung, 2012). It explains that how women have to do two full-time jobs like one in their professional setting and also the majority household chores. Independence for women comes with extra responsibilities, duties which further leads to emotional burnout. The second challenge is known as the glass ceiling effect, which explains the invisible barriers for women. The reason being it stops women to reach the higher position of the organization, even though she is educated, skilled and possess the ability to do so. This in turn creates stress, exhaustion and negative effects on women's psychological wellbeing. These social changes are closely related to the psychological variables, which are examined in the study and indicated under three core variables, which affect the women's psychological well-being.

Three Core Variables Affecting Psychological Well-being of Women

The first variable is financial self-efficacy which is different from financial literacy. Financial literacy means knowing about financial concept while financial self-efficacy is a bit different term, which refers to a person's ability to manage money or financial situations like earning, budgeting, saving, planning expenses and how much financial problems they can handle. Many women may understand financial terms, but still gets hesitated in financial matters and taking financial decisions. The Indian society has a prominent role to play in this platform, which often portrays financial decision making as a man's responsibility.

The second variable is self-esteem, which means a person's own opinion about their worth. The women with higher self-esteem are usually confident about her capabilities, wherein she thinks that she is valuable and handle the challenges well. Meanwhile, the opposite to these women with low self-esteem, doubts herself and easily effected by criticisms, which further leads to comparison with others, anxiety and disappointment.

The third variable is psychological well-being which is more than just being happy. We have used Ryff's (1989) psychological well-being model. It is further divided into six dimensions which are: self-acceptance, positive relationships, autonomy, environmental mastery, purpose in life and personal growth. According to Ryff, psychological well-being means living a meaningful, balanced and fulfilling life. The better education, employment, financial confidence and self-esteem can together play a significant role in better overall psychological well-being.

Literature Review

The literature review included various aspects of women, which are discussed in accordance with the intent of the present research study.

Psychological Well-Being among Women

Amaro et al. (1987) conducted a study on 303 Hispanic working women and found that women with higher income and stronger peer support had better mental health. The discrimination in the workplace negatively affects their psychological well-being. Furthermore, research on 82 employed women have been compared with equal number of homemakers by Sinha (2017), wherein she found that employed women had better psychological well-being and lower psychological distress. Also, employed women reported less social support than the unemployed.

Financial Self-Efficacy

The existing Indian research has not properly examined financial self-efficacy of employed & unemployed women, which is one of the important research gaps that the present study aims to address. Moreover, the research conducted by Joo and Grable (2004) found that people with higher financial self-efficacy are more likely to budget, save and manage money effectively. It helps to better financial and psychological well-being.

Self-Esteem, Employment and Gender

A study by Azar and Vasudeva (2006) compared women in Iran who had jobs, non-professional jobs and no jobs. They found that women with jobs had higher self-esteem and confidence. This suggests that having a job, not just any job is important for women's self-esteem. Another study by Waters and Moore (2002) looked at 201 men and women who were unemployed, wherein they found that not having money affected men's self-esteem more; to the contrary women had support from friends and family that helped their self-esteem. Moreover, Midha (2015) studied 300 women in India, wherein she found that women who worked had self-esteem and having a job gave them independence, challenges and support. Also, Jan and Ashraf (2008) studied on how family structure affects self-esteem, wherein they reported that women from family backgrounds had different levels of self-esteem.

Employment, Self-Esteem & Well-Being: Intersecting Evidence

A study by Yilmazer and Hızlı Sayar (2017) compared women in Turkey who worked and those who did not and they found that working women are happier in their marriages. They also found that having an income and being happy with oneself are linked. A study conducted by Goldsmith et al. (1997) studied women in the US, which found that being unemployed affected their self-esteem and longer they are unemployed; the lower their self-esteem. Akram (2017) studied 70 women in India and found that working women had self-esteem and well-being. Furthermore, Sharma and Chawla (2023) reviewed studies in India, wherein, they found that having a job affects self-esteem. Also, they reported that working women generally had self-esteem. The relationship, between jobs and mental health is complex.

Need & Relevance

The literature review through various research studies have examined the financial self-efficacy, self-esteem and psychological well-being separately or looked after the relationship among in pairs. Only very few studies have reported that all the variables together on a particular variable, which significantly predicts psychological well-being. Most of the previous research studies have focused on specific groups like entrepreneurs or college students, which cannot be applied to all women in general. This research gap is even more because women's lives are mostly influenced by many external factors like traditional gender roles and changing social norms and economic development. Although women's financial empowerment has been a growing focus in the recent times, but still financial self-efficacy has received very little attention in the Indian context.

Objectives

- To analyze the interrelationships between financial self-efficacy, self-esteem and psychological well-being
- To investigate how psychological well-being is predicted by financial literacy and self-esteem
- To examine the differences between psychological well-being, self-esteem and financial self-efficacy among employed and unemployed women

Methodology

Research Design

The study adopted quantitative approach and cross-sectional research design for observing and discussing the findings accordingly.

Sample Size & Sampling

The study included 102 women from different districts of Odisha, India through convenience sampling method, wherein data are collected through both online google forms and offline using printed questionnaire. The sample included both employed and unemployed women who have consented to participate in this research. Employed women who are into full-time or part-time paid work; unemployed women included homemakers, students and women who are not doing paid work. Only questionnaire with complete responses have been included in the data analysis.

Scales & Measures

The study included three scales, viz., Financial Self-Efficacy Scale, Rosenberg's Self-Esteem Scale and Ryffs Psychological Wellbeing Scale.

Lown's Financial Self-Efficacy Scale (Lown, 2011)

Financial self-efficacy is measured using the Financial Self-Efficacy Scale (FSSES) developed by Lown (2011). It contains 6 items and responses are entered on a 5-point Likert scale ranging from strongly disagree to strongly agree, wherein higher scores indicate higher financial self-efficacy.

Rosenberg's Self-Esteem Scale (Rosenberg, 1965)

Rosenberg Self-Esteem Scale contains 10 items in the 4-point Likert scale. The responses are entered accordingly, wherein negative items are reverse scored before calculating the final score (Rosenberg, 1965).

Ryff's Psychological Wellbeing Scale (Ryff, 1989)

Psychological well-being is measured by using 18 items of Ryff's psychological well-being scale in 7-point Likert scale. Furthermore, it has 6 dimensions, but the overall scoring has been carried out by reverse scoring the negative items (Ryff, 1989).

Procedure

Before collecting data, every participant has been informed about the purpose of present research study. The participation has been voluntary and informed consent is obtained from all the participants. Participants have been assured that their data will remain confidential, anonymous and used only for academic research. The basic demographic details like age, employment status have been collected.

Statistical Analysis

The collected data are analyzed using IBM SPSS statistics version 25.0, wherein Descriptive statistics, Pearson's correlation, Multiple regression and One-way MANOVA are performed accordingly.

Findings

The statistical findings are placed in four stages: 1) Descriptive statistics characterizing the sample 2) Pearson product-moment correlations assessing bi-variate associations among study variables 3) Simple and multiple regression analyses identifying predictors of psychological well-being and 4) One-way MANOVA examining group differences by employment status. All analyses are conducted using IBM SPSS Statistics Version 27 with a significance criterion of $\alpha = .05$.

Descriptive Statistics of Study Variables by Employment Status

Table 1 presents means and standard deviations for all three study variables broken down by employment status. Employment status has been evenly distributed: 51 employed and 51 non-employed among the respondents. Descriptive values across all three variables are strikingly similar between groups, indicating minimal raw differences prior to formal statistical testing.

Table 1: Descriptive Statistics of Study Variables by Employment Status

Variables	Employment Status	M	SD
Financial Self-Efficacy	Employed	14.90	4.42
	Non-Employed	14.98	3.82
	Total	14.94	4.11
Psychological Well-Being	Employed	89.53	10.78
	Non-Employed	93.41	13.56
	Total	91.47	12.34
Self-Esteem	Employed	29.63	5.10
	Non-Employed	29.57	4.60
	Total	29.60	4.83

N = 102; M = Mean; SD = Standard Deviation

Pearson’s Correlation

Pearson product-moment correlations are computed to examine the bivariate relationships among financial self-efficacy, self-esteem and psychological well-being. As shown in Table 2, all three variable pairs are statistically significant at $p < .001$. The strongest association has been existing between self-esteem and psychological well-being ($r = .573$, $p < .001$), which exhibited a moderate-to-strong positive relationship indicating that women with higher self-worth tended to report meaningfully better psychological functioning. Financial self-efficacy also correlated moderately with psychological well-being ($r = .419$, $p < .001$) and self-esteem ($r = .475$, $p < .001$). The shared variance between the two predictor variables has been taken into account when interpreting regression coefficients.

Table 2: Pearson Correlations Among Study Variables

Variables	1	2	3
Financial Self-Efficacy	-		
Self-Esteem	.475**	-	
Psychological Well-Being	.419**	.573**	-

N = 102; ** $p < .01$ (Two-tailed)

Regression Analysis

Two separate simple linear regression analyses have been conducted prior to the multiple regression to examine each predictor’s individual relationship with psychological well-being.

Self-Esteem as Predictor

A simple linear regression with self-esteem as the sole predictor has been found statistically significant, $F(1, 100) = 48.83$, $p < .001$, accounting for 32.8 percent of variance in psychological well-being ($R^2 = .328$, adjusted $R^2 = .321$). The Durbin-Watson statistic of 1.941 indicated no problematic auto correlation. Self-esteem emerged as a strong positive predictor ($B = 1.464$, $SE = .209$, $\beta = .573$, $p < .001$). For every one-unit increase in self-esteem,

psychological well-being increased by an average of 1.46 points. Table 3a presents the regression coefficients.

Table 3a: Simple Linear Regression: Self-Esteem Predicting Psychological Well-Being

Predictor	B	SE B	β	t	p
Constant	48.147	6.280			
Self-Esteem	1.464	.209	.573	6.989	< .001

N = 102; B = Unstandardized Regression Coefficient; SE B = Standard Error;
 β = Standardized Coefficient, $R^2 = .328$; Adjusted $R^2 = .321$; Durbin-Watson = 1.941

Financial Self-Efficacy as Predictor

A second simple regression with financial self-efficacy as the sole predictor was also significant, $F(1, 100) = 21.30$, $p < .001$, explaining 17.6 percent of variance in psychological well-being ($R^2 = .176$, adjusted $R^2 = .167$). The Durbin-Watson statistic of 1.966 confirmed independence of residuals. Financial self-efficacy has emerged as a significant positive predictor ($B = 1.258$, $SE = .273$, $\beta = .419$, $p < .001$), with each one-unit increase associated with a 1.26-point rise in well-being, wherein the aforesaid results are indicated in Table 3b.

Table 3b: Simple Linear Regression: Financial Self-Efficacy Predicting Psychological Well-Being

Predictor	B	SE B	β	t	p
Constant	72.678	4.222			
Financial Self-Efficacy	1.258	.273	.419	4.615	< .001

N = 102; B = Unstandardized Regression Coefficient; SE B = Standard Error;
 β = Standardized Coefficient, $R^2 = .176$; Adjusted $R^2 = .167$; Durbin-Watson = 1.966

Multiple Linear Regression

A standard multiple regression with self-esteem and financial self-efficacy entered simultaneously as predictors of psychological well-being produced a statistically significant overall model, $F(2, 99) = 27.31$, $p < .001$, $R^2 = .356$ and adjusted $R^2 = .343$.

The two predictors combinedly explained approximately 35.6 percent of variance in well-being more than either could account for alone. The Durbin-Watson statistic of 2.023 confirmed independence of residuals. As shown in Table 3c, both predictors contributed independently and significantly. Self-esteem remained the dominant predictor ($\beta = .483$, $p < .001$) with each one-unit increase associated with a 1.23-point rise in well-being after controlling for financial self-efficacy.

Financial self-efficacy also made a significant, independent contribution ($\beta = .190$, $p = .041$), with each one-unit increase linked to a 0.57-point increase in well-being after holding self-esteem constant. The incremental gain including financial self-efficacy moving from 32.8 percent to 35.6 percent of explained variance has been modest, but statistically meaningful and practically significant.

Table 3c: Multiple Regression: Self-Esteem & Financial Self-Efficacy Predicting Psychological Well-being

Predictor	B	SE B	β	t	p
Constant	46.461	6.233			
Self-Esteem	1.233	.234	.483	5.274	< .001
Financial Self-Efficacy	.569	.275	.190	2.073	.041

N = 102; B = Unstandardized Regression Coefficient; SE B = Standard Error; β = Standardized Coefficient, $R^2 = .356$; Adjusted $R^2 = .343$; Durbin-Watson = 2.023

One-Way MANOVA: Employment Status & Group Differences

A one-way MANOVA has been performed to examine whether employment status produced significant multivariate group differences across psychological well-being, self-esteem and financial self-efficacy considered simultaneously.

As shown in Table 4, the multivariate effect of employment status is not statistically significant across all four criteria: Pillai’s Trace = .040, Wilks’ Lambda = .960, Hotelling’s Trace = .041 and Roy’s Largest Root = .041, all yielding $F(3, 98) = 1.347$, $p = .264$. Therefore, employment status did not produce meaningful differences between employed and non-employed participants when all three outcomes are examined together.

Table 4: Multivariate Test Results for Employment Status (One-Way MANOVA)

Effect	Criterion	Value	F	df	p
Employment Status	Pillai’s Trace	.040	1.347	3, 98	.264
	Wilks’ Lambda	.960	1.347	3, 98	.264
	Hotelling’s Trace	.041	1.347	3, 98	.264
	Roy’s Largest Root	.041	1.347	3, 98	.264

N = 102; All F Statistics are Exact; Design: Intercept + Employment Status

The follow-up of uni-variate test between-subjects tests presented in Table 5 confirmed this pattern. Moreover, none of the three dependent variables, viz., psychological well-being, $F(1, 100) = 2.562$, $p = .113$; self-esteem, $F(1, 100) = .004$, $p = .951$; and financial self-efficacy, $F(1, 100) = .009$, $p = .924$ showed a significant group difference. It is inferred from the above table that employment status alone emerged as a sole grouping factor, which is not sufficient to meaningfully separate the two groups on any of the three psychological outcomes.

Table 5: Tests of Between-Subjects Effects for Employment Status (MANOVA)

Dependent Variables	Type III SS	df	MS	F	p
Psychological Well-Being	384.35	1	384.35	2.562	.113
Self-Esteem	0.088	1	0.088	.004	.951
Financial Self-Efficacy	0.157	1	0.157	.009	.924

N = 102

Discussion

The present study examined the relationships among financial self-efficacy, self-esteem and psychological well-being among women and explored whether employment status contributed to differences across these variables. The findings provide important insights into the psychological resources associated with women's well-being and largely support previous research in this area.

Relationships Among Psychological Variables (Correlation)

The correlation analysis showed that financial self-efficacy, self-esteem and psychological well-being were positively and significantly related to one another. This indicates that women who reported higher self-esteem and greater confidence in managing their finances also tended to report better psychological well-being. Among these relationships, self-esteem showed the strongest association with psychological well-being, highlighting the important role of positive self-worth in women's overall psychological functioning. These findings are consistent with previous research conducted by Dare et al. (2023), which reported that individuals with higher financial self-efficacy demonstrated better financial behaviour and greater psychological well-being. Similarly, Midha (2015) found that women with higher self-esteem experienced better psychological well-being, while Akram (2017) also reported that employed women with higher self-esteem showed better psychological adjustment. The present findings therefore support existing evidences that positive psychological resources are closely associated with women's well-being.

Predictive Findings: Self-Esteem & Financial Self-Efficacy (Regression)

The regression analysis revealed that both self-esteem and financial self-efficacy significantly predicted psychological well-being. Among the two predictors, self-esteem emerged as the strongest predictor, indicating that it had the greatest influence on women's psychological well-being. Financial self-efficacy also made a significant independent contribution, although its effect was comparatively smaller. These findings are in agreement with earlier studies done by Midha (2015) and Akram (2017), wherein both have highlighted the significant role of self-esteem in promoting women's psychological well-being. Moreover, the study conducted by Dare et al. (2023) have demonstrated that financial self-efficacy contributes positively to overall well-being by improving confidence in financial decision-making and encouraging positive financial behaviour. The present findings suggested that women who believe in their own abilities and feel confident about managing financial responsibilities are more likely to experience better psychological well-being.

Employment Status: A Null but Informative Finding (MANOVA)

The MANOVA analysis showed no statistically significant differences between employed and non-employed women in terms of self-esteem, financial self-efficacy, or psychological well-being. Although the mean scores indicated slightly higher psychological well-being among non-employed women, these differences are not statistically significant and may have occurred

by chance. This finding differs from the results found in the studies conducted by Sinha (2017), Midha (2015) and Akram (2017), which reported that employed women generally experienced higher self-esteem and better psychological well-being than non-employed women. The difference may be explained by variations in the study sample and its context. In the present study, the non-employed group included homemakers and students rather than only women experiencing involuntary unemployment. Factors such as family support, personal satisfaction, job quality, financial security, work environment and individual life circumstances may also influence psychological well-being irrespective of employment status.

Overall, the findings suggested that employment status alone may not be sufficient to explain women's psychological well-being. Instead, internal psychological resources such as self-esteem and financial self-efficacy appear to play a more important role in determining positive psychological functioning.

Limitations

Firstly, the sample size ($N = 102$) is relatively small and convenience sampling has been used, which limits the generalizability. Secondly, several potentially important variables including social support, marital status, socio-economic background, type and quality of employment and physical health are not measured that could meaningfully influence the outcomes. Lastly, all data are collected through self-report measures, which introduces the possibility of social desirability bias. Despite these limitations, the study contributes original, contextually grounded evidence on the psychological factors associated with women's well-being in the Indian context.

Suggestions & Implications

The future researchers can use qualitative methods such as interviews or narrative studies to understand women's experiences in greater depth. This would provide a clearer picture of how different life experiences influence women's psychological well-being. In furtherance, the future researchers can also include other psycho-social variables such as marital status, social support, job satisfaction, work-life balance and cultural expectations. Moreover, including these factors may help explain women's psychological functioning more completely. Research studies with larger and more diverse samples from different socio-economic backgrounds, occupations and regions would improve the generalizability of the findings. The findings of this study carry practical implications as it highlights the fact that simply providing employment opportunities may not be enough to enhance women's psychological well-being, but programs that focus on building self-esteem through skill development, leadership training, mentoring and recognition can have greater psychological benefits. Similarly, financial empowerment programs should not only teach financial knowledge but also help women develop confidence in making financial decisions. The findings suggested strengthening women's financial self-efficacy could improve both financial behaviour and overall psychological well-being.

Conclusion

The present study emphasized on how self-esteem, financial self-efficacy and psychological well-being are connected. In furtherance, the findings portrayed that self-esteem is the strongest predictor for psychological well-being. Also, financial self-efficacy has significantly predicted both on its own and when combined with self-esteem. It has been observed from the study that women's psychological well-being is more about internal factors like self-esteem and financial self-efficacy, regardless of employment status. Moreover, just having a job or being jobless does not make a difference in how women feel about themselves. What really matters is how women think about themselves and how confident they feel about money making. Therefore, to facilitate women feel better, one should focus on making their self-esteem stronger than helping them feel more confident about money and molding them to become more equipped to deal with situations.

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